CATEGORIZATION OF WOMEN'S LOWER BODY SHAPES USING MULTI-VIEW 3D BODY SCAN MEASUREMENTS, AND DEVELOPMENT OF SHAPE-DRIVEN AUTOMATED CUSTOM PATTERNS

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CATEGORIZATION OF WOMEN'S LOWER BODY SHAPES
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In this dissertation, automated customization is considered as a promising way of improving garment fit. This research addressed the commercial systems that use 3D body measurements to generate custom fit patterns by applying automated alterations to a graded pattern. The goal of this study was to test whether improved customization could occur if the process is started from base patterns that are balanced and corrected for each customer's figure type and posture.

Data collection and analysis intertwined in this multi-step project which consists of (stage 1) statistical analysis for lower body shape categorization based on 2,981 women aged 18 to 35 from SizeUSA data, identifying three distinct shape groups, (stage 2) development of basic block pants patterns in each body shape by fitting three representative women in each of the three shape groups, and (stage 3) validation of the use of the basic block patterns for different shape groups in a custom fit process by comparing the fit of two pairs of pants on 27 study participants (9 women in each group); one pair was generated from the automated custom patternmaking system using a standard base pattern, and the other pair was generated using the appropriate block pattern driven by body shape.

In stage 1, five components were identified to represent distinctive shapes from the silhouette and profile views of the lower body using principal component analysis: PC1: body measurements that define waist to top hip silhouette, PC2: body

measurements that define top hip to hip silhouette, PC3: body measurements that define buttocks prominence, z-score 1: the drop of front abdomen depth to waist front depth, and z-score 2: the drop of front abdomen depth to front hip depth. From cluster analysis, three body shape groups were found: group 1 (curvy shape) has the curviest silhouette between waist level and top hip level, and the most prominent abdomen among the three groups; group 2 (hip tilt shape) has the most prominent buttocks, and their lower body is tilted toward the back; group 3 (straight shape) has a non-curvy silhouette and less prominent buttocks. From 83 participants, 3 primary fit models for development of base block patterns and 9 fit testers for validation of the use of the basic block patterns in a custom fit process were selected for each group. From 83 participants, 3 fit models (one primary) were chosen for each shape group for stage 2, and 9 participants from each shape group were selected for stage 3. In stage 3 an automated custom-made system for which alterations started from the three block patterns driven by body shape was developed, and the fit of pants (type A) developed from this system was compared with the fit of pants (type B) created from an automated custom-made system using a single block pattern. Evaluation of fit was conducted by 3 experts and by the 27 wearers. The results of experts' evaluations showed that type A provided significantly better fit at waist ease, waist placement, crotch length, and side seam placement. At abdomen ease, buttocks ease, front crotch ease, front thigh ease, and side seam location, type A was also judged to have a tendency to exhibit better fit even though the differences of the two types were not significantly different. At back crotch ease, thigh ease, and inseam length, type B had a tendency to exhibit equal or better fit, but the fit variables were not significantly different and the values of the differences were not large. Wearers' fit analysis showed some similar responses to those of the expert analysis.

BIOGRAPHICAL SKETCH

Hwa Kyung Song was born in Seoul, Republic of Korea. She earned a Bachelor of Science in Clothing and Textiles and a Master of Science degree in Clothing and Ergonomics at Ewha Womans University in Republic of Korea in 2004. After graduation, she received a two-year Associate in Applied Science degree in Patternmaking Technology at Fashion Institute of Technology in New York in 2006.

In 2007, she entered the Graduate Program to pursue her Ph.D. in Apparel Design at Cornell University. The research interests of Hwa Kyung Song are fit and sizing of clothing, the use of 3D body scanning in the apparel industry, custom-made clothing developed by automated made-to-measure system, issues of patternmaking and grading, virtual fit, visual fit assessment, technical design, and functional apparel design.

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CHAPTER 1. INTRODUCTION

Overview

Clothing fit is considered as a central element in clothing quality and customer satisfaction in the apparel industry. The right fit cannot be emphasized enough, and an appropriate fit not only ensures that the garment will wear well, but it will be worn often (Cotton Incorporated, 2002). However, in a study of young women's attitudes toward clothing fit almost 54% of the respondents reported being from only somewhat satisfied to mostly unsatisfied with the fit of ready-to-wear apparel (Alexander, Connell, & Presley, 2005), and these figures are consistent with survey results from Kurt Salmon Associates (Kurt Salmon Associates., 2000): approximately 50% of women and 62% of men cannot find good fit. Many studies concluded that substantial problems exist in the fit of ready-to-wear apparel.

3D body scanning technology has shown the potential of providing data that can be used to improve the fit of clothing. 3D body scanners can generate a set of over 100 measurements accurately in a short time (5 to 15 seconds for the scan, 1 to 2 minutes to generate measurements), and provide realistic 3D visualization of objects as well. It has the potential of improving the fit of clothing either through large-scale body scan anthropometric studies or through custom fit of a garment made to the dimensions provided by the scan of an individual. In the U.S. SizeUSA, the national anthropometric survey using 3D body scanners, was conducted in 2003, and the U.K., Germany, Japan, Korea, and Thailand among others have also used 3D body scanners for large-scale anthropometric surveys (Charoensiriwath & Spichaikul, 2009). Up-to-date anthropometric data assist ready-to-wear apparel companies in the identification of the sectors of their target market, and analysis and development of sizing systems for their target market customers.

Mass customization and automated custom clothing have recently been regarded as additional methods for the apparel industry to create well fitting clothing for consumers; 3D body scanners are useful tools in implementing these processes. Companies such as Brooks Brothers, Lori Coulter, and C&A have produced custom-made garments using measurements taken from 3D body scanners ([TC]², 2009). By providing fit that is individualized on the basis of the customer's objective body measurements, these apparel companies provide improved fit for their customers.

In this dissertation, automated customization is considered as a promising way of improving garment fit. There are different types of automated custom fit systems, but this research addressed the commercial systems that use body measurements to generate custom fit patterns by applying automated alterations to a graded pattern. Current automated computer-aided design (CAD) programs for custom pattern generation cannot generate custom clothing with perfect fit for each individual (Ashdown & Dunne, 2006; Buckner, Ashdown, & Lyman-Clarke, 2007). Critical factors to improve the fit of clothing using these programs include various elements such as body measurement data and its incorporation in a body chart, shaped block patterns, basic grading, alteration rules, and individual fit preferences that must be correctly set up in the system. Not many studies have been published that address the issue of custom fit, so a method to improve the system is proposed in this dissertation.

Among these critical factors, this study focused first on the development of an effective method for lower body shape analysis, which addresses issues in the creation of a body chart, of block patterns, and the initial grading of the pattern. As a second step basic pants patterns were developed for each body shape group identified in the first stage of the study. Pants were selected for the focus of this study because (1) customers are least satisfied with the fit of pants compared to all other apparel products (Alexander et al., 2005; LaBat & Delong, 1990) and (2) many Made-to-

Measure apparel companies primarily deal with pants as a custom garment style. There have been some studies that analyze the relationship between lower body shape and clothing patterns (Petrova & Ashdown, 2008; C. J. Salusso-Deonier, Delong, Martin, & Krohn, 1985; Schofield, Ashdown, Hethorn, LaBat, & Salusso, 2006). Findings include the acknowledgement that body shapes such as buttocks or abdomen shapes were a critical factor in the fit of pants and creation of patterns, and shape variations were applied to areas of the pattern such as side seam placement, back seam angles, and crotch extension to accommodate a variety of body shapes. However, these studies were conducted based on the body shape analysis using visual judgment of buttock shape, or ratios of waist and hip girth measurement. The difference in the approach I took is the development of block patterns that are based on more detailed body shape analysis and objective grouping.

This study concluded that improved customization occurred if the process is started from base patterns that are balanced and corrected for each customer's figure type and posture (identified by body shape analysis) by developing and comparing two made-to-measure systems; one was an automated custom-made system using a standard base pattern (s*tandard customization method)*, and the other was an automated custom-made system using multiple patterns driven by body shape *(body shape driven customization method).* This study can be considered as the first trial to test an automated system utilizing different block patterns shaped for different body shapes, as no previous study was found of this issue. Therefore, this dissertation can provide new and valuable information for both the academic field of apparel design and the apparel industry.

Background

Customized Clothing

Historical Look at Custom Fit

In the 1860s consistent units of measurement, practical theories of cutting, simple but viable systems of grading patterns based on body measurement proportions, and emerging new production technologies such as industrial sewing machines enabled the development of mechanized ready-to-wear mass production of garments (Aldrich, 2007). However, as the fashions from 1830 to 1910 for women were extremely close fitting garments, mass-produced clothing that aimed to fit a large proportion of the women could not provide good fit for them. Therefore, women continued to wear clothing made by bespoke tailors or high-class dressmakers, or made their clothing at home by copying existing garments or using patterns provided in journals (Aldrich, 2003).

Once women's styles changed to less fitted garments in the teens and 20s, and ready-to-wear (mass-produced) clothing become more affordable than custom clothing, women began to wear more ready-to-wear clothing. However, ready-to-wear provided uncertain fit due to proportional grading issues. Vast alteration workrooms in the department stores, small workshops or employed home sewers became essential in order to alter the fit the ready-made clothing (Aldrich, 2003).

By the end of the 19th century women's mass-produced clothed production in America began to outstrip the production of the dressmakers due to the cost and the time it takes to manually measure, create patterns, and construct garments (N. L. Green, 1997). Most clothing was available as ready-to-wear products that were sold through catalogs such as Montgomery Ward or in the nascent urban department stores by the 1920s. The modern age of apparel production had begun. Historian Claudia Kidwell describes this evolution from custom-made to ready-to-wear clothing as the "democratization of clothing." (Kidwell & Christman, 1974). Class distinctions based on clothing abated somewhat as relatively inexpensive ready-to-wear clothing, which often fit better than home-made, became readily available for purchase.

Custom Clothing Today

In recent years, apparel mass customization has emerged as a viable alternative to mass production due to new technologies. The goal of mass customization is to achieve choice at a low cost through the use of technology. Apparel firms are experimenting with economical strategies that individualize clothing for each customer by offering a variety of design and fit options. Large and small stores and Internet-based companies are now making custom-made clothing for individuals.

Many companies implement mass customization to focus solely on 'style and design' customizations rather than fit since this is easy to do online. Sites such as Nike iD, Converse, Timberland, Polo Ralph Lauren and CafePress.com allow only design customization of footwear or apparel.

The first large apparel company which offered a mass customized individualized 'fit' for each customer was Levi Strauss & Co., which introduced "Personal Pair" jeans, later marketed under the name "Original Spin", in selected Levi's stores. Consumers could customize their jeans by choosing from a selection of styles, fabrics, finishes, colors, leg-opening sizes, and inseam lengths. Custom fit was also provided. Individual measurements were taken by a salesperson in the store. Jeans fit was determined by inputting the individual's measurements and style selections into a computer program, and then trying on jeans that were kept in the store for that purpose. Thus, the customer could identify the exact fit that matched their preference. The jeans were individually manufactured and shipped to the customer's home. However, this program was discontinued in 2004, when the last U.S. factory was finally closed due to cost cutting efforts. Piller contends that from a mass customization perspective, the major reason of the closure was that it was never a real business model, and the concept was only based on the availability of flexible manufacturing technology. According to Piller, Levi's managed neither to turn the customized product into a customized relationship with its customers (during all its existence, re-orders were never easily possible, and feedback from customers was not considered important) nor to use the knowledge from the individual orders for customer knowledge management. Also, the purchasing experience was not a special experience in most of the stores and did not address the high emotional content and complexity (from a customer's eye) of the customized garments (Piller, 2004).

Brooks Brothers uses a 3D body scanner in their Manhattan store to collect customer measurements to create customized suits at their New York City retail store . Style, fabrics, and design features are selected from a computer screen in consultation with a trained sales professional, who facilitates the discussion of fit preferences, such as loose or form-fitted clothing. Brooks Brothers uses their own custom patternmaking system to create an individual pattern based on body measurements from the 3D scanner. The garment is manufactured and shipped to the store where a single fitting ensures customer satisfaction. Scan data and patterns for each customer are stored for reorders (Haisley, 2002). Lori Coulter produces custom-made swim suits using their 'TrueMeasure' process. Customers can choose style, fit, color and details, and then measurements are taken from 3D body scanners in their store ([TC]^2, 2009). Expert consultants analyze each customer's body type, and provide the consumer with suggestions about flattering swimsuit styles for her body type. Then the custom-made swimsuits are made.

Online mass customization initiatives can also be successful using self-reported measurements from the consumer. Archetype Solutions is a representative service provider for the made-to-measure apparel industry, and brings mass customization to the apparel industry (Archetype Solutions, n.d.). Archetype has developed a simple and intuitive ordering process that allows the consumer to order a garment based on their body specifications and style preferences in a few minutes through the web using self measurement. JCPenney, Lands's End, QVC, and indiDenim utilized Archetype technology for custom-made women/men's Chino pants or jeans, or men's dress shirts. An automated custom patternmaking process is used to create a pattern specific to each individual, and then the garment is made and shipped to the customer's home. According to their reports, custom-made clothing market seemed to be successful. Around 40% of Lands' End shoppers chose a customized garment over the standard-sized equivalent when it was available. Reorder rates for Lands' End custom-clothing customers were 34% higher than for customers of its standard-sized clothing (Schlosser, 2004).

However, in 2009 JCPenney suspended all custom fit clothing, and Lands' End decided to stop producing custom-made pants or jeans for men and women while keeping men's custom-made dress shirts. Even though the reason of the closure of pants line was not announced, the major reason may be the difficulty of providing fit satisfaction for their customers since lower body shapes are various and complex to identify, so the process of development of individualized pants patterns is more difficult than for shirts.

The Technologies

Mass customization is defined as a business strategy that uses advanced information and production technologies and involves the customer in the development, production or distribution of a product or service in order to provide the right product to a customer at the right time (Duray, Ward, Milligan, & Berry, 2000;

Pine, 1993). In the apparel industry, mass customization can be applied at multiple levels using various technologies; the body scanner for collecting body measurements; computer-aided design (CAD) systems for design or patternmaking; the Internet for communication between the customer and the customizer; production systems such as Unit Production Systems; and other computerized processes that assist with accurate and rapid production and delivery.

Many apparel companies are operated based on Internet ordering processes for mass customization, but mass customization of clothing offers special challenges. Consumers generally do not know their measurements exactly, and accurate self measurement is difficult. The 3D body scanner can be a tool for collecting measurements accurately and reliably, and capturing visual image in a short time. At the patternmaking level, specialized automated CAD systems for generating custom patterns can create patterns using measurements taken from the 3D body scanner, and modify, file, store, and reuse patterns. The types of automated patternmaking CAD programs have been developed to quickly adapt sizes: firstly, a system that uses graded patterns and body charts. The closest-fitting pattern is selected from the graded patterns by comparing the chart with personal measurements, and automated alterations are applied to the pattern. Secondly, a system for which graded patterns are not necessary, but the system defines a set of dimensions for a specific style, and the system automatically shapes the patterns to fit these dimensions for each individual. Both types of programs also include automatic pattern layout functions (marker making) and are digitally connected with plotting and cutting technology, resulting in fast, accurate, and individualized pattern for production.

However, the process of setting up a made-to-measure system using the automated patternmaking CAD programs is complicated and requires great effort. Also, this technology is still in its infancy, so it is risky to commit to the production of complex designs or items. Therefore, apparel companies have focused on style and design customizations rather than fit. In academia, this issue has currently not been actively studied.

Body Shape Analysis

Body type, sometimes referred to body shape, is important when developing sophisticated ready-to-wear sizing systems that accommodate different proportioned bodies, and when developing systems to provide good fit in mass customization systems.

Apparel companies such as Gap Inc., The Limited, Levi's, Banana Republic, L.L.Bean, Eddie Bauer LLC., and Catherines provide 'Straight' and 'Curvy' pants styles for customers with different lower body shapes. They provide their fit guide including body shape pictures (e.g., waist to hip proportion, seat shape and thigh shape) in addition to brief descriptions to help customers to choose their appropriate pants style. Some companies ask customers to measure their waist and hip size and to report fit problems when they fit pants at the waist and hip. Then the search engine in their website automatically chooses pants style for each customer.

Zafu, an online size selection company, offers recommendations on which jeans are likely to fit the user best among 90 denim brands on the basis of a user's body shape and previous fit problems with their jeans. Zafu spent over six years researching body types, tested hundreds of pairs of jeans on 11,500 women, and developed a 'shape matching' technology (Zafu, 2009). They found that women with identical hip measurements can have totally different body types, resulting in different fit problems. They claim that their body type-based recommendations make it possible for 94% of 5,872,964 users to find their perfect jeans, while overall online return rates generally are 50% (Zafu, 2009).

Variations in body type are also one contributing factor to consumers' complaints about garment fit, and body type categories could be useful when developing fit solutions for mass customization. Nancy Staples in Clemson University was the first researcher in U.S. who created block patterns designed for different body types while developing men's dress uniforms for U.S. army in 2000 (Ashdown, personal communication, April 16, 2001). In Archytype's custom ordering process, customers are asked to specify their own body type from pictures of basic silhouettes and a text description in addition to their self-reported measurements. Automated made-to-measure computer-aided design programs (e.g., AccuMark MTM of Gerber Scientific, FitNet of Lectra Systems, and MtM.assyst of Human Solutions), may also benefit from use of body type information.

Research Objectives

Automated customization is considered as a way of providing better fit for people with variations in body shape and posture. However, previous studies showed that an automated customization system cannot provide custom-made patterns with perfect fit since it is influenced by various factors such as body chart data choices, base pattern shapes, accurate body measurements, fit preferences (Ashdown & Dunne, 2006; Buckner et al., 2007). Among these factors, I think body shapes and posture analysis are the most important and the first issue that needs to be solved to improve custom-made clothing fit, since body shape information influences the shapes of base patterns that are the basis for alterations, size ranges and intervals of a body chart. Current methods of categorizing body shape are limited, and therefore I first develop a method of lower body shape categorization, and then develop basic pants patterns for each body shape group for use in the automated custom patternmaking program. This study was designed to test whether improved customization could occur if the process is started from base patterns that are balanced and corrected for each customer's figure type and posture. The detailed objectives of this study are as follows:

1. To develop a reliable and objective categorization method for lower body shapes of women aged 18 to 35, who are within the 90^{th} percentile (16.2 to 34.1) of body mass index (BMI) scores (excluding more obese women), using principal component analysis and cluster analysis.
2. To create discriminant functions that classify lower body shapes identified in objective 1, as a tool for classification of individuals to body shape groups.
3. To identify the rate of predictive accuracy of the discriminant functions in classifying body shapes by comparing the original group membership identified from cluster analysis with predicted group membership obtained from discriminant functions.
4. To develop basic pants patterns for each body shape group.
5. To compare the fit of pants created from an automated custom-made system using a single pattern (*Standard customization method)* with pants developed from an automated custom-made system using multiple patterns driven by body shape *(Body shape driven customization method)*.

I hypothesized that:

1. The base patterns will be different according to body shape groups.
2. Pants from an automated custom-made system using multiple patterns driven by body shape *(body shape driven customization method)* will be judged to have better fit than pants created from an automated custom-made system using a single pattern (*Standard customization method)*.

Significance of Study

Current methods for categorizing body shapes are limited since they generally rely on visual analysis or simple and limited ratios of body circumferences. This study developed a new method of body shape categorization that combines information from both front and side perspectives of the body, that distinguishes many different body relationships, and that uses objective 3D body measurements. The analysis was developed using principal component analysis and cluster analysis with 2,981 women (in the ASTM Missy size range) aged 18 to 35 in the SizeUSA data. New types of measurements such as width, front depth, back depth, front and back arc measurements, and their drops made it possible to describe front and side silhouettes more distinctively and completely. Cluster analysis categorized the body shapes into three groups: group 1 (curvy shape), group 2 (hip tilt shape), and group 3 (straight shape). Creating body shape categories was only the first step. Previous studies which used these methodologies (PCA and cluster analysis) did not progress past this stage. However, in order to create a system that can be simply and intuitively used in industry and for further research, I also developed a simple and intuitive method for defining a new person's body shape group using a discriminant analysis. Since functions just consist of two simple equations, the scores can be calculated simply without access to the full database used to identify PC clusters. To identify an individual's place in the cluster, it is only necessary to compare the two scores with a bivariate scatterplot that shows the composition of each group plotted by their discriminant analysis scores.

A block pants pattern was then developed for each body shape group identified from this study. Variance in pattern shape was found in five areas of the pattern: center back seam slope, center front seam slope, front dart amount, silhouette of side seam, and proportion of front and back pattern pieces. There have been a few studies that analyze the relationship between lower body shape and pattern shapes. Earlier studies for pattern development based on body shape are limited to classification of the degree of buttocks prominence into two or three groups by visual judgment, or calculation of waist to hip proportion associated with simple pattern manipulations (Petrova & Ashdown, 2008; Schofield et al., 2006). The development of block patterns for this study was based on more detailed body shape analysis and objective grouping, and used more sophisticated patternmaking and fitting procedures to arrive at an appropriate pattern shape. This study discovered new ways of selecting fit models and developing pattern blocks. Block patterns were developed by fitting pants on multiple fit models, so block patterns had more reliability and validity than those that are developed by fitting to a single model. When fit models are selected, their body sizes (e.g., bust girth, waist girth, and hip girth) are mainly considered, but in this study, fit models were selected with consideration of body shape as well. Eighty three participants' five variable scores were compared with the median size model's scores of their body shape group using pentagonal graphs. Each individual's placement of five variables was compared within the group and among the groups, and the most representative three fit models were selected.

The final goal of this study was to test a shape-driven customization system whose alterations start from appropriate block patterns. The hypothesis was that pants from an automated custom-made system using multiple patterns driven by body shape *(body shape driven customization method)* are judged to have better fit than pants created from an automated custom-made system using a single pattern (*Standard customization method)*. Nancy Staples was the first researcher who considered body shape information critical to custom-pattern generation. After her, there has been no study addressing this issue. The results of this study showed that the made-to-measure system incorporating body shape information into block patterns can generate custom patterns with better fit. I hope this study can work as a pioneer in these kinds of studies, and provide information to apparel industry.

CHAPTER 2. REVIEW OF RELATED LITERATURE

Following is a presentation of the research that provides the foundation, the inspiration, and ideation of the present work in detail. The following background and justification will address four aspects in detail – made-to-measure systems, body shape analysis, pattern development for various body shapes, and clothing fit analysis.

Made-to-Measure Systems

Several sophisticated computer-aided design (CAD) patternmaking programs for apparel patternmaking, grading, and markermaking have been created for the apparel industry. They enable the development of complex patterns and grade rules easily and accurately. Most apparel companies initially adopted CAD programs to create and adapt patterns. The availability of CAD databases streamlined the product development process in mass production system by storing old patterns for adjustment and reuse.

Specialized automated CAD programs for custom pattern generation (AccuMark Made-to-Measure of Gerber Scientific, FitNet of Lectra Systems, Modulate of Optitex, and MtM of Assyst) have been developed for customization systems. Setting up the made-to-measure process using these CAD programs requires a significant amount of knowledge and skills such as an understanding of body size and proportion analysis of the target market, creation of body size charts, preparation of base patterns for alteration, grading of the patterns, and alteration methods for modifying the patterns. CAD alteration systems are complex, and they need sophisticated skills to harmonize all these aspects. Since there have only been a few studies about methods of utilizing these systems (Ashdown & Dunne, 2006; Istook, 2002), little information exists in current literature, so more studies are needed in this field.

Generating Custom Patterns in Commercial CAD Program

There are several commercial automated CAD systems for generating custom patterns. Methods of altering patterns are slightly different depending on each system, but they can be categorized in approximately two ways: firstly, systems based on graded patterns and body charts. The closest-fitting pattern is selected from the graded patterns by comparing the body chart with personal measurements, and automated alterations are applied to this pattern. Secondly, graded patterns are not necessary, but the system needs to define a set of dimensions for a specific style, and the system automatically shapes the patterns to fit these dimensions to each individual.

The first method applies measurements to sized pattern from a graded nest. These systems need to be set up with a body size table, graded patterns, and alteration rules for critical points on the pattern. The program selects the pattern from the graded set that will be the base size for an individual by comparing key body measurements of the individual with the standard body measurements that would fit the pattern size selected. Then, measurement differences at identified critical fit locations are automatically calculated. The system automatically applies specific changes to the chosen base pattern according to alteration rules developed for the pattern based on the measurement differences of the individual from the standard body measurements for that pattern. Multiple successive alterations are made to the base pattern, and a final pattern is generated that merges the full set of alterations. AccuMark Made-to-Measure of Gerber Scientific, FitNet of Lectra Systems, and MtM of Assyst are all systems that operate in this way (Figure 2-1).

The second method parametrically changes a base pattern according to a set of defined dimensions. The system does not require the development of a body size table

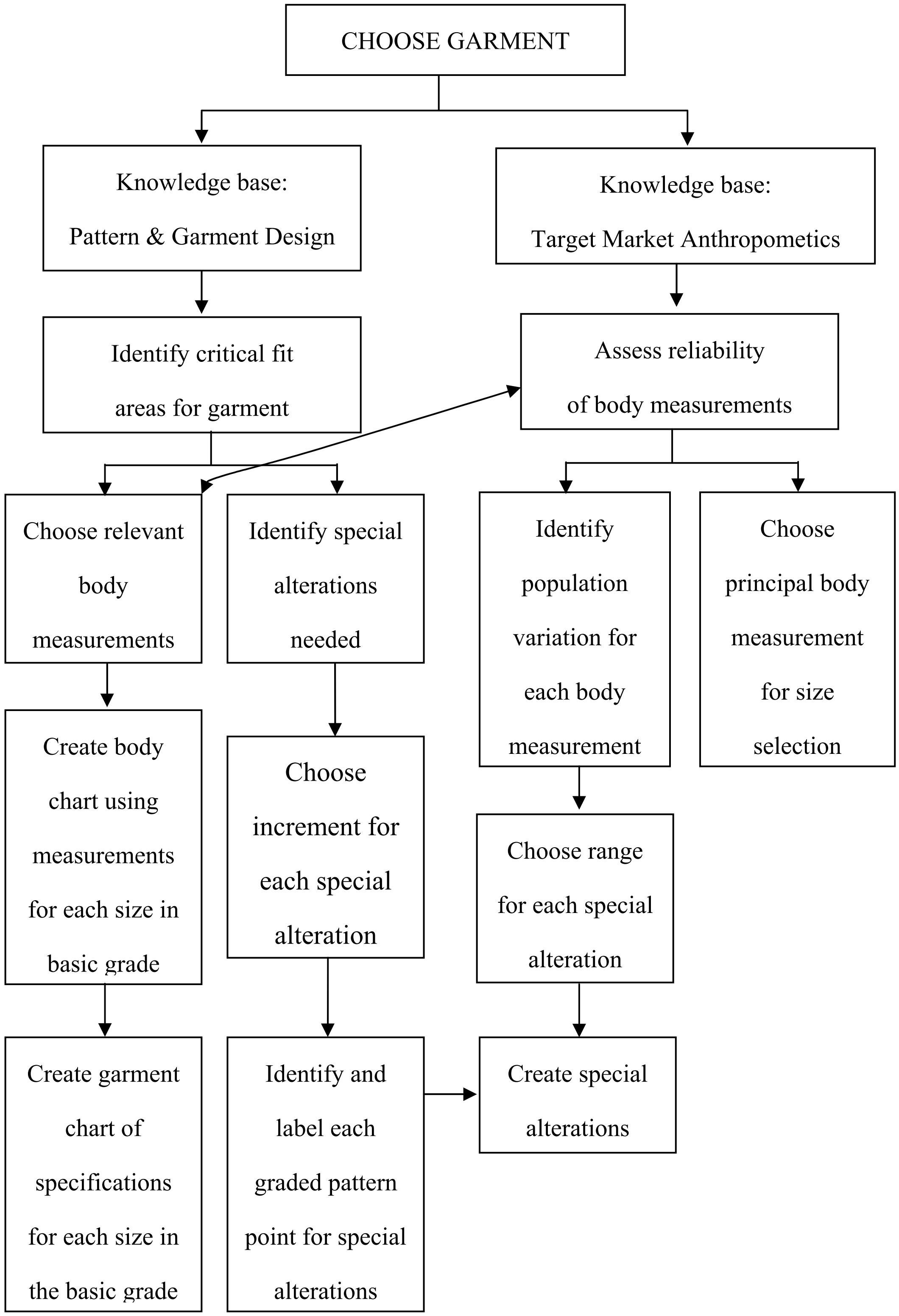


Figure 2-1. Flow chart showing knowledge base required for each decision point for an automated custom patternmaking system (Ashdown & Dunne, 2006; Istook, 2002).

and alteration rules. Instead, it is necessary to define a set of dimensions for a specific style. For example, a parametric jacket can be defined using dimensions annotated as "Shoulder", "Bust", "Waist", and "Hips". The system shapes the jacket to fit these four dimensions. Each modification to the jacket can be visualized interactively when changing names and values. Once the parametric product is fully defined by a set of dimensions, it is ready to generate custom patterns. MTM of PAD System and Modulate Made-to-Measure of Optitex are operated in this way.

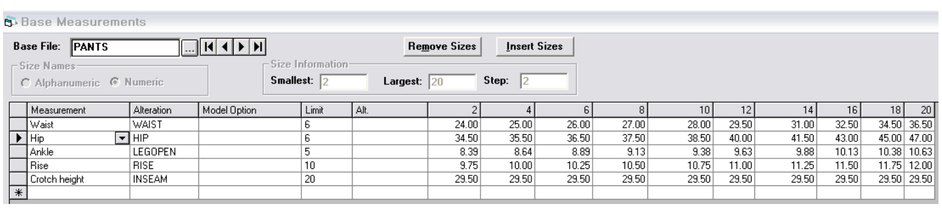
The two systems seem to be different, but the underlying theory is the same. In the apparel industry, more companies have used the first system than the second one. Figure 2-1 shows a flow chart of the decision points and knowledge base needed to create a custom-fit system using the FitNet software of Lectra system. Based on my experience using AccuMark MTM of Gerber Technology and FitNet of Lectra system, the following initial decisions are required to be made and entered into the software for each different style to implement this custom fit process:

1) What is the representative body size and shape of the target market? (body chart)
2) Does the block pattern fit well on the fit model of the base size? (base block pattern)
3) How should patterns be graded to accommodate the body chart? (graded patterns)
4) Which body measurement can be a principal measurement for selecting an individual's base size? (key measurement)
5) Which body measurements and special alterations should be made for the design? (alteration location)
6) How should alteration amounts be divided for each point of the patterns? (alteration rules at each location)

The body chart should be developed to reflect body size and shape of the target market population. Accordingly, base patterns should fit well on the fit model of the base size, and graded patterns should be made to accommodate the body chart and correspond to each set of measurements on the body chart. After determining locations which need alterations, it is necessary to consider how alteration amounts are divided across each pattern, and specifically how they will be assigned to each point. Then, connecting alteration rules and relevant body measurements in a body chart is the next step. The system is designed to compare key measurements between an individual and the body chart, automatically select a base size from the graded pattern, and calculate measurement differences of the individual from the measurements on the body chart associated with the base size selected at each pattern location where alterations are made.

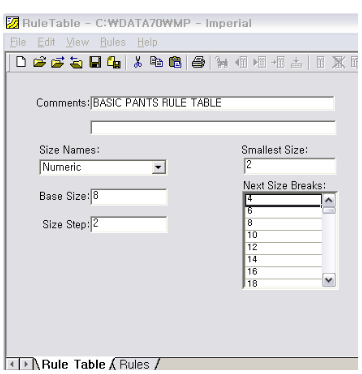
Multiple alterations are made to the base pattern, and a final pattern is generated that merges the full set of alterations. The process for custom fit garments in AccuMark program as follows:

1) Determine a body size chart.



Measurement	Alteration	Model Option	Limit	Alt.	2	4	6	8	10	12	14	16	18	20
Waist	WAIST		6		24.00	25.00	26.00	27.00	28.00	29.50	31.00	32.50	34.50	36.50
Hip	HIP		6		34.50	35.50	36.50	37.50	38.50	40.00	41.50	43.00	45.00	47.00
Ankle	LEGOPEN		5		8.39	8.64	8.89	9.13	9.38	9.63	9.88	10.13	10.38	10.63
Rise	RISE		10		9.75	10.00	10.25	10.50	10.75	11.00	11.25	11.50	11.75	12.00
Crotch height	INSEAM		20		29.50	29.50	29.50	29.50	29.50	29.50	29.50	29.50	29.50	29.50

2) Create a file for a grading rule table.



3) Create the grading rule table.

RuleTable - C:₩DATA70₩MP - Imperial

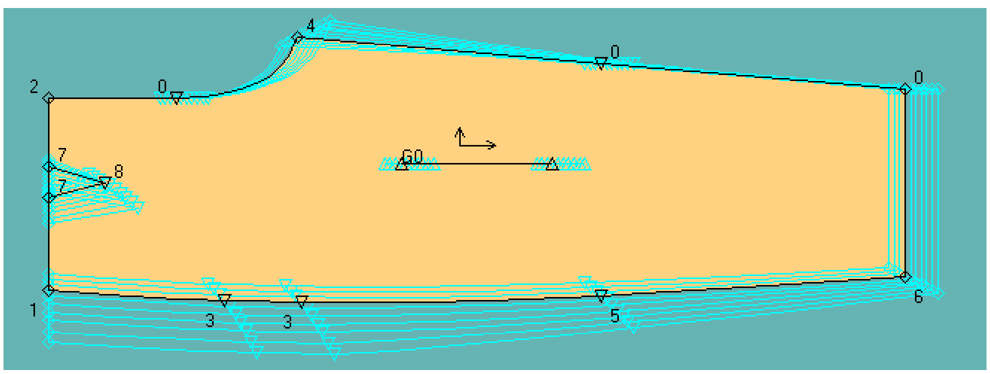
File Edit View Rules Help

Grade Method: Small-Large Incremental

Grade Rules in Library: 10 Total Size Breaks: 9

	Rule		Rule		Rule		Rule		Rule	
Number:	0		1		2		3		4	
Comment:										
Point Attribute:										
Size Breaks	X	Y	X	Y	X	Y	X	Y	X	Y
2 - 4	0,000	0,000	-0,250	-0,250	-0,250	0,000	0,000	-0,250	0,000	0,125
4 - 6	0,000	0,000	-0,250	-0,250	-0,250	0,000	0,000	-0,250	0,000	0,125
6 - 8	0,000	0,000	-0,250	-0,250	-0,250	0,000	0,000	-0,250	0,000	0,125
* 8 - 10	0,000	0,000	-0,250	-0,250	-0,250	0,000	0,000	-0,250	0,000	0,125
10 - 12	0,000	0,000	-0,250	-0,375	-0,250	0,000	0,000	-0,375	0,000	0,125
12 - 14	0,000	0,000	-0,250	-0,375	-0,250	0,000	0,000	-0,375	0,000	0,125
14 - 16	0,000	0,000	-0,250	-0,375	-0,250	0,000	0,000	-0,375	0,000	0,125
16 - 18	0,000	0,000	-0,250	-0,500	-0,250	0,000	0,000	-0,500	0,000	0,125
18 - 20	0,000	0,000	-0,250	-0,500	-0,250	0,000	0,000	-0,500	0,000	0,125

4) Assign the grade rule to each point.

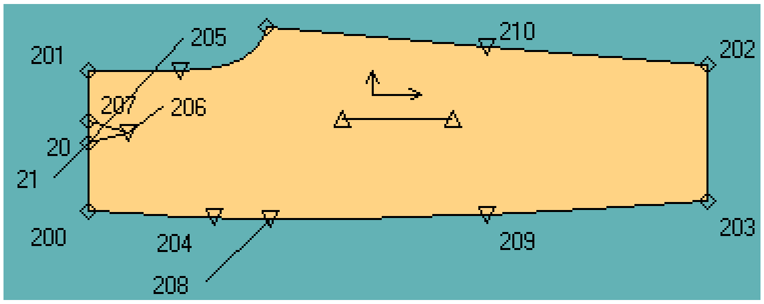


5) Set alteration rules.

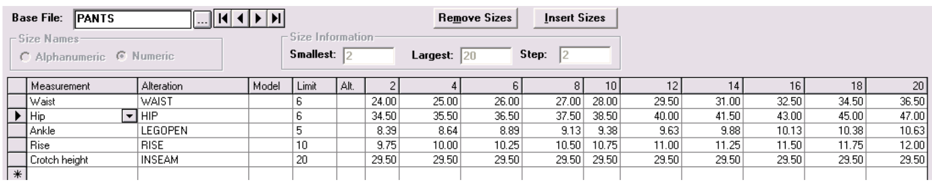
	Alt Type	First PT	Second	Movement X	Movement Y
1	X Y MOVE	105	105	0,000%	-12,500%
2	X Y MOVE	107	107	0,000%	-12,500%
3	X Y MOVE	106	106	0,000%	-12,500%
4	X Y MOVE	100	100	0,000%	-25,000%
5	X Y MOVE	200	200	0,000%	-25,000%
6	X Y MOVE	205	205	0,000%	-12,500%
7	X Y MOVE	206	206	0,000%	-12,500%
8	X Y MOVE	207	207	0,000%	-12,500%
9	X Y MOVE	300	301	0,000%	-25,000%
10	X Y MOVE	401	401	0,000%	-25,000%
11	X Y MOVE	501	502	100,000%	0,000%
12					
13					

WAIST / HIP / RISE / INSEAM / LEGOPEN

6) Assign the alteration rule to each point

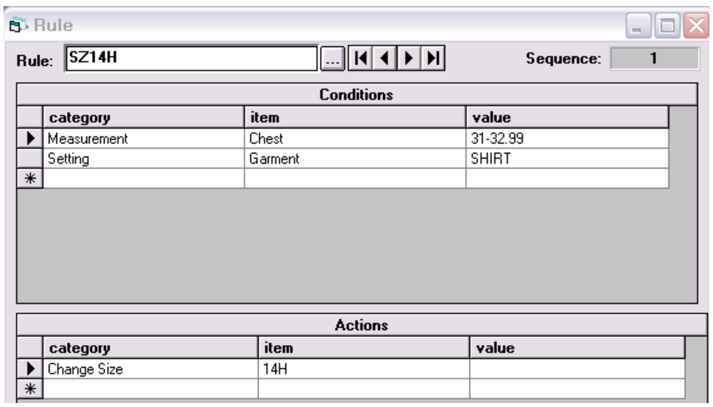


7) Connect alteration rules to measurements in the body size chart.

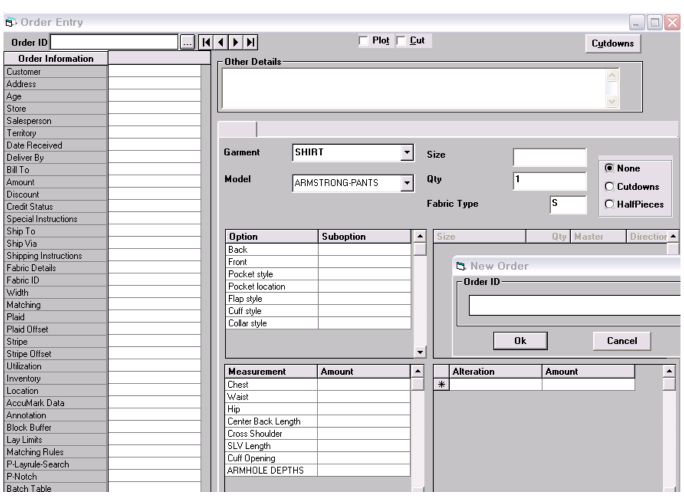


Measurement	Alteration	Model	Limit	Alt.	2	4	6	8	10	12	14	16	18	20
Waist	WAIST		6		24.00	25.00	26.00	27.00	28.00	29.50	31.00	32.50	34.50	36.50
Hip	HIP		6		34.50	35.50	36.50	37.50	38.50	40.00	41.50	43.00	45.00	47.00
Ankle	LEGOPEN		5		8.39	8.64	8.89	9.13	9.38	9.63	9.88	10.13	10.38	10.63
Rise	RISE		10		9.75	10.00	10.25	10.50	10.75	11.00	11.25	11.50	11.75	12.00
Crotch height	INSEAM		20		29.50	29.50	29.50	29.50	29.50	29.50	29.50	29.50	29.50	29.50

8) Determine a primary body measurement for selection of a base size.



9) Input an individual's measurements.



Current Issues of Automated Alteration Process

Automated custom patternmaking processes in conjunction with a 3D body scanner allow custom patterns to be rapidly and repeatedly generated in a quick, but the technologies are still in the initial experimental stage. Body scan data does not automatically integrate with all commercially available CAD systems or measurement extraction algorithmic processes (Carrere, Istook, Little, Hong, & Plumlee, 2002). Istook (Istook, 2002) noted that the process is far from automatic, and commercial CAD alteration systems are not only complicated, they also require a significant level of knowledge and practical experience not easily obtained. Apeagyei and Otieno (2007) found that the software can manipulate standard type garments with basic features, but complicated styles such as asymmetric designs is still problematic. Ashdown and Dunne (2006) explored issues in setting up a custom apparel patternmaking process using 3D body scanning and CAD software (FitNet of Lectra System) designed to automate custom patternmaking. When the first set of custom patterns were tested for six participants, only one of the prototypes fit well, two had very poor fit, and three were marginal. After three iterative corrections of all issues such as the reliability of body measurement data, the accuracy of body chart data, and the issue of fit preferences, seven of ten participants were provided with good fit.

In spring 2007, the students in 'Anthropometrics and Apparel' class, at Cornell University, collaborated with the technical design department at Nike to conduct a research project to create custom-made jackets. All of the first four sets of custom-made jackets fitted very poorly, and even after several revisions of the system, the fit at the bust still remained problematic for many subjects (Buckner et al., 2007). My responsibility for this project was to develop the automated custom-made system using FitNet software. When the hip girth was determined as a primary measurement for choosing a base size, the fit at the hip was good, while the fit at the bust was poor. In contrast, when the bust girth was set as a primary measurement, the fit at the hip was not good.

Similar results were found in a study that I participated in for another sports apparel manufacturer using Gerber custom fit. In this custom jacket study, again, when the hip girth was determined as a primary measurement for initiating the custom fit process, the fit at the bust was poor although the fit at the hip was appropriate and when the bust girth was set as a primary measurement, the fit at the bust was appropriate, but the fit at the hip was not good. The custom-made clothing had especially poor fit for those people with a body type different from that of the fit model for the base pattern, resulting in a different silhouette, since this situation created the need for an extreme pattern alteration in a specific area.

Previous research projects and my experiences showed that the process of custom patternmaking cannot generate patterns with perfect fit since the system is influenced by various factors. Critical elements in setting up automated made-to-measure CAD software are a body size chart that reflects the target market, well designed base patterns, correctly graded patterns that are used for alteration, appropriate alteration rules, accommodation for fit preference and accurately taken measurements (Figure 2-2).

It was found that the system cannot generate custom garments with good fit and keep the original silhouette, if a person has a body size or body shape that differs greatly from the original body chart and fit model's body shape. One solution for this issue would be providing the system with different types of block patterns, rather than a single block pattern. Nancy Staples was the first researcher in U.S. who created different patterns designed for different body types for base block patterns while developing men's dress uniforms for the U.S. army (Ashdown, personal communication, April 16, 2001). However, unfortunately there is no publication with

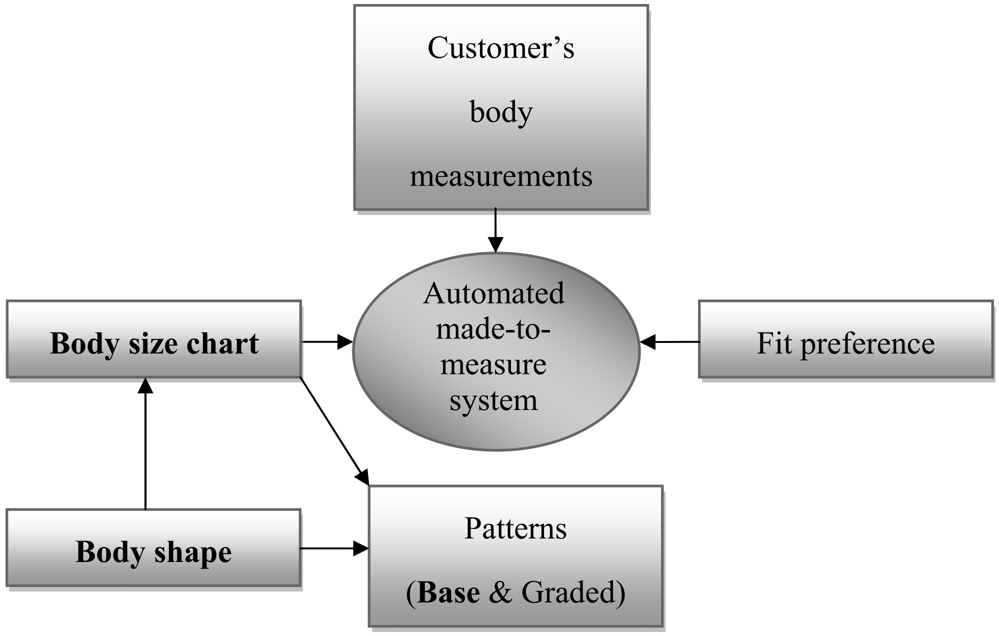


Figure 2-2. Critical elements in automated custom-made systems.

details of this system. Simmons, Istook, and Devarajan (Simmons, Istook, & Devarajan, 2004) also hypothesized that optimal customization could occur if customization starts from the most correctly shaped garment for each customer's figure type. There has been no study to test this issue, and this study can be considered as the first trial to test the automated system using different block patterns created for different body shapes. I hypothesized that a system in which alterations are applied to differently shaped block patterns that are corrected and balanced for each body type could improve the automated customization system.

Body Shape Analysis

In the apparel industry, body shape has increasingly been recognized as fundamental to good fit. Apparel companies such as Lane Bryant, Lands' End, Levi's, Gap Inc., The Limited, Banana Republic, L.L.Bean, Eddie Bauer LLC., and Catherines provide two to four pants styles (e.g., straight style and curvy style) for customers with different lower body shapes. Catherine Lippincott, spokeswoman for Lane Bryant said that their customers complained about pants fit problems such as gaping waistbands and super sung thighs (Lane Bryant, 2010a). In response, in July 2007, they unveiled a new sizing system focusing on hip and waist contours. They created 'Right Fit System' from their research where thousands of women nationwide were measured using a 3D body scanning system. They have produced three different fits for three distinctive body shapes: a 'curvy' figure accented by a cinched waist and slightly fuller hips; a 'straight' figure with broader hips and straighter figures; and a 'moderately curvy' figure with waists and hips roughly in proportion. Lippincott did not call the system flawless, but said it has gone a long way toward improving what's been bothering women. Customers' demand for good fit has played a role in creating different pants fit by other companies as well. Michele Casper of Lands' End, a denim expert, also developed a response to women lamenting the problems of jeans that gaped in the waist on certain figures. Lands' End recognized that not all women are built the same. The company focuses on issues of fit and proportion, and they offer a separate curvy line. Levi's also announced a new line of custom fit jeans made to fit the curves of a woman's body. The new line, Levi's Curve ID, utilizes a revolutionary fit system based on shape, not size and was created as a result of studying more than 60,000 body scans and listening to women around the world of all shapes and sizes (Benander, 2010). Through this research, Levi's designers created a new approach to measuring a woman's body and identified three distinct body types that they claim account for 80 percent of women's shapes. The three Levi's Curve ID fits (slightly curvy, demi curvy, and bold curve) are based on these body types.

Body shape analysis has also been used in the development of size selection systems. Zafu is an online size selection company which offers recommendations on which jeans are likely to fit the user best among 90 denim brands on the basis of a user's body shape and previous fit problems with their jeans. Zafu spent over six years researching and understanding body types, tested hundreds of pairs of jeans on 11,500 women, and developed a 'shape matching' technology (Zafu, 2009). They found that women with identical hip measurements can have totally different body types, resulting in different fit problems. Only 6% of women have the same body type as the typical tall and slim fit model, but the problem is that most jeans companies consider these women 'average'. Zafu claims that their body type-based recommendations make it possible for 94% of 5,872,964 users to find their perfect jeans, while online return rates generally are 50% (Zafu, 2009).

Body type is also recognized to be a factor in creating custom-fit solutions. Staples created different patterns designed for different body types for base block patterns while developing a custom system for U.S. army men's dress uniforms in 2000 (Ashdown, personal communication, April 16, 2001). Archytype, a provider of automated custom solutions for apparel companies, uses self perceived body shape to help provide good fit. In Archytype's custom ordering process, customers are asked to specify their own body type from pictures of basic silhouettes and a text description, in addition to their self-reported measurements. Automated made-to-measure computer-aided design programs (e.g., AccuMark MTM of Gerber Scientific, FitNet of Lectra Systems, Modulate of Optitex, and MtM.assyst of Human Solutions), may also benefit from use of body type information. In order to test this concept for automated custom patternmaking, a reliable method for body shape analysis is needed as the first stage. In the following section, body shape categorization systems used in the research of apparel are examined, and their strengths and weakness are discussed. Then body shape categorization methods used in the apparel industry are presented in the last section.

Methods Developed in Academia

An early significant contribution to body shape classifications was made in the 1930s by William Sheldon. In 1940, Sheldon introduced the concept of ‘somatotype’ in his book ‘The Varieties of Human Physique’. For his study of the human physique, Dr. Sheldon started with 4,000 photographs of college-age men, which showed front, back and side views (Sheldon, Stevens, & Tucker, 1940). After carefully examining these photos he discovered that they could be classified using three fundamental elements which, when combined together, made up all these physiques or somatotypes. With great effort and ingenuity he worked out ways to measure these three components and to express them numerically so that every human body could be described in terms of three numbers, and that two independent observers could arrive at very similar results in determining a person's body type. These basic elements he named endomorphy, mesomorphy and ectomorphy, for they seemed to derive from the three layers of the human embryo, the endoderm, the mesoderm and the ectoderm.

- Endomorphy is centered on the abdomen, and the whole digestive system.
- Mesomorphy is focused on the muscles and the circulatory system.
- Ectomorphy is related to the brain and the nervous system.

No one is simply an endomorph without having at the same time some mesomorphy and ectomorphy, but each individual has these components in varying degrees. Sheldon evaluated the degree a component was present on a scale ranging from one to seven, with one as the minimum and seven as the maximum. In the 1960s, Lindsay Carter and Barbara Heath continued modification of Sheldon’s somatotype methodology (Carter & Heath, 1990).

Helen Douty, a clothing specialist in the School of Home Economics at Auburn University, realized it was difficult to measure the body according to Sheldon’s method since there was no visual guidance (Douty, 1968). Therefore, she developed two scales used for front (body build: .5 to 5.5 scale from thin to heavy) and side (posture: .5 to 5.5 scale from faulty to excellent) views, and presented corresponding silhouette pictures. Minott (1978) offered categories for visual analysis of the lower body (hip shape and posture type), the upper body (posture, neck with and length, shoulder width and height/slopes, chest shape, bust size and placement, back width and curvature, arm size), and waistline characteristics. She described six hip

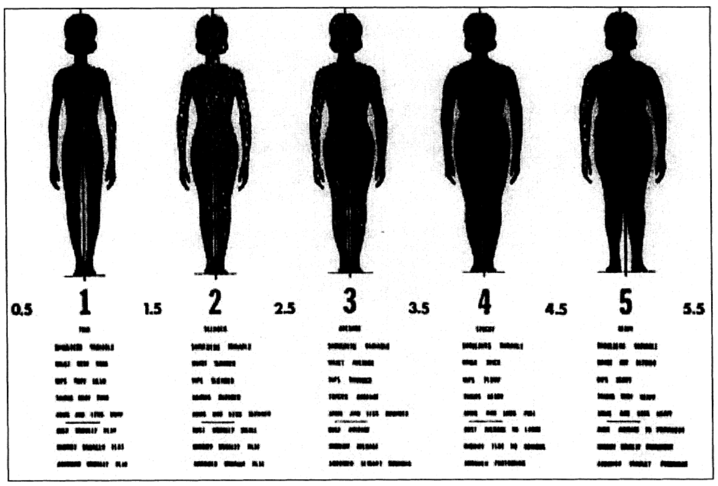


Figure 2-3. Douty body build scale (Douty, 1968).

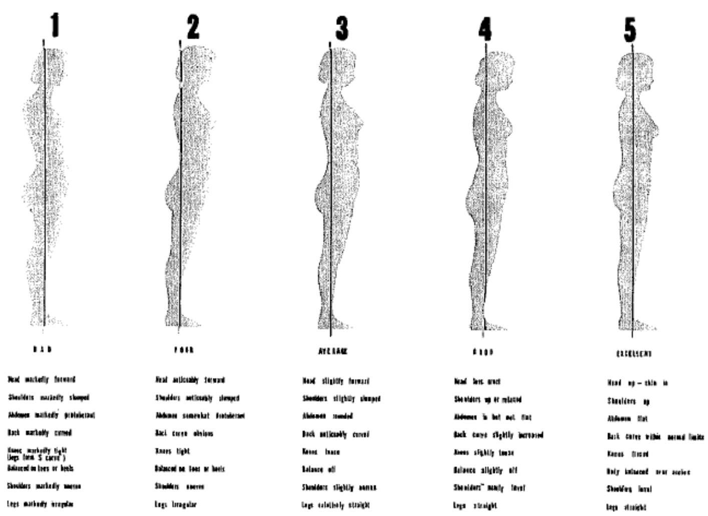


Figure 2-4. Douty body posture scale (Douty, 1968).

shape types (average, little difference, heart, semi-heart, diamond, and rounded diamond), and identified 13 categories of figure characteristics profiling body parts either above or below the waist. August (1981) presented four whole body shapes (circle, pear, rectangle, and inverted triangle hourglass) and secondary descriptions of bust, buttocks, and abdomen prominence (simple, flat, and prominent).

Connell, Ulrich, Brannon, Alexander, & Presley (2006) developed visual shape analysis scales from 3D body scans. They first selected scales from literature (Armstrong, 1987, 2006; August, 1981; Douty, 1968; Minott, 1978) and established a set of whole and component body shape assessment templates. Then, they critiqued them and developed a new set consisting of nine scales for body shape assessment from front and side views. Three (body build, body shape, and posture) were for whole body analysis, and six (front torso shape, hip shape, shoulder slope, bust shape, buttocks shape, and back curvature) were for analysis of component body parts (Figure 2-5). For validation, five experts used the Body Shape Assessment Scale (BSAS©) to rate 100 additional body scans. These ratings were used to program software to classify female body scan data using the BSAS©.

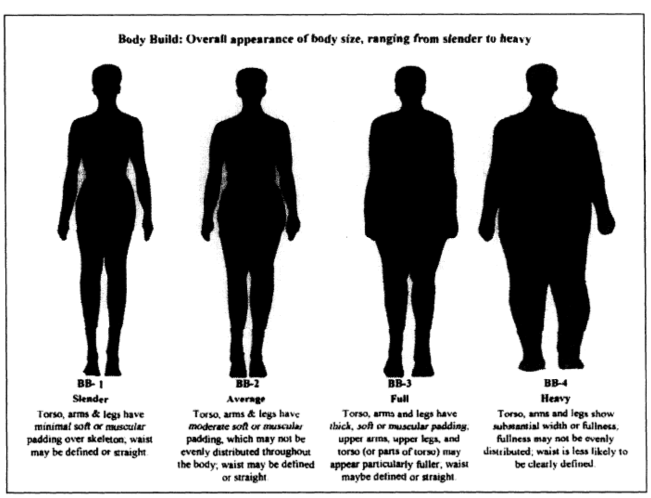


Figure 2-5. Example of scales used in front torso shape, which were created by Connell et al. (2006).

Above all these shape variations are determined visually. Only one body projection onto the view plane can be evaluated at a time, and therefore the analysis can be misleading, as bodies with the same front projection can have significantly different side projections and vice versa. Also, traditional garment pattern construction relies on circumferential and arc body measurements. Therefore, body shape categorization with comparisons of widths and depths from the view plane are not as directly related to patternmaking as categorization based on body circumferences.

Beyond visual analysis, it was found that three major methods have been used for body shape analysis for objective analysis: (a) *proportions of body circumference measurements* (Petrova & Ashdown, 2008; Simmons et al., 2004), (b) *linear multiple regression analysis* (Churchill, Churchill, McConville, & White, 1977; O'Brien & Shelton, 1941), and (c) *principal component analysis* (M. E. Green, 1981; C.J. Salusso-Deonier, Borkowski, Reich, & Goldsberry, 2006; C. J. Salusso-Deonier et al., 1985).

Simmons et al. (2004) categorized whole body into nine shapes (hourglass, bottom hourglass, top hourglass, spoon, rectangle, diamond, oval, triangle, and inverted triangle) based on circumference measurement ratios or drops between bust, waist, high hip, stomach, abdomen, and hip (Figure 2-6). They developed the software 'Female Figure Identification Technique (FFIT) for Apparel©' for 3D female body scans. Petrova and Ashdown (2008) categorized lower body shapes into three groups (straight, medium, and curvy) by the ratio of hip and waist circumference measurements for identifying ease values of pants depending on body shape. However, bodies with the same circumferential proportions may differ in width/depth proportions, or in some other shape-defining measurements, such as angles, or anterior / posterior variations defined by arc measurements, rendering the circumferential proportion definition unable to differentiate shapes completely (Watkins, 1995). A more elaborate combination of circumference/arc proportions along with width/depth proportions may be needed to define the full body shape.

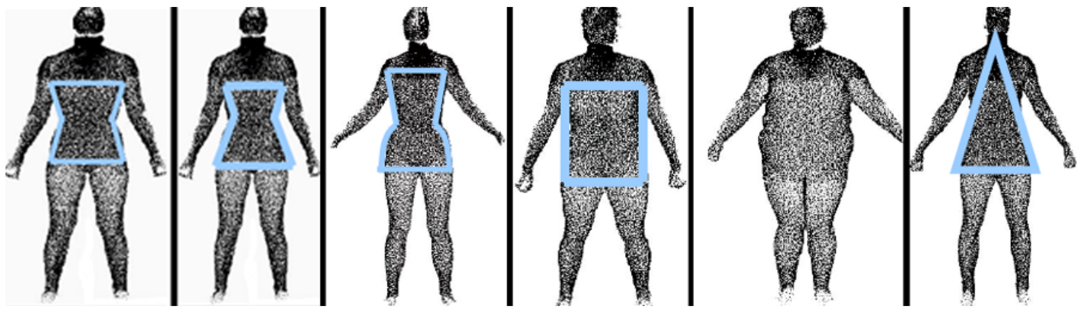


Figure 2-6. Hourglass, bottom hourglass, spoon, rectangle, oval, triangle shapes defined by Simmons et al. (2004).

The second method (b) utilizes one of the statistical methods, multiple regression analysis, to define body shape. It is based on the assumption that people generally have a certain combination of measurements at key body locations. Two key dimensions are selected to identify body type (e.g., stature, bust girth, waist girth or hip girth) by the *drop*, or the difference between the two dimensions in order to

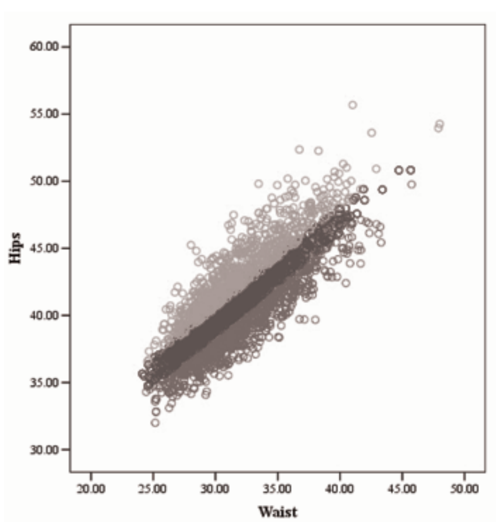


Figure 2-7. Three groups divided by hip to waist drop using regression analysis.

represent a specific body proportion. Other body measurements are then calculated from these initial key dimensions using multiple regression functions. O'Brien & Shelton (1941) separated stature into 'regular, long, short', and then did an additional separation by abdomen and hip: 'stouts' for people with specified stature and bust girth if abdomen and hip are larger, and 'slims' if abdomen and hip are smaller. Then, values of the secondary body dimensions were calculated from the key dimensions using multiple linear or nonlinear regression analyses.

The International Organization for Standardization (ISO) published Technical Report ISO/TR 10652:1991 presenting guidelines for creating a sizing system based on anthropometric data of a particular population for use by different nations. They classified figure types based on bust to hip drop values into A type (9 cm), M type (4 to 8 cm), and H type (3 to -4 cm or greater) (International Organization for Standardization, 1991). Accordingly, several countries such as Germany, Japan, Korea and Hungary revised their sizing systems. In Germany, the height and hip types defined nine figure types. Heights were grouped into average height, short and tall. Each group is divided into three hip types; slim hip, average, and full hip type (DOB-Verband, 1983). Japanese Standards Association (2001) defined body shapes by height and bust to hip drop (A, Y, AB, and B) for their national sizing systems (JIS L 4005:2001 Sizing Systems for Women's Garments) (Japanese Standards Association, 2001). Korea also classified body types by height and bust to hip drops for their national sizing system (KS K0051:2009 Sizing systems for female adult's garments) (Korean Standard Association, 2009).

These analyses can be done simply, but this method is limited in terms of the number of measurements (two or three) that can be used for the body categorization. Also, the secondary body dimensions calculated by multiple regression analysis are only for women with average body size and proportions, so it has limitations as it does not represent populations with a wide range of proportional shapes.

The last method (c) utilizes principal component analysis (PCA), which reduces the number of variables by combining similar variables into new composite dimensions called principal components (PC). Previous studies using this method utilize girths, front/back arcs, lengths, or heights as independent variables for the whole body shape analysis, with six to fifteen principal components extracted in order of contribution to explaining variation (Croney, 1977; M. E. Green, 1981; C.J. Salusso-Deonier et al., 2006; C. J. Salusso-Deonier et al., 1985) (Table 2-1). The Salusso-Deonier system (2005), as an example, used Varimax rotation was used to secure independence among principal components. Since the use of several principal components to define body shapes was difficult, only the first two components, PC1 and PC2, with the most powerful explanation, were selected to define the body shape (Figure 2-8). The result showed that PC1 and PC2 were related to either horizontal measurements (body thickness) or vertical measurements (body length).

Table 2-1. Studies using principal component analysis for body shape analysis.

Researcher (Year)	Croney (1977)	Green (1981)	Salusso-Deonier et al. (1985)	Salusso-Deonier et al. (2005)
Target	317 college women in London	5,000 U.S. Army women aged 17-35	1,217 U.S Army women aged 17-35	6,657 women aged 55 and older (from 1990 ASTM survey)
Independent variables	17 measurements	47 measurements	60 measurements	57 measurements
Number of PC	6	6	15	3
PC1	Height & lengths	Height & lengths	Horizontal measurements (widths, depths, & girths)	Horizontal measurements (widths, depths, & girths)
PC2	Age & circumferences	Lower body girths	Lengths & heights	Limb lengths
PC3	Upper body circumferences	Upper body heights	Upper body lengths	Upper torso lengths
PC4	Torso lengths	Torso lengths	Lower body lengths, torso length	-
Body shape group	-	-	PC1 × PC2	PC1 × PC2-
Sizing system	-	-	Partition the distribution of PC 1 by 2 into 26	Partition the distribution of PC 1 by 2 into 25

Table 1. Principal Component Analysis with Varimax Rotation

Body Measurements	Rotated Principal Component Loadings
Principle Component 1: Thickness	
A. Mid-Neck Girth	.757
B. Full Bust Girth	.874
C. Waist Girth	.881
D. Abdominal Girth	.927
E. Full Hip Girth	.921
F. Full Thigh Girth	.765
G. Knee Girth	.739
H. Ankle Girth	.494
I. Upper Arm Girth	.881
J. Elbow Girth	.778
K. Wrist Girth	.671
L. Vertical Trunk, Front	.799
M. Vertical Trunk, Back	.795
T. Crotch Length	.811
S. Cross-Back Width	.561
O - P Hip Depth	.622
Principal Component 2: Limb Length	
O. Crotch Height	.888
P. Knee Height	.868
V + T. Hanger	.671
Principal Component 3: Torso Length	
N. Waist Length, Back	.658
R. Waist Length, Front	.726
T. Shoulder -to-Wrist Length	.839

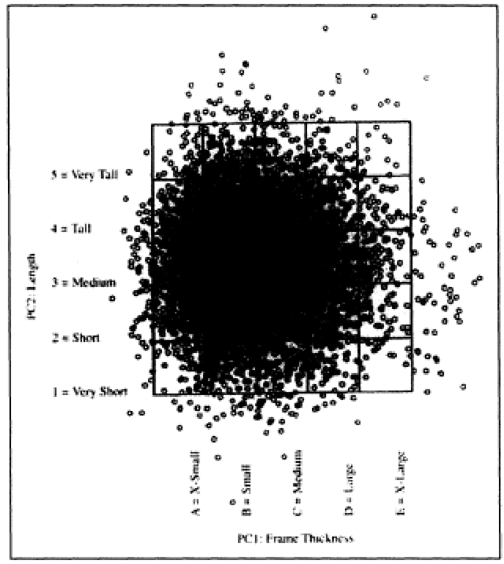


Figure 2-8. Results of body shape analysis using principal component analysis developed by Salusso et al. (2005).

A combination of PC1 and PC2 could represent different body shapes. However, these analyses tend to collect most of vertical measurements (heights and lengths) under one PC, and most of the horizontal measurements (girths and front/back arcs) under the other PC, which results in specific body shape characteristics such as waist and hip relationships not being distinguished from one another.

As discussed above, each of the current methods of categorizing body shape is limited in some aspects. A new method of body shape categorization needs to be developed that combines both front and side perspectives of the body, that distinguishes many different body relationships, and that uses objective body measurements. In this study, principal component analysis was selected to extract distinctive shapes from silhouette and profile views of the body. In order to address the problems found in the previous PC studies, I employed two strategies: The first strategy was to focus on classifying only the lower body shapes rather than whole body shapes. Lower body shape analysis was selected for this study because: (a) customers are the least satisfied with the fit of pants compared to all other apparel items (Charoensiriwath & Spichaikul, 2009; LaBat & Delong, 1990) and (b) many of the made-to-measure apparel companies currently provide pants as a custom garment style ([TC]², 2009). The second strategy was to include various types of shape defining measurements such as width, front/back depth, arc measurements and the drop values between measurements of primary body locations instead of simple circumference and length measurements. The third strategy was to use drops and angles instead of the measurement variables.

Methods Used in the Apparel Industry

The lower body shape categorizing methods used in the apparel industry are much simpler than those developed in academia. Apparel companies such as Lane Bryant, Lands' End, Levi's, Gap Inc., The Limited, Banana Republic, L.L.Bean, Eddie Bauer LLC., and Catherines classify women's body shapes into two to three lower body shapes ('Straight' and 'Curvy') based on visual analysis of waist to hip proportion, seat shape, and thigh shape. To help customers to identify their body shapes and to choose their appropriate pants style, they provide fit guide including body shape pictures (e.g., waist to hip proportion, seat shape and thigh shape) and their brief descriptions on their web pages. Some companies ask customers to measure their waist and hip size and to report fit problems when they try pants, at the waist and hip. Then they automatically choose pants styles for each customer.

Lane Bryant found three distinctive lower body shapes based on their customers' measurements taken from their 3D body scanners: a 'curvy' figure accented by a cinched waist and slightly fuller hips; a 'straight' figure with broader hips and straighter figures; and a 'moderately curvy' shape with waists and hips roughly in proportion. As shown in Figure 2-9, they ask customers to choose fit problems and to compare their sizes with the size charts. (Lane Bryant, 2010b).

ORIGINAL RIGHT FIT SIZE	NEW RIGHT FIT SIZE	WAIST	YELLLOW HIP RANGE	RED HIP RANGE	BLUE HIP RANGE
1	14	34	36-39	40-43	44-47
2	16	36	38-41	42-45	46-49
3	18	38	40-43	44-47	48-51
4	20	40	42-45	46-49	50-53
5	22	42	44-47	48-51	52-55
6	24	44	46-49	50-53	54-57
7	26	46	48-51	52-55	56-59
8	28	48	50-53	54-57	58-61
9	30	50	52-55	56-59	60-63
10	32	52	54-57	58-61	62-65

Figure 2-9. Lane Bryant fit guide for pants styles.

Levi's classifies lower body shapes into 'Slight curve' (straight waist, slim hips and thighs), 'Demi curve' (Evenly proportioned from waist and thighs), and

‘Bold curve’ (defined waist, fuller hips and thighs). There are four stages to identify customers’ body shapes: choose pictures of lower body shape (straight waist and slim hips and thighs, evenly proportioned from waist to thighs, and defined waist and fuller hips and thighs), seat shape (slim, proportional, and curvy), and thigh shapes (straight, balance, and full), and their issues with jeans fit at the hips and thighs (waist is too tight, waist fit but doesn’t flatter, waist gap in the back) (Levi's, 2010) (Figure 2-10).

Lower body shape

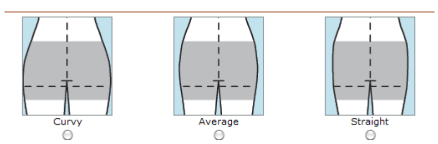
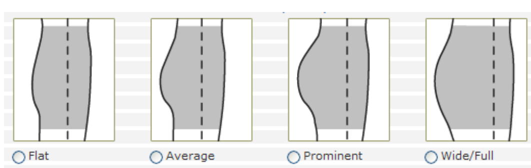
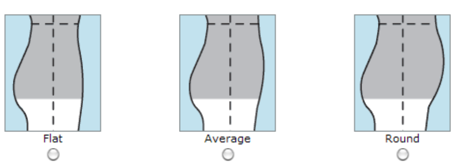
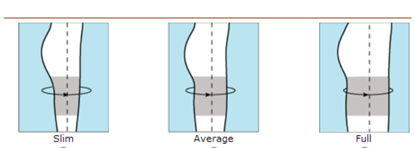
Seat shape

Thigh shape

Figure 2-10. Levi’s fit guide.

Archetype developed a process of identifying customers' lower body shapes for online apparel companies dealing with custom-made pants. They define lower body shapes according to waist to hip proportion, seat shape, abdomen shape, and thigh shape (Table 2-2). Customers are asked to specify their own body type from pictures of basic silhouettes and a text description, in addition to their self-reported measurements.

Table 2-2. Lower body shapes defined by Archetype Technology.

Location	Body shapes defined for customers
Waist to hip shape 	**Curvy -** body shape: triangle or pear. You typically carry and gain weight in your lower body (hips, seat, and thighs). Your thighs may be full in relation to your upper body **Average -** average or hourglass. You typically carry and gain weight equally in your upper and lower body. **Straight -** rectangle, apple, or inverted triangle. You typically carry and gain weight in your upper body (chest or abdominal area). Your thighs may be slim in relation to your upper body.
Seat shape 	**Flat** - The seat of your pants usually fits you loosely. **Average** - The seat of your pants usually fits you satisfactorily. **Prominent/High** - You many find the waistband of most pants gapes at the back. Your seat could be described as very round and may sharply curve away from your lower back. **Full/Wide** -Your seat is not prominent, but may be ample, full or wide.
Abdomen shape 	**Flat** – You have little or no body fat on your lower tummy. **Average** – You have a bit of roundness to your tummy, but it doesn't affect the way your pants fit at the waist. **Round** – You have a rounder-than-average tummy shape, and may have trouble getting pants to fit well at the waist. **Very Round** – Your body shape could be described as apple. You typically carry and gain weight in your abdominal area and it definitely affects the way pants fit at the waist.
Thigh shape 	**Slim** — You are slender, have slim thighs, or find that most of your casual pants fit more loosely than you would like in the thigh area. **Average** — Most of your casual pants fit satisfactorily in the thigh area. **Full** — You have athletic or large thighs, or you find that most of your casual pants fit more snugly than you would like in the thigh area.

Pattern Development for Various Body Shapes

Apparel professionals have recognized the necessity of developing pattern shapes that incorporate body proportions, shapes, and posture in addition to linear surface measurements. Goldsberry, Shim, & Reich (1996) suggested that seat shape could be a significant issue in the fit of pants for older women from the results of their survey targeting women aged 55 and older. Schofield, Ashdown, Hethorn, LaBat, & Salusso (2006) found that the contrast of flat versus protruding buttocks was a particularly relevant component when seeking to optimize fit for the lower body. They divided 176 participants into two groups (flat or full seat) visually (Figure 2-11). Two

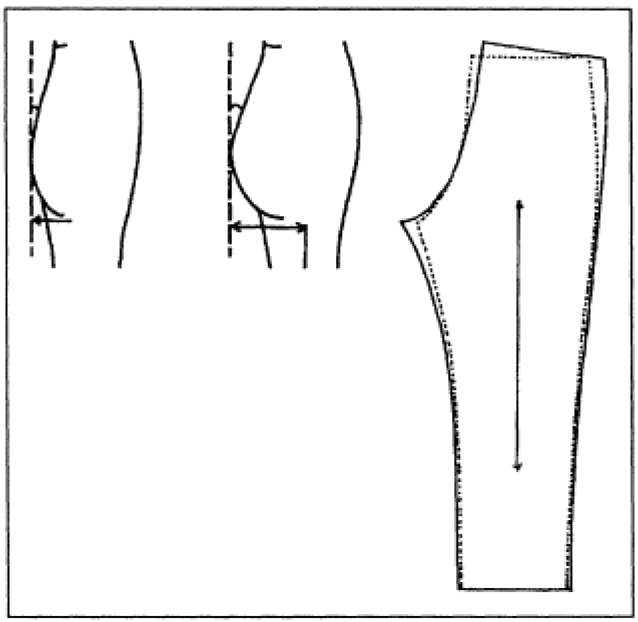
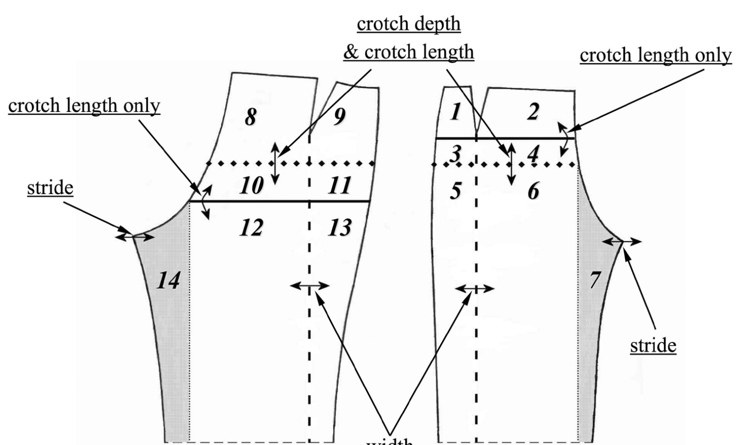


Figure 2-11. Visual classification of seat shapes as viewed from the side. Related pants shapes show changes in angle and crotch extension as seat shape differs (Schofield et al., 2006).

sets of pants were designed to accommodate two shape options (full and flat seat) in five sizes. The variance in shape was addressed in three areas of the pattern: relative side seam placement, back seam angles, and crotch extension. Participants with flatter seat shapes were significantly more satisfied with fit at the hip indicating that the introduction of a shape variable can improve satisfaction with fit for population segments with equivalent body shape variations. They noted that addressing the shape differences in only one area, seat shape, was not enough to provide good fit, so they recommended that other complex proportional and shape factor such as abdomen and thigh shape also need to be incorporated to development of pattern shapes for further study.

In order to identify appropriate ease amount depending on body shape, Petrova & Ashdown (2008) separated subjects into three shape groups by the ratio of hip to natural waist circumference measurements. These groups were designated ‘straight’, ‘medium’, and ‘curvy’ (cutoffs at 1.26 and 1.33). They constructed special test pants with adjustable Velcro sections to provide custom fit for each participant (Figure 2-12). Using the Velcro, crotch length, crotch depth, center front seam, center back seam, waist circumference, hip circumference, thigh circumference, knee circumference, and inseam length were altered.



Legend
- dashed lines: overall width adjustments
- diamond lines: crotch depth and crotch length adjustments
- solid lines: crotch length adjustments only—pieces pivot from side seam
- shaded pieces: full pieces interchanged with different sized pieces to adjust stride

Figure 2-12. Pattern sections (numbered) and adjustment lines used in test pants developed by Petrova & Ashdown (2008).

Few studies developed methods to improve shape of patterns in consideration of body shapes at the stage of development of block patterns as shown above. Most publications such as patternmaking books or journals for home sewers present pattern drafting methods, and then sections for methods of alteration to adjust the pattern to various body shapes are separately presented. Traditionally alterations of garment patterns are considered as an essential step in producing attractive and precisely fitting clothing from the block patterns. Bray (1978) noted that it is difficult to apply contour measurements to a flat surface and stated that results are bound to be somewhat approximate, and inaccuracies have to be allowed for. Another reason that alterations are necessary is that circumference and length measurements are necessary when patterns are developed, but Whife (1965) found that although the circumferential measurements of bust, waist and hips of the three figures might appear similar, the shapes of these figures were quite different and would require different shaped garments to give an accurate fit. Zafu (2009) and some apparel companies such as Lane Bryant, Levi's and Gap also found that women with identical hip measurements can have totally different body types, resulting in different fit problems. In the following section, I introduce several studies that scientifically approached alteration procedures in academia, and then list alteration methods presented in publications such as pattern drafting books or journals.

Scientific Approach for Pattern Alteration

In order to create well-shaped patterns and reduce trial and error in fitting, several researchers have studied the relationship between body shapes and patterns, and methods of applying 3D shape information to 2D flat patterns scientifically. The somatometry (the study of human body types) approach was popular in development of methodologies for pattern alterations until the early 1990s. Brinson (1977) used

Douty's somatometry procedures to compare two processes for altering basic bodices and skirts. One process used traditional measurements to determine needed alterations; the second experimental method added information about body angles taken from somatographs. Farrel-Beck & Pouliot (1983) acknowledged it was not easy to alter pants patterns especially in the hip area, so they compared two sets of pants altered by traditional methods that used body lengths and circumferences, and experimental methods that used body length, circumference, and angles. Data points from somatographs were used to plot full-scale body contours for 36 female subjects. Quadratic interpolation and cubic spline interpolation processes were developed to correct and plot full-scale representations of the body curves. Results showed that the experimental method was preferred over the traditional method for front waist placement, front waist dart size, back crotch curve and horizontal grain. For the other areas, the fit was similar between the two methods. Brackelsberg, Ferrell-Beck, & Winakor (1986) also utilized body angle information to an experimental method similar to the previous two studies, but for the area where a bodice is attached to the skirt. The angle information was used to alter dart size, length and slope of the shoulder seam. The results indicated that models with deep body angles were more satisfactorily fitted when using the traditional methods, while models with shallow body angles benefited more from the use of the experimental methods. Gazzuolo, Delong, Lohrs, LaBat, & Bye (1992) used statistical regression models to compare the traditional linear measurements (lengths and circumferences taken over the body surface with a tape measure) with the measurements taken of frontal and lateral view photographs for use in patterns for the upper torso of female body forms. The regression model indicated that while linear measurements provided slightly more accuracy in predicting a few of the pattern dimensions, the photographic measurements were more accurate in predicting others, particularly pattern angles.

They concluded that photographic measurements held promise as an alternative to the more intrusive linear measurements for predicting pattern dimensions.

Pattern Alteration: General Techniques

Many publications illustrated methods of alteration of pants patterns due to irregularity in body shape, size and posture (Armstrong, 2006; Brackelsberg & Marshall, 1990; Bray, 1994; Liechty, Pottberg, & Rasband, 1992; Oblander & Anderson, 1996; Rasband, 1994). Based on these publications, alteration methods that are generally used are listed in the Table 2-3.

Table 2-3. Alteration methods introduced in publications.

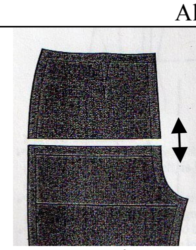
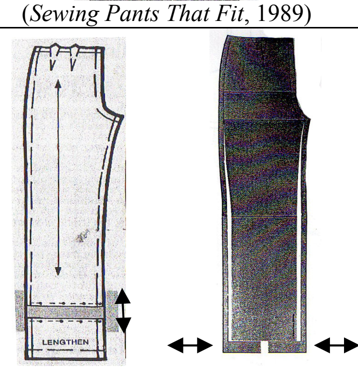
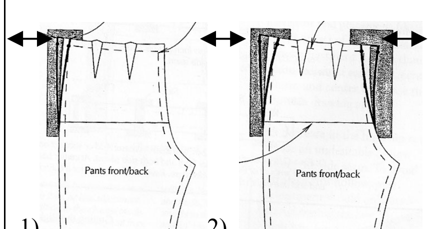
Locations	Alteration Methods	
Waist to crotch length	 (*Sewing Pants That Fit*, 1989)	Lengthen or shorten at the area between the waist and the crotch level.
Pants length / girth	 (Rasband, 1994)	Pants length: Lengthen or shorten at the area between the knee and the hem level. Leg girth: Divide the alteration amount into 2, and increase or decrease the amount with the points at the crotch level fixed.
Waist girth	 (Perry, 1972)	If alteration amount is less than 2 in, make the adjustment at each side on the front and back at the same level at the waist seam. If alteration amount is more than 2 in, divide the total alteration amount by 8, and make the adjustment at side, center front, and center back.

Table 2-3 (Continued)

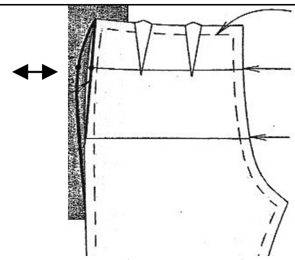
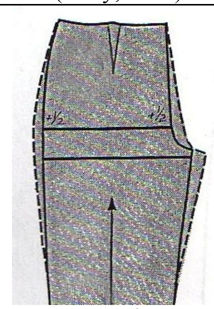
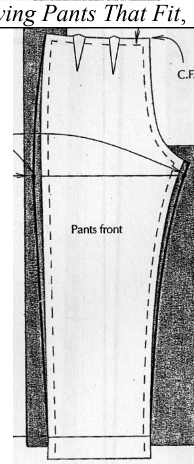
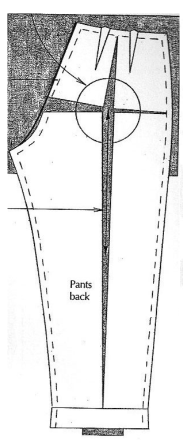
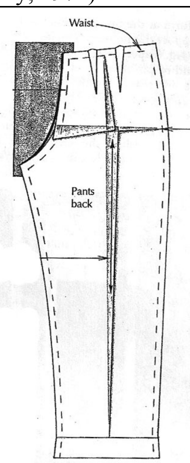
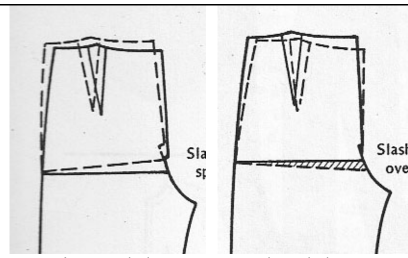
High hip girth	 (Perry, 1972)	Increase or decrease at the high hip level.
Hip girth	 (*Sewing Pants That Fit*, 1989)	Increase or decrease at the hip level and crotch level.
Thigh girth	 (Perry, 1972)	Add or subtract the alteration amount at the thigh distance from waist and at the side and inseam of the front and back. Add or subtract the same amount at the crotch point that you added or subtracted at the inseam thigh level, tapering to nothing at the hemline.
Buttocks prominence	 Prominent buttocks  Flat buttocks (Perry, 1972)	Prominent buttocks: spread the alteration amount at the back seam line with the side seam point at the hip level, increasing the center back seam length and decreasing the slope. Flat buttocks: overlap the alteration amount at the back seam line with the side seam point at the hip level, decreasing the center back seam length and increasing the slope.

Table 2-3 (Continued)

Abdomen prominence	 Prominent abdomen Flat abdomen (*Sewing Pants That Fit*, 1989)	Prominent abdomen: slash from the front seam line horizontally to but not through the side seam line. Spread the alteration amount, increasing the length of the front seam. Flat abdomen: Overlapping the slash reduces the pattern for a flatter abdomen.

Clothing Fit

Subjective Assessment of Clothing Fit

Clothing fit is considered as a critical element of clothing quality and customer satisfaction in the apparel industry. However, it is difficult to universally define what a well-fitted garment is, since the definition of fit depends on individual perception of fit and is affected by fashion, style, and many other factors. Even though there are varying opinions on what constitutes good fit (Cain, 1950; Chambers & Moulton, 1961; Geršak, 2002; Hackler, 1984; Hudson, 1980; Shen & Huck, 1993), fit is traditionally defined as a combination of five factors; ease, line, grain, balance and set (Erwin, Kinchen, & Peters, 1979). Clothing that fits well provides an adequate amount of wearing ease (e.g., ease to allow for body movement) and design ease (e.g., ease developed by the designer to create a desired visual effect, silhouette and style), and follows the silhouette of the body with no undesirable wrinkles.

Clothing fit is generally assessed by qualitative methods based on an individual's subjective perception of fit. Since each individual has their own standard for judging fit satisfaction, apparel companies have difficulty in understanding fit from a consumer's perspective. Several researchers found some indication of influential factors on fit satisfaction. LaBat & Delong (1990) found relationships between lower body fit satisfaction and body cathexis (positive or negative feelings toward one's body) of study participants, citing correlations that were positive, though not very strong. Alexander, M., Connell, L.J., Presley, A.B. (2005) explored the relationships between body type and fit preferences with body cathexis, clothing benefits sought by consumers, and demographic profiles of consumers. Significant associations were found between body cathexis and body type. The degree of satisfaction with different body parts depended on the body type of the individual, although the level of satisfaction with head/upper body, height and torso did not vary by body type. No significant interactions were found between fit preferences and body type for lower body garments.

Secord & Jourard (1953) found that self-concept is developed by comparing oneself with socially structured symbols; in the case of clothing comparing oneself with the ideal female figure for apparel. LaBat & Delong (1990) also noted that social ideal body image and fit models used in apparel industry affected customers' body cathexis, influencing the degree of satisfaction with fit. The preferred body figure used by the apparel industry is taller and slimmer than the general population, and has an hourglass shape. These figures are shown in fashion illustrations, advertisements, and catwalks. When sizing systems are created in the apparel industry, they are generally developed on the basis of measurements that define an hourglass shape, ignoring people with other body shapes. The ASTM International committee provides a standard structure for developing and updating voluntary clothing sizing standards that may be used by clothing producers. But Newcomb & Istook (2004) found that ASTM D 6829 (the Junior Standard) and ASTM D 5585 (the Missy Standard) were developed for only for people with an hourglass shape, while the predominant body shape in the actual U.S. population in these age groups are rectangle and spoon shapes. This disconnection between industry standards and fit models, and the population as a whole, can lead to confusion on fit and dissatisfaction with fit and sizing.

Fit assessment methods vary among manufacturers and researchers. In order to standardize the fit scenario, reference procedures have been developed to perform the subjective evaluation of clothing fit. McConville (1986) described a procedure used to test protective clothing for the military that included assessment questionnaires for the participants and assessment by two investigators who recommended changes to the program manager or manufacturer. That procedure included task simulations to test the clothing in active positions and the fit judges assessed limitations on mobility caused by misfit and garment stress lines. Huck, Maganga, & Kim (1997) also developed a exercise protocol for evaluating protective overalls, which consists of a series of body movements which represented the physical movements which are needed in a work environment where the garments under investigation are worn and stretched. This protocol was adapted to ASTM F1154 - 10 (Standard practices for qualitatively evaluating the comfort, fit, function, and durability of protective ensembles and ensemble components). The National Association of Hosiery Manufacturers (NAHM) standard also described a testing procedure (standing, sitting and walking exercising) for women's pantyhose (AFNOR, 1995).

Even though there are several protocols to assess the fit of protective clothing, there is currently no standard protocol to assess the quality of fit for apparel in general. Despite the common need for effective tools to assess or correct fit, most strategies used for this purpose are not well defined and can result in varied outcomes. In the apparel industry, prototype garments are produced in a base size and fitted to a fit model with measurements, body shape, and proportions similar to their target market. Fit is examined by experts (designers, patternmakers, and fit models), but their perceptions of good fit are different, so it is hard to control the fit consistently even within the company (Bye & LaBat, 2005).

In academia, fit testing is generally conducted by both wearers and expert fit judges. Expert fit analysts have high skills of assessment of fit, but they can only analyze the fit by examining the appearance of the clothing. On the other hand, wearers can feel and perceive the fit and comfort, but generally they do not have deep knowledge of fit. Therefore results by both wearers and expert judges are generally combined to judge the fit. For the wearer's fit test, the commonly used rating scale is Likert scaling consisting of a set of attitude statements (Likert, 1932). Wearers are asked to express agreement or disagreement on a five-point scale. Huck et al. (1997) designed a wearer acceptability scale. The nine-point scale consists of a series of descriptive adjective sets to determine how wearers felt and how they perceive the fit and comfort of their clothing. For both wearers' and experts' assessment, Shen & Huck (1993) developed a subjective scale which contained 25 items in three categories: overall fit, bodice front fit and bodice back fit. For each item, nine responses were possible, ranging from 'much too tight (1)' to 'much too loose (9)'. The middle position for each fit criterion indicated a 'good' fit. Yu, Yeung, & Lam (1998) slightly changed this scale for the fit evaluation of men's jackets: 'much too tight (-4)' to 'much too loose (4)'. Ashdown, Loker, Schoenfelder, & Lyman-Clarke (Ashdown, Loker, Schoenfelder, & Lyman-Clarke, 2004) developed a three-point scale for a simple rating: acceptable (1), marginal (0), and unacceptable (-1). When evaluating the fit satisfaction, a five-point scale is generally used: (1) very unsatisfactory to (5) very satisfactory (Schofield et al., 2006). Depending on the test styles or purpose of various studies, the various numbers of scales and types of descriptive adjectives have been developed.

Objective Assessment of Clothing Fit

Clothing fit is generally assessed by subjective and qualitative methods, but the drawback of these methods is the lack of precision, lack of agreement on good fit, and ineffective communication. Therefore objective evaluation that can quantify the relationship between the body and garment are necessary.

During the 1990s, the moiré technique was used to measure and evaluate clothing fit (wrinkle, drape, and bagging) and body shape by means of moiré topography. Yu, Harlock, Leaf, & Yeung (1997) developed a moiré system for the measurement of bra cups, employing a special instrumental design and technique to enhance the fringe visibility. Yu developed a grid plate using photo-chemical processing and a pneumatic grid translation system for removing background noise. The moiré picture was digitized and the coordinates of the sectional profiles were quantified. Yu et al. (1998) developed another moiré topographic system for a jacket (Figure 2-13). By placing the jacket close to the grid, a sharp image of the moiré fringes was obtained. The fringe pattern was digitized and the co-ordinates of the sectional profiles were quantified using fourth-order polynominal functions and root-mean-square measures derived of the shape characteristics.

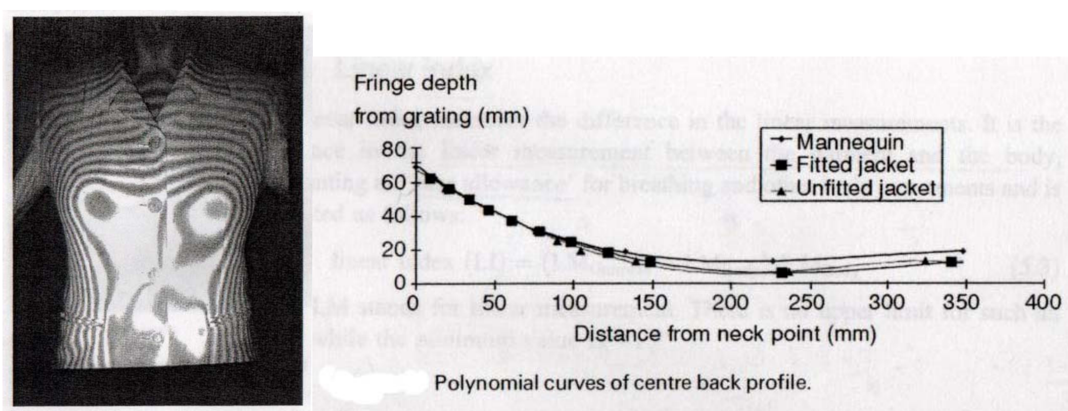


Figure 2-13. Moiré image of jacket, and polynominal curves of center back profile (Yu et al. 1998).

Yu, Fan, Qian, & Tao (2001) developed a soft mannequin to simulate the human body for measuring contact pressure for judging the fit of tight fitting clothing.

It was developed with the exact dimensions of the lower torso of a female body, with a full-size bone skeleton, imitating soft tissue and skin made by polyurethane foam and silicone rubber (Figure 2-14). It was found that the clothing pressure on a live model can be predicted by using linear equations which correlate the relationship between the measurements obtained from the soft mannequin with those of the human body.

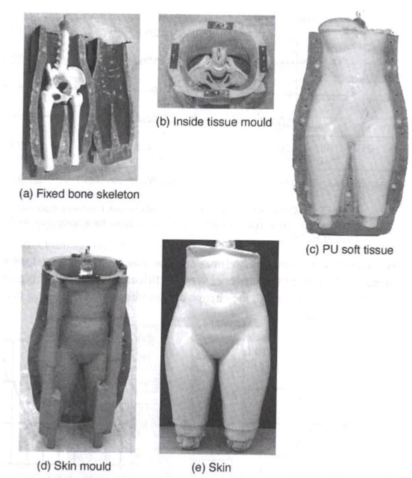


Figure 2-14. Manufacture of soft mannequin (Yu et al. 2001).

The development of 3D body scan technology enables assessment of fit more reliably than the previous methods. Kathleen Robinette (1993) proposed merging 3D scans of the unclothed and clothed body in order to investigate the space between them. Ng, Chan, Pong, & Au (1997) proposed a set of different measures of the space between the clothing and the body, including linear, cross sectional, volume, and a ‘signature curve’ created by plotting cross sectional measures against the height of each cross section. Other studies have made use of cross sectional data derived from 3D scans in various ways to quantify fit (Kim, Suh, Suk, Park, & Lim, 2001; Li, Corner, Paquette, Lee, & Kim, 2000; Loker, Ashdown, & Schoenfelder, 2005; Song, 2007; Taya, Shibuya, & Nakajima, 1995). Ashdown, Devine, & Erickson (2010) used radial measures from the garment cross sections to the dress form cross section to analyze the differences in fit among the skirts (Figure 2-15).

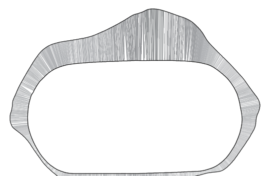
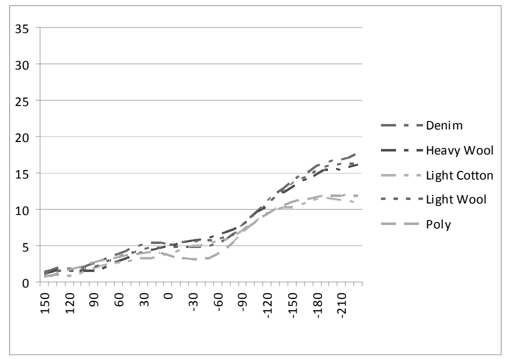
a)  b)  c) 

Figure 2-15. a) Flared skirt and dress form scans merged, b) Cross section of straight denim skirt at the form bottom, c) Average variability of radial measures for the straight skirts made from various fabric types (Ashdown et al., 2010).

Visual Tools for Collecting and Assessing Clothing Fit

Videotape analysis has been used as a visual tool for collecting and assessing fit for apparel studies. In academia, Kohn and Ashdown (1998) used videotape images to analyze fit of slashed test jackets for women aged between 55 and 65. Ashdown & O'Connell (2006) conducted a study to investigate the relationship between a panel of trained paraprofessional judges' responses and a panel of expert judges' responses in a garment fit test for reliability and validity. In this study, videotapes were used as a tool for assessing the jacket fit. Schofield, Ashdown, Hethorn, LaBat, and Salusso (2006) also used a videotape method to record and analyze pants fit for women aged 55 and older. The protocol specified wearer responses to the pants and an evaluation of the fit by an on-site expert. An additional expert fit evaluation was conducted later by a panel of geographically dispersed experts who viewed videotapes of each participant in her test pants.

Apparel companies have also realized the value of visual analysis in fit testing of prototypes that are not onsite, and currently they are using video and internet conferencing to assess the clothing fit on fit models or dress forms from distant locations. As an example, Victoria's Secret is using FastFit™ imaging technique developed by Shapely Shadows, Inc. (Speer, 2008). Multiple photographic images are taken as a fit model poses on a 'turnable' platform, generating a 360° view of the garment that can be shown as a rotating image for online fit approvals. FastFit™ software creates up to 99 frames for 15 seconds, and each of the frames can be viewed separately as a jpeg file which can be attached to an e-mail. After Victoria's Secret implemented this technology at all locations of their vendors in February 2008, they experienced fewer difficulties communicating with vendors located offshore. The tool allows the company to view fit sessions in great detail and offline at their convenience, and to identify and convey problems or changes back to the vendor. This means all parties involved in the fit process, which includes technical designers in different locations, are able to view the same images from a fit session. It enables them to generate or receive instructions about the precise location where there may be a problem.

While 3D scans have not been practically implemented as a tool for analyzing fit in industry for everyday onsite fit sessions, 3D scans are considered as a potential tool that could be used in the future, and that may solve some problems of other image techniques. Most research using the 3D scanner uses the capability of the scanner to capture, visualize, and measure the body. However, visualization of 3D scans taken of a model wearing a garment are also useful for apparel research as these 3D images can facilitate the viewing of stress folds and wrinkles occurring from tight or loose fit (Ashdown, Loker, & Adelson, 2005; Ashdown et al., 2004). One important issue in fit analysis from images is the resolution of the image. The resolution of videotape images is generally quite low and video conferencing by satellite or the Internet can further reduce the clarity of the images. 3D scanners can generate images with excellent resolution. A scanned image of the clothed figure can be zoomed and rotated, making it possible to comprehend the depth, origin and path of stress folds as small as 4 mm deep around the body (Ashdown et al., 2004).

In addition to visual images, 3D scanners can generate reliable measurements along and across the scanned surface. Ng, Chan, Pong, and Au (1997) proposed using various types of 3D scan data for objective measurements to assess fit. Loker et al. (2005) offered new possibilities to quantify and visualize fit by superimposing scans made with and without clothing using appropriate software such as Polyworks v7.2® (InnovMetric Software Inc., 2002). The linear distances between the body scan and the clothed scan, the ease value, can be calculated. 2D and 3D data such as circumference slices, surface areas, and volumes between the body scan and the clothed scan can be used to provide comprehensive and objective analyses of fit. Kim, Suh, Suk, Park, and Lim (2001) studied comparative evaluation of wearing fitness of women's ready-to-wear jackets using a 3D scanner. They quantified wearing ease, the distance between the body and the garment at critical locations, using merged cross section slices between the body scan and clothed scans.

Apparel companies have begun to realize the value of visual analysis of 3D scans in analysis of body types and sizing systems. A recent apparel industry study of body shape conducted by Victoria's Secret used visual analysis of 3D body scans to categorize different body types in order to address issues in their sizing system ([TC]^2, 2006). Companies such as Jockey International, JCPenney, and Sears partnered with [TC]^2, who conducted the Size USA project, an anthropometric study. These companies have worked with data from 3D body scans to improve the fit of their products (Davis & Munro, 2008). 3D body scan data of their target customers can help companies to visualize their customer's body proportions and body shapes more clearly, and give them valuable data for revision of their sizing systems.

Another powerful use of 3D data could be for analysis of fit from 3D clothed scans for validation of a sizing system. The technical design department at Nike collaborated with Cornell University to conduct a research project to analyze fit of their ready-to-wear jackets across full range of sizes (Buckner et al., 2007). Seventy-three college women were recruited and asked to wear a Nike ready-to-wear jacket in their best fitting size. Fit at critical locations was evaluated for each participant from their clothed scans by several fit judges. These analyses were used to assess the overall effectiveness of the sizing system, allowing Nike to determine what sizes and areas need revision based on the results of fit assessment. In order to produce a garment, apparel companies normally choose a fit model whose body shape and proportions are consistent with their target market, and fit prototype garments in a single base size. A set of additional sizes are created using grade rules developed by the firm to create the full range of sizes for their sizing system. However, the full ranges of sizes in the system are seldom tested, and most companies do not know how their sizing actually fits their target market. Feedback from consumers on problems with fit is limited. Retailers who interact directly with the customer are not trained in fit and the general shopping culture does not allow time for retailers to obtain fit data as customers are trying on clothing. In terms of this issue, 3D scans have potential as a tool for fitting garments on target market consumers as well if 3D scanners are installed in retail stores. This would give apparel technicians in the industry the opportunity to see the actual fit of their garments on target market customers.

CHAPTER 3. METHODOLOGY

Research Design

Data collection and analysis intertwine in this multi-step project which consists of (1) statistical analysis for lower body shape categorization based on SizeUSA data, (2) development of basic block pants patterns in each body shape by fitting three representative women in each group, and (3) validation of the use of the basic block patterns in a custom fit process by fit testing two pairs of pants, made from the *standard customization method* and *body shape driven customization method*, on nine women in each group (Figure 3-1).

Stage 1: Statistical analysis for lower body shape categorization

Recruitment of 83 participants for Stage 2 and 3

Stage 2: Development of basic block pants patterns in each body shape by fitting 3 representative women in each group

Stage 3: Validation of the use of the basic block patterns in a custom fit process by fit testing two pairs of pants, made from the *standard customization method* and *body shape driven customization method*, on 9 women in each group

Figure 3-1. Research workflow.

Statistical Analysis for Lower Body Shape Categorization Based on SizeUSA Data (Stage 1)

Measurement Selection

The dataset used for this study was measurements of women aged 18 to 35 from the SizeUSA dataset ($[TC]^2$, 2004). Measurements that are related to lower body shape analysis were selected on the basis of two considerations: (a) selection of front/back arcs, widths, and front/back depths in order to categorize both the silhouette and profile of the lower body, instead of limiting to the more common ratios or drops of girth measurements, (b) measurements chosen for their usefulness for application to pants pattern making. Width and depth measurements are difficult to apply to a traditional pattern making process, but they provide direct measures defining the silhouette and profile of the body. Therefore, I chose to utilize all of these measures; girths, front/back arcs, widths, and depths for this study. Length measurements (waist to hip height, waist to abdomen height, and waist to crotch height) and length proportions (waist to hip height/waist to crotch height, and waist to abdomen height/waist to crotch height) were also considered in the initial calculations.

The SizeUSA dataset used for the study contained only one depth measurement, the distance between the abdomen prominence point and buttocks prominence point, which was calculated by subtracting 'Buttocks Back X' from 'Abdomen Front X' (Figure 3-2). However, this measurement by itself could not represent the degree of abdomen prominence and buttocks prominence in relation to other body areas such as the waist. Therefore, I asked the Textile Clothing Technology Corporation ($[TC]^2$) to generate 'Front X', and 'Back X' at the waist and hip level from the original SizeUSA scans. The ability to generate new measurements from the 3D body scans from the study demonstrates one of the key advantages of an anthropometric study conducted using 3D scan technology.

The side seam location was determined by a plane centered at the mid-point between the abdomen prominence point and buttocks prominence point. Front depth, back depth, and full depth were calculated at the waist level and hip level. Waist widths and hip widths were additionally provided by $[TC]^2$. Girth, front arc, and back arc at the waist level, top-hip level (mid-level between waist and hip level) and hip level; girth at the max-thigh level; and buttocks angle measurements were selected from the original SizeUSA data (a total of 18 raw measurements). Length measurements were not used in the final analysis. The discussion of testing and discarding length measurements can be found in 'Consideration of length variables' of Results section.

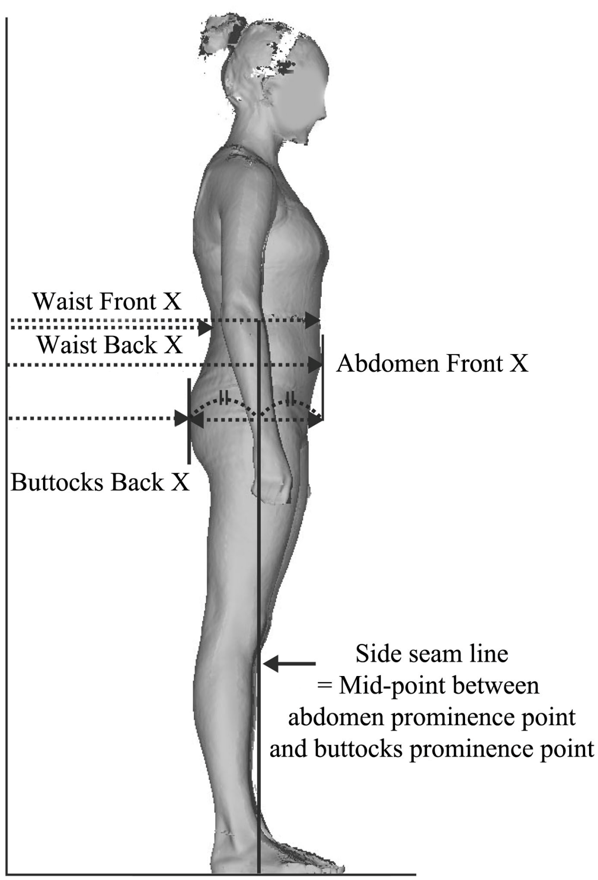


Figure 3-2. Method of generating front and back depth measurements from SizeUSA data.

Table 3-1 presents the measurement procedures and landmarks used to derive SizeUSA data from body scans for those measurements which were used in the final analysis. In order to capture various proportional relationships a total of 15 drops and 1 angle were calculated: Drop values of girths (hip to waist, top hip to waist, and hip to top hip 1-3), drop values of back arcs (hip to waist, top hip to waist, and hip to top hip 4-6), drop values of front arcs (hip to waist, top hip to waist, and hip to top hip 7-9, drop values of widths (hip to waist 10), drop values of depths (hip to waist 11), drop value of back depths (hip to waist 12), and drop values of front depths (abdomen to waist, and abdomen to hip 13-14) and buttocks angle (15) (see measurements coded by numbers illustrated in Figure 3-3). The side seam location for the arc measurements were different from that of the front/back depth measurements. Arc measurements were defined automatically and constrained to the definition used in SizeUSA. Even if

Table 3-1. Measurement procedures and landmarks.

	Measurement Procedures
Girth	A horizontal circumference around the body, taken parallel to the floor.
Front (back) arc	The front (back) portion of the girth from left to right side seam locations. - Side seam for waist front (back) arcs: a vertical line extending from the center of the armscye to the floor. - Side seam for top hip front (back) arcs: a vertical line from the center of side body at the top hip level. - Side seam for top hip front (back) arcs: a vertical line from the center of side body at the hip level.
Width	A horizontal distance taken parallel to the floor on the frontal plane.
Depth	A horizontal distance taken parallel to the floor on the sagittal plane.
Front (back) depth	A front (back) portion of the depth bisected by a frontal plane located at the side seam. - Side seam for front (back) depths: a vertical line located at the mid-point between the abdomen prominence point and buttocks prominence point (see Figure 3-2)
	Landmark locations
Waist	The smallest point of the waist as seen from the side.
Top hip	A point half the distance between waist and hip level.
Abdomen	The greatest prominent point of the abdomen as seen from the side.
Hip	The greatest prominent point of the buttocks as seen from the side.
Max-thigh	One inch below the crotch.

we had an 'optimal' single definition of side seam placement, it would not affect my results as differences are small among the different methods.

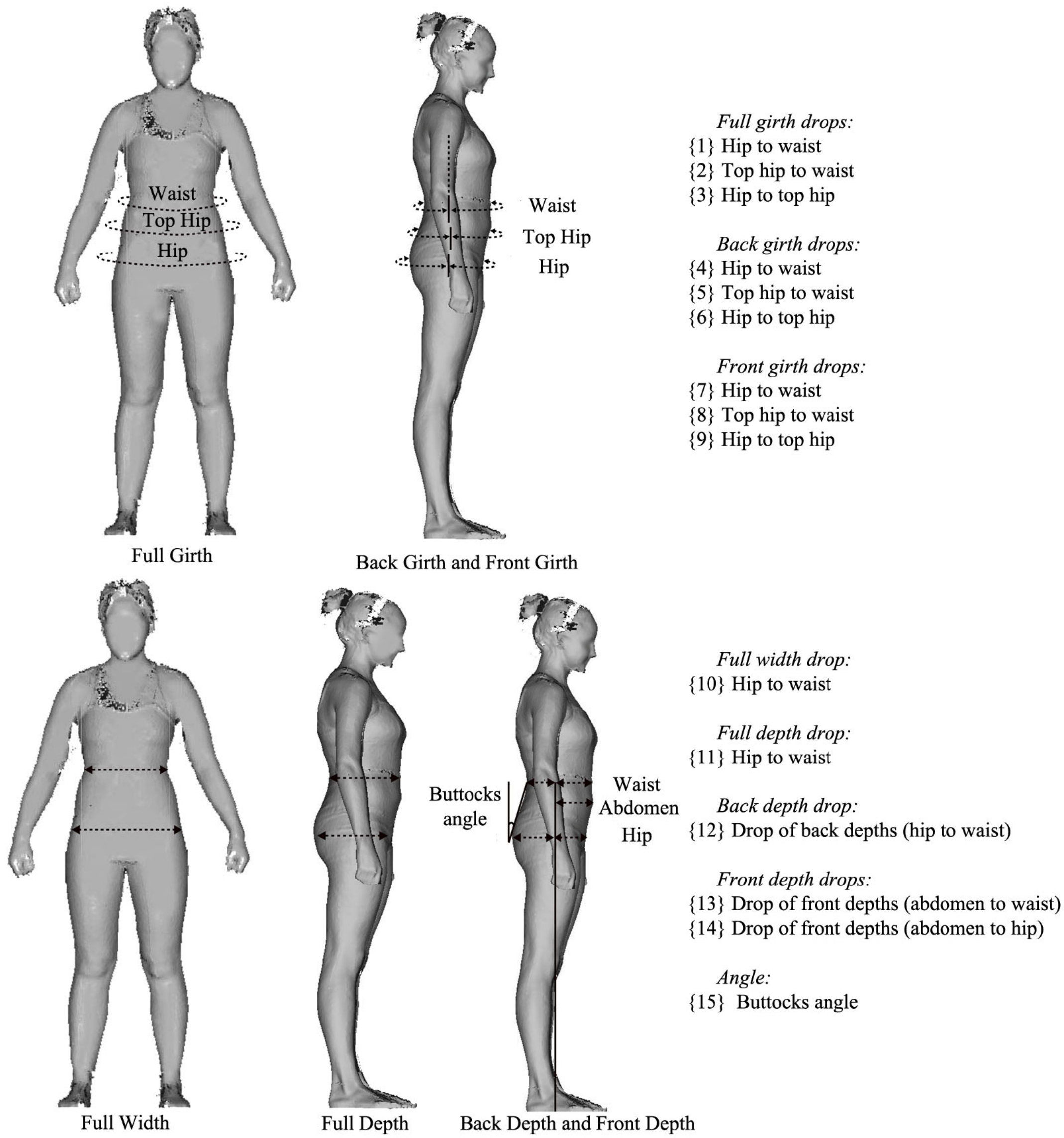


Figure 3-3. Measurement locations.

Since this study focused on body shape analysis regardless of body size, the strength of the relationship between weight (a representative measurement related to body size) and 33 variables (18 raw measurements and 15 drops) was examined by running bivariate correlation analysis using the statistical package SPSS 17.0. If there was a weak linear relationship between weight and a measurement, it was considered a shape-related variable. Out of 18 raw measurements, the buttocks angle had only a low correlation value ($r=0.088$, $p<0.01$). Most drops also had low correlation values ($r=-.281$ to $.345$, $p<0.05$), with the exception of the hip girth to max-thigh girth drop ($r=.696$, $p<0.01$). Bivariate correlation analysis found that there were weak linear relationships between weight and 15 variables (buttocks angle and 14 drops). Linear relationships such as a curvature relationships not revealed in single correlation calculation could also possibly exist. Therefore, we conducted a regression analysis with weight as a dependent variable, and a variable and its square as independent variables. If r value was significantly high ($p<0.05$), the function [weight = a + b × (variable) + c × (variable)^2] could be judged to be meaningful; expressed as curvature relationships. R values did have significance, but when r value in the linear model was compared with that in the model which a quadratic term was added, the explanatory

Table 3-2. Descriptive statistics of 15 variables.

Variable	Mean	Range	S.D.	Skewness	Kurtosis
Girth: Hip – Waist	23.1 (9.1)	31.3 (12.3)	1.99	-.04	-.14
Girth: Top hip – Waist	14.9 (5.8)	21.8 (8.6)	1.42	.09	-.05
Girth: Hip – Top hip	8.2 (3.2)	18.9 (7.4)	1.41	-.03	-.50
Front arc: Hip – Waist	8.2 (3.2)	16.1 (6.3)	1.04	-.10	-.14
Front arc: Top hip – Waist	4.9 (1.9)	12.8 (5.0)	.83	.01	-.15
Front arc: Hip – Top hip	3.2 (1.3)	10.4 (4.1)	.68	-.16	-.17
Back arc: Hip – Waist	12.9 (5.1)	16.6 (6.5)	1.12	.10	-.14
Back arc: Top hip – Waist	10.0 (3.9)	14.9 (5.9)	.98	.26	-.10
Back arc: Hip – Top hip	2.9 (1.1)	9.5 (3.7)	.64	.03	-.12
Width: Hip – Waist	8.2 (3.2)	11.3 (4.5)	.75	.16	-.17
Front Depth: Abdomen – Waist	0.7 (.3)	7.5 (3.0)	.34	-.02	2.04
Front Depth: Abdomen – Hip	2.6 (1.0)	10.8 (4.2)	.46	.11	.81
Front Depth: Hip – Waist	6.8 (2.7)	9.6 (3.8)	.65	.12	-.13
Depth: Hip – Waist	4.9 (1.9)	9.4 (3.7)	.62	-.11	-.10
Buttocks angle	22.66	23.23	3.99	-.01	-.17

Note. For means and ranges of the 14 variables (except for buttocks angle), the first unit listed is cm, with inches listed in parentheses.

power was not improved; r values were only increased by about 0.02 to 0.10. Therefore, we can conclude that the 15 variables had only weak linear relationships and weak curvature relationships to weight. Therefore I considered them to be shape-related variables, and included them in the following analysis. Table 3-2 presents the descriptive statistics of the 15 variables.

Sample Selection

There were 2,981 women aged 18 to 35 in the SizeUSA data. Percentiles of BMI (Body Mass Index), waist girth measurement, and hip girth measurement were calculated (Table 3-3). The Size USA sample was sorted to contain only those women who would fit in the ASTM Missy size range. Waist girth measurements and hip girth measurements of size 2 (the minimum size) and size 20 (the maximum size) of the sizing standard *ASTM 5585-95 (Standard of body measurements for adult female misses figure type sizes 2-20)* were compared with the girth measurements of SizeUSA data. Both the waist girth (59.7 cm) and hip girth (86.4 cm) of size 2 were positioned below the 5^{th} percentile of SizeUSA data. Both the waist girth (95.2 cm) and hip girth measurements (121.9 cm) of size 20 were positioned between the 75th and 90th percentile of SizeUSA data. The percentile of BMI women in the SizeUSA data was compared with BMI categories provided by National Heart Lung and Blood Institute[1] (National Heart Lung and Blood Institute, 2009). The BMI value of 30 (classified as the ‘obese’ category) was positioned between the 75th and 90th percentile of the SizeUSA data. In consideration of the distributions of all three values (BMI, waist girth, and hip girth), women (n=2,682) within the range of the 16.2 (minimum) to 34.1

[1] Body Mass Index (BMI) is a number calculated from a person's weight and height. BMI provides an reliable indicator of body fat and is used to screen for weight categories. BMI Categories: Underweight=<18.5, Normal weight= 18.5-24.9, Overweight=25-29.9, Obesity=BMI value of 30 or greater (http://www.nhlbi.nih.gov/guidelines/obesitylbmi tbLhtm).

(the 90th percentile of BMI) only were selected. This was done for two reasons; to eliminate body shapes that belong in a plus size category, and to retain all waist and hip sizes in the Missy category. In addition, outliers (n=194), for whom any one measurement exceeded three times the standard deviation from the mean of the measurement were removed. As the number of outliers was less than 10% of the total sample, the remaining dataset (n=2,488) was considered appropriate for the statistical analysis.

Table 3-3. Size distribution of subjects aged 18 to 35 in SizeUSA data.

	Percentile						
	5th	10th	25th	50th	75th	90th	95th
BMI	18.6	19.6	21.2	23.9	**28.1**	**34.1**	38.3
Waist girth	67.9 (26.7)	70.1 (27.6)	74.5 (29.3)	80.6 (31.7)	**89.9** (35.4)	**101.7** (40.0)	110.2 (43.4)
Hip girth	91.8 (36.1)	93.9 (37.0)	98.5 (38.8)	104.0 (40.9)	**112.3** (44.2)	**123.4** (48.6)	130.6 (51.4)

Note. Waist girth and hip girth are reported in cm, and inches are reported in parentheses.

Body Classification Method

Statistical methods for body classification consisted of principal component analysis and cluster analysis. Principal component analysis is a mathematical procedure that transforms a number of possibly correlated variables into a smaller number of uncorrelated variables called principal components. Two major rotation systems for extracting principal components are available: Orthogonal and Oblique. The assumption of Orthogonal system is that each measurement is correlated to each component, but components are not correlated each other. On the other hand, the assumption of Oblique system is that each measurement is not correlated to each component, but components are correlated each other. For this study, Varimax rotation method, a representative method of Orthogonal coordinate system, was selected since it could provide independence among principal components. The decision on the number of components to be retained was made with consideration of three aspects: (a) eigenvalues that correspond to the sum of the squared loadings for a principal component, (b) rotated component loadings, and (c) the number of variables that have high correlations with each component (Warner, 2008).

With respect to eigenvalues, principal components should have eigenvalues greater than 1.0 (Kaiser-Guttman's standard) (Warner, 2008) and they should also be large enough to be distinguished from the rest of the principal components. The next consideration was that each measurement should have high component loadings (correlation) with one principal component. If a measurement was highly correlated with more than two components, the analysis re-conducted with this measurement removed. Regarding the third criteria, each principal component should have a minimum of three variables in practice. If a component had less than three variables, the component could not be retained since it did not have enough indicator variables. However, for variables that were important for patternmaking and that represented a distinctive lower body shape, the z-score[2] of the measurement was calculated and used for cluster analysis as an independent variable.

Using each principal component that clearly represented a distinctive shape from silhouette and profile views of the lower body, K-means cluster analysis was conducted using the principal component scores as independent variables to categorize body shapes. I classified the data into two, three, four, and five clusters for comparison, and then the final number of the clusters was decided with the consideration of the following three criteria: a similar number of people in each cluster, significant differences among clusters, and a reasonable number of clusters for further study. In order to analyze whether clusters were significantly different from one another, each

[2] A z-score indicates how many standard deviations an element is from the mean. A z-score can be calculated from the following formula [$z = (X - \mu) / \sigma$] where z is the z-score, X is the value of the element, μ is the population mean, and σ is the standard deviation [21].

body measurement was compared through Duncan's multiple range test of ANOVA post-hoc analysis.

Prediction Method

A discriminant analysis method was developed in order to classify individuals into a body shape group identified from the cluster analysis, using their body measurements. The dataset included body shape group memberships coded by the cluster analysis as a ‘grouping variable’, and the measurements corresponding to principal components identified as ‘independent variables’. The discriminant analysis was performed by stepwise-method, and key measurements were extracted that discriminate among groups. Once the discriminant functions were calculated, their significance and their percentage of the variances were examined. In order to identify the rate of predictive accuracy of the discriminant functions in classifying body shapes, the original group membership identified from the cluster analysis and the predicted group membership from discriminant functions were compared. Means of function scores and a scatter plot depicted by function scores were presented that will enable any individual to identify her body shape group from her SizeUSA measurements.

Recruitment of Participants

Recruitment Process

For development of base block patterns for each body shape group (stage 2), three to four subjects with hip girths in the range between 86.4 cm (38 in) and 106.7 cm (42 in) needed to be recruited for each body shape group as *fit models*. For validation of the use of the basic block patterns in a custom fit process (stage 3), an additional ten participants for each body shape group (in range of body sizes) were desirable as *fit testers* (only nine in each shape group were recruited ultimately). Two pairs of custom pants were made for each of these participants for fit testing, one made using the standard customization method and the other using the body shape driven customization method. Fit models with a hip girth measurement close to 101.6 cm (40 in) were selected, that represented their body shape group as a whole, to develop a pattern for each shape group in a base size. However, the fit testers were in a range of sizes. The only requirement was that their hip girth was less than 123.4 cm (48.6 in) measurement (90th percentile of the hip girth distribution in SizeUSA). It was difficult to find fit models for stage 2 specifically. Therefore participants were recruited for both stage 2 and 3 together, and fit models in appropriate size and shape groups were selected after recruitment of all participants.

Eighty three female participants aged 18 to 35 in Ithaca were recruited by distributing fliers and placing advertisements in January 2010. At the beginning of the recruitment, participants were recruited regardless of their body size and shape. When participants came to room 217 in MVR building at Cornell University, they read and signed a consent form, and filled out a brief questionnaire with general demographic questions (age and ethnicity). They were then scanned twice in minimal clothing (underwear and close fitting tank top/leggings) using a VITUS/XXL 3D Body Scanner by Human Solutions. To provide a clear view of the side of the body, they were asked to stand with their arms held about 25 cm (10 in) away from the body. Height, weight and crotch height were manually measured since the scanner could not reliably measure these areas. A $10 incentive was given to each study participant for this stage of the study.

Scan files were converted to .rbd format of *NX16 Software version 6* from $[TC]^2$, in order to detect landmarks and measuring locations using the same automated body measurement software used to derive the SizeUSA data. Using the $[TC]^2$ automatic measuring software, a mep file was developed for detecting the specific landmarks and measuring locations needed to extract the set of measurements necessary to classify body shapes and to make the first prototype fitting outfits (Figure 3-4). In order to validate the mep file that I developed, I asked $[TC]^2$ to provide five scans (with id number) from the SizeUSA survey, and compared measurements in the SizeUSA dataset with those extracted by the mep file that I developed. Measurements from SizeUSA were almost the same as the ones I extracted. The range of the differences between the measurements in SizeUSA data and those that I measured were between -0.25 cm (-0.1 in) and 0.25 cm (0.1 in).

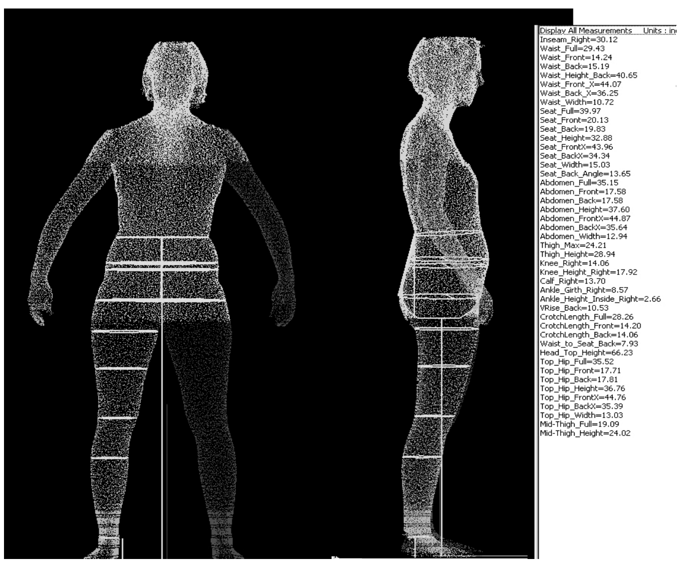


Figure 3-4. Measurements taken from my Mep file which was used to extract the set of measurements necessary to classify body shapes and to make the first prototype fitting outfits.

Based on measurements derived from the scans using the $[TC]^2$ software, principal component analysis and cluster analysis was run again to classify each participant's body shape group and identify their position within the body shape groups in five variables. The number of participants in each shape group and their hip size was tracked while recruiting. Originally, I planned to recruit a total of only 40 participants for both stage 2 and 3. However, at the beginning of the recruitment, most of participants were included in body shape group 3, while participants in the other groups were not well represented. Therefore, I needed to recruit many more participants until I could find enough participants for body shape group 1 and 2. I created new fliers and advertisements to recruit the other body shape groups (e.g., “Attention women aged 18 to 35 with CURVY lower body shape” for recruiting participants in body shape group 2). For stage 3, I tried to recruit women across the full range of body sizes as proportionally as possible in order to test the custom fit process across the full range of body sizes. The hip girth in ASTM D5585-95 was selected as a key measurement for categorizing body size, and I tracked the number of participants in each size based on hip measurement while recruiting.

After a total of 83 participants were recruited, I found enough appropriate fit models and fit testers for each body shape group to go to the next stages, with group 3 over-represented and group 2 with the smallest number (group 1: n = 26, 31.3%, group 2: n = 18, 21.7%, group 3: n = 39, 47.0%). Among the 83 participants, the majority were aged 18 to 25 (n = 65, 78.3%), and the rest were aged 26 to 35 (n = 18, 21.7%) (Table 3-4). Caucasian respondents comprised 61.8% (n = 51), non-Hispanic black 21.7% (n = 18), Asian 10.8% (n = 9), Mexican Hispanic 2.4% (n = 2), and non-Mexican Hispanic 1.2% (n = 1) of the participants (Table 3-5).

Table 3-4. Body shape group × Age group Crosstabulation.

		Age group		Total (frequency, %)
		18 to 25	26 to 35	
Body shape group	1	22	4	26 (31.3%)
	2	15	3	18 (21.7%)
	3	28	11	39 (47.0%)
	Total	65 (78.3%)	18 (21.7%)	83 (100.0%)

Table 3-5. Body shape group × Ethnic Crosstabulation.

		Ethnic						Total
		Non-Hispanic White	Non-Mexican Hispanic	Asian	Non-Hispanic Black	Mexican Hispanic	Other	
Body shape group	1	20	0	2	3	0	1	26 (31.3%)
	2	8	1	0	8	0	1	18 (21.7%)
	3	23	0	7	7	2	0	39 (47.0%)
	Total	51 (61.4%)	1 (1.2%)	9 (10.8%)	18 (21.7%)	2 (2.4%)	2 (2.4%)	83 (100.0%)

I eventually recruited women from size 2 to 20 somewhat evenly, though size 12 was over-represented and size 2 was under-represented compared to other sizes (Figure 3-5).

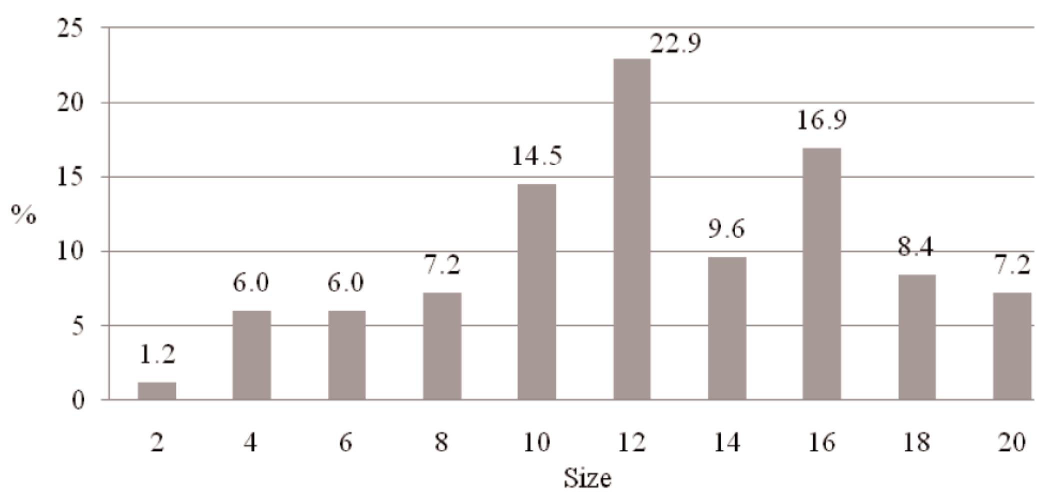


Figure 3-5. Participants sizes determined by hip size in ASTM D 5585-95 (n=83).

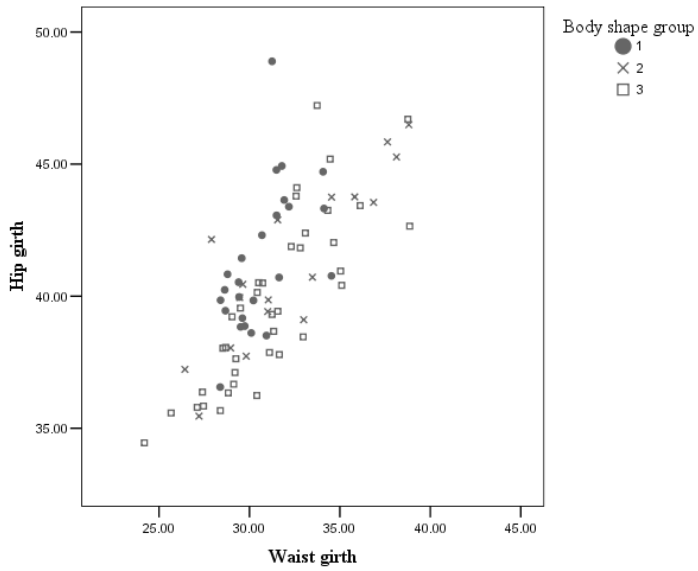


Figure 3-6. Distribution of size categories in waist girth (in) (x) and hip girth (in) (y) measurements.

After recruitment of 83 participants, 9 participants (3 fit models × 3 groups) for stage 2 and 30 participants (10 fit testers × 3 groups) for stage 3 were selected (the method of selecting fit models and fit testers, and their measurements will be described in the 'Results' section). I contacted each participant to ask if they would take part in the 2^{nd} and 3^{rd} stages of the study. Participants were each given \$20 for taking part in these stages of the study. Most of participants were willing to continue with the study, but three participants needed for stage 3 could not be reached. Fortunately, these three participants were included in groups 1, 2 and 3 respectively, so I had 9 fit testers in each body shape group. The process of dividing 83 participants into stage 2 and 3 is shown in Figure 3-7.

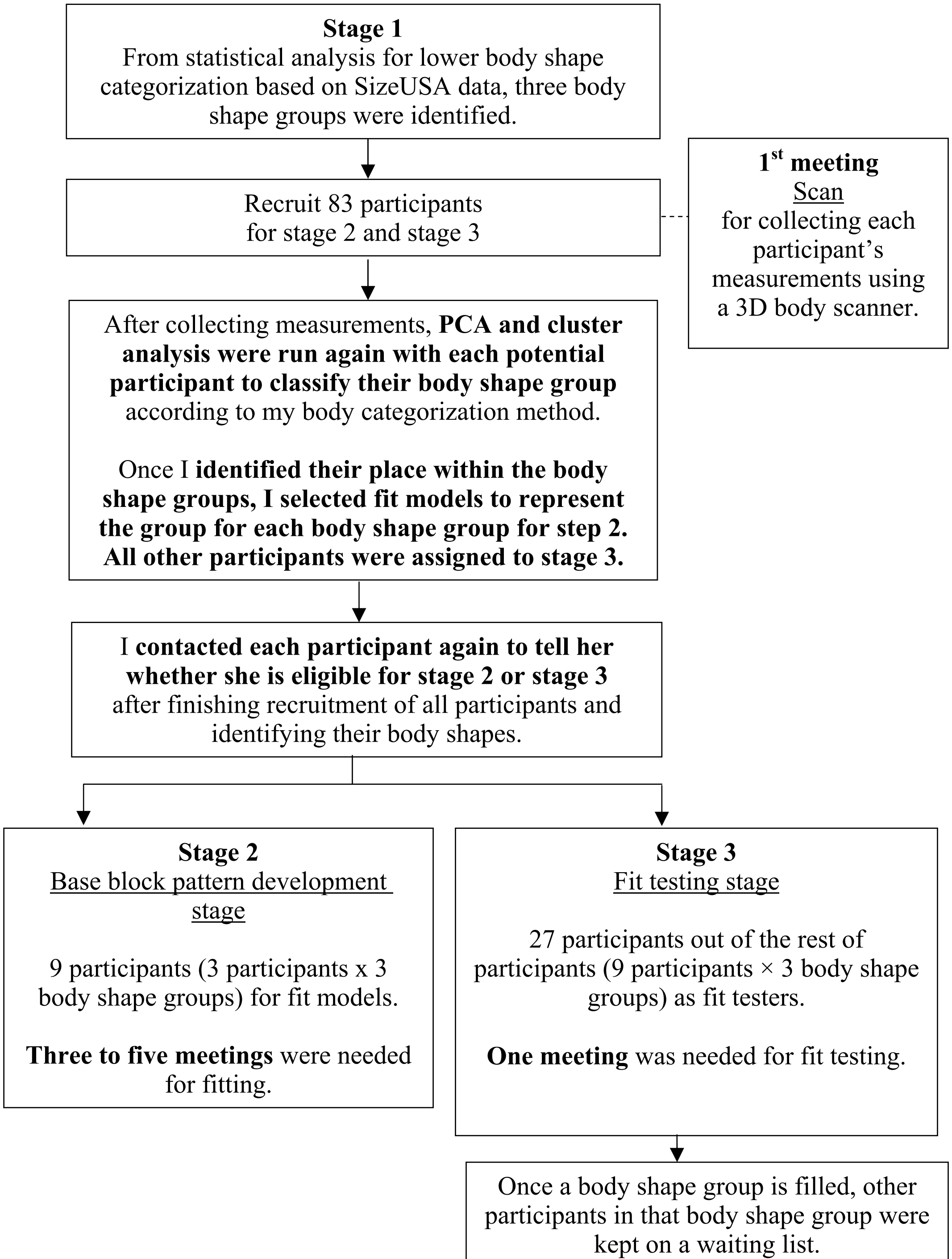


Figure 3-7. Recruitment Process.

Fitting Session (Stage 2)

Three participants for each body shape group were invited to be fit models in order to refine the fit of patterns designed to be basic block patterns for each group. A pair of custom-made pants was sewn for each participant. At the beginning of the 1st fitting, they were scanned in the scan suit (tank top and leggings). Then, they changed the leggings to their custom pants that I prepared. The fit of the pants was evaluated using a standard list of fit parameters described by Leichty, Pottberg, and Rasband (1992), which represent the indicators of the five basic components of fit: ease, line, grain, balance, and set (Erwin, Kinchen, & Peters, 1979). A fit test was conducted with four postures (standing, sitting on a chair, walking, and stepping) to analyze the fit in both the standard position and in active positions. The pants were not expected to fit well at this stage due to the difficulty of creating perfect fit from measurements only. Therefore it was critical to mark via colored pens, pin in areas that needed to be altered, and to take photographs and scans of each participant wearing the pants to record the fit. After fitting the garments, the needed alterations indicated during the fitting were transferred back to the patterns using Pattern Design 8.3 of Gerber Scientific software. The patterns were then plotted again and a new pair of custom pants was made. Each fit model was asked to return for an additional fitting with their new pair of custom pants. To get perfect patterns, each fit model came to fittings for at least three iterations. Once well-fitted patterns were obtained, participants were provided with patterns of their pants and a $20 incentive. Each of these fitting sessions took 45 minutes to 1 hour.

Fit Analysis Session (Stage 3)

For each participant of stage 3, two custom pairs of pants were prepared using the AccuMark MtM, made from the *standard customization method* and *body shape* *driven customization method*. At the beginning of the meeting, they were scanned in the scan suit (tank top and leggings). Then, they were asked to try on the first pair of their custom-made pants and to be scanned. Four photographs (front view, side view, and back view of the standard posture, and side view of the sitting posture) were taken of the pants for expert fit judges' analysis (only standing view photographs were used ultimately). Each participant looked at themselves in their pants in the mirror, and tested the fit in four postures: standing, sitting on a chair, walking, and stepping. They then filled out a questionnaire regarding fit of the pants and satisfaction at each location. They repeated this process with the second pair of custom pants. In order to prevent bias introduced from the order of donning pants, I alternatively provided the two pairs of pants, made from the *standard customization method* (A) and *body shape driven customization method* (B). After trying on both pairs of pants, the participant was asked to choose which of the two pair of pants fitted them best. They were provided patterns of their pants and a $20 incentive. This process took about an hour.

Development of Basic Block Patterns in Each Body Shape Group (Stage 2)

Test Style

The test garment style was a pair of pants with two front darts, two back waist darts, a straight silhouette from thigh to hem, and 17.8 cm (7 in) front closure (Figure 3-8). The pants had no waist band. The waist location was determined at the position of the natural waist. This style was chosen because of its ubiquity and potential for use as base pattern for other styles. The pants were made from stable medium weight cotton twill fabric in neutral color donated by Galey & Lord, located in Society Hill, SC. To establish which multiple bolts donated by the company carried fabric of similar properties, fabric from each bolt was tested for weight, initial modulus, and tenacity and elongation at break both along the grain and the crossgrain of the cotton fabric. The fabric used had mean weight of 256 g/m2 (7.56 ounces/yard^2) with standard deviation of 4 g/m2 (0.12 ounces/yard^2).

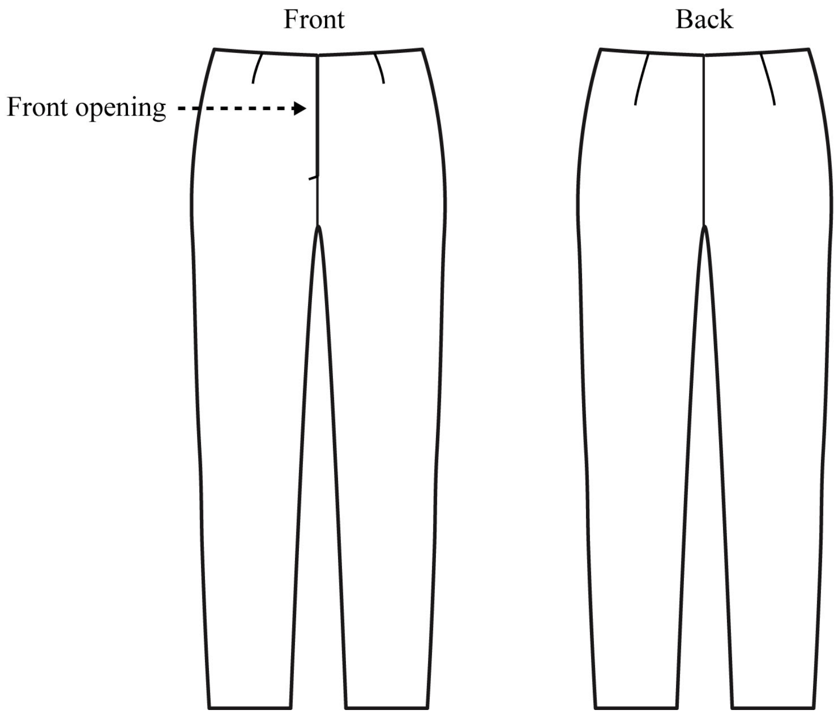


Figure 3-8. Test style.

Prototype Patterns from an Industry Pattern from a Major Direct Marketing (Catalog and Internet) Retailer

Use of an industry pattern was best for this study since the industry has developed well-shaped block patterns that embody much knowledge on good pants fit. I selected a major direct marketing (catalog and internet) retailer which has invested in the development of block patterns for their target market of women aged 18 to 35. From styles that they are producing, the style 'Women's regular original comfort waist Audrey slim every day chino pants' (item # 38180-1AE9) was selected. The main criterion for selection of the style was fabric property since this influences ease amounts. This item was made from 100% cotton twill similar to the fabric used in this study, so it was considered appropriate for this study. In terms of silhouette and designs, the difference between the test style and this item were as follows: this item had no front darts, but it had a waistband, slightly low waist line, and a slimmer leg style than the test style. These design elements could be easily altered, so this style was selected for this study.

Figure 3-9. Pants style selected from a major direct marketing (catalog and internet) retailer.

Due to regulation of the retailer, patterns could not be officially provided for this study. Instead, I bought a size 10 (hip size: 40 in) of this style from their website. Then, the patterns were rubbed off and digitized using Pattern Design 8.3 of Gerber Scientific (Figure 3-10). In order to change this item to the test garment style, first the waist band pattern shapes were merged to the front and back pants patterns. A front dart was then created in the center line of the front panel (Figure 3-11).

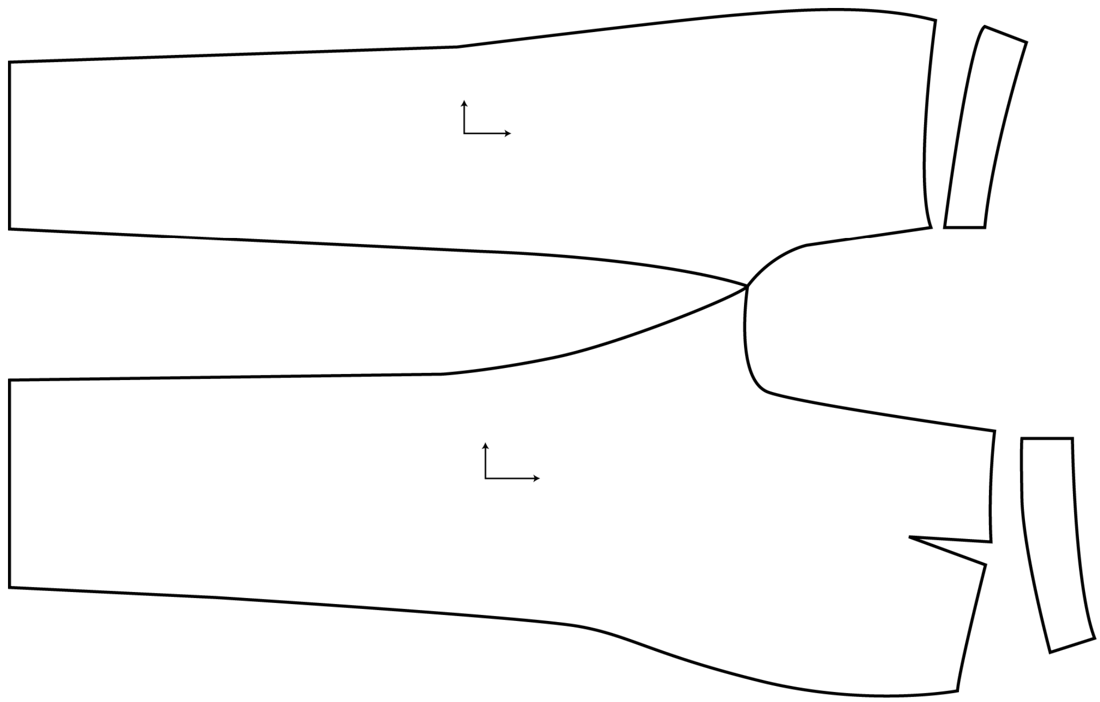


Figure 3-10. Digitized patterns.

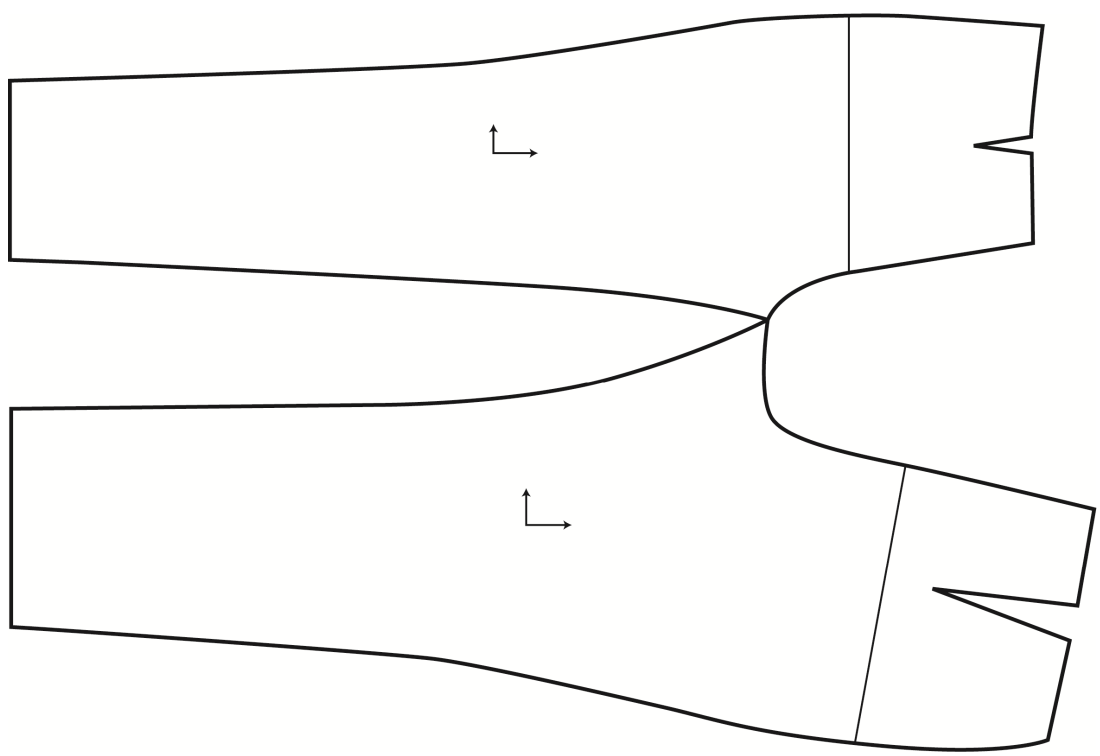


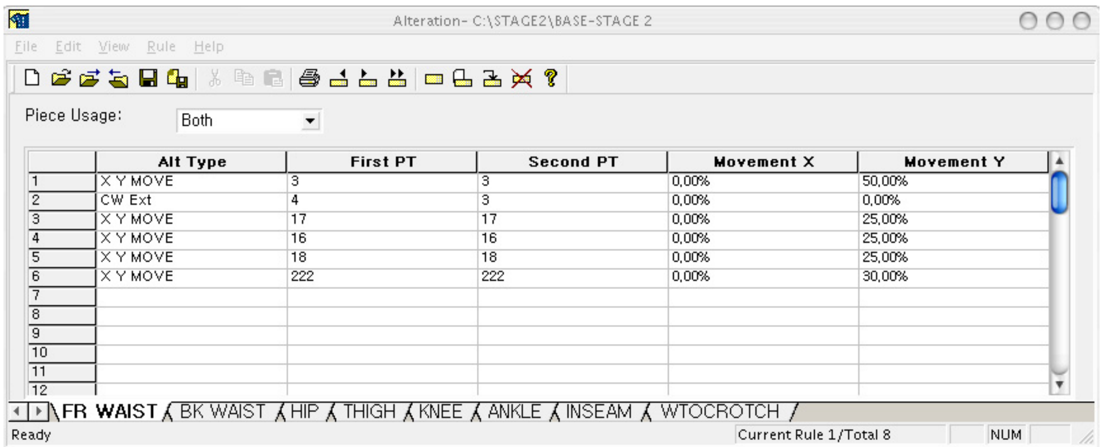
Figure 3-11. Altered patterns (The waist band pattern was merged to pants bodice, front dart was inserted).

Modification of the Industry Pattern for Development of Three Prototype Patterns for Each Body Shape Group

In order to reduce the number of fittings in stage 2, three prototype patterns were developed by manipulating the industry pattern shown in Figure 3-11. Women with hip girth 100.3 to 102.9 cm (39.5 to 40.5 in) were selected from the SizeUSA data used in the body shape analysis (stage 1), and median values of several body measurements (i.e., front/back waist girth, front/back top hip girth, front/back hip girth, thigh girth, knee girth, ankle girth, waist to crotch length, crotch height, buttocks angle, abdomen depth minus front waist depth), measurements needed to develop patterns, were calculated. The median values of the body measurements were compared with the dimensions of the industry pattern. Regarding ease amounts, percent ease differences (ease amount / body measurement) found by Petrova & Ashdown (2008) were applied to this study: 1.3 cm (1/2 in) at waist (1.7% of the waist girth), 5.1 cm (2 in) at hip (4.8% of the hip girth), 2.5 cm (1 in) at top hip (2.7% of the top hip girth), 7.6 cm (3 in) at mid-thigh (15.8% of the mid-thigh girth). Three patterns were made to meet ease amounts plus the median values of each body shape group by altering the industry patterns. The variance in shape was addressed in the following areas of the pattern: inseam length, waist to crotch height, front/back waist girths, front/back hip girths, thigh girth, center front seam angle, center back seam angle, front/back dart lengths, and front/back stride lengths.

Setting up Made-to-Measure System for Stage 2

An automated custom-made system was developed to generate custom patterns for the fit models' for stage 2 in both Pattern Design 8.3 and AccuMark MtM. The three proposed patterns for the body shape groups were developed in Pattern Design 8.3. The next phase was to decide locations which needed alterations. In stage 2, eight alteration locations were determined: front waist girth, back waist girth, hip girth, mid-thigh girth, knee girth, ankle girth, waist to crotch length, and inseam length. In Pattern Design 8.3, points to which alterations were applied in were numbered. Alteration rule files in AccuMark Explore were created with a set of alteration rules at seven critical locations.



	Alt Type	First PT	Second PT	Movement X	Movement Y
1	X Y MOVE	3	3	0.00%	50.00%
2	CW Ext	4	3	0.00%	0.00%
3	X Y MOVE	17	17	0.00%	25.00%
4	X Y MOVE	16	16	0.00%	25.00%
5	X Y MOVE	18	18	0.00%	25.00%
6	X Y MOVE	222	222	0.00%	30.00%
7					
8					
9					
10					
11					
12					

Figure 3-12. Alteration rule table.

Alteration rules at the front waist girth and back waist girth were set up separately. Since the pants were symmetric between left and right, one side of each of the front and back patterns were stored in the system. Therefore 50% of the alteration amount (base size measurement – an individual's measurement) at the front waist girth was allocated to a side waist point in the front pattern (50% × 2 front patterns = 100%). 50% of the alteration amount at back waist girth was allocated to a side waist point in the back pattern (50% × 2 back patterns = 100%).

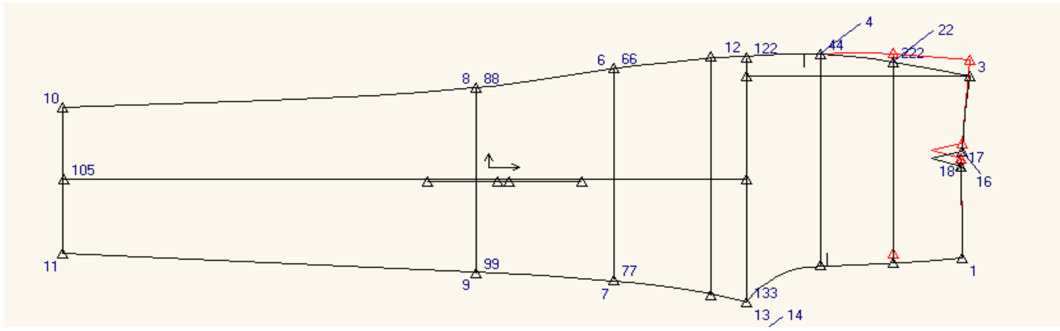


Figure 3-13. Alteration rule at front waist girth.

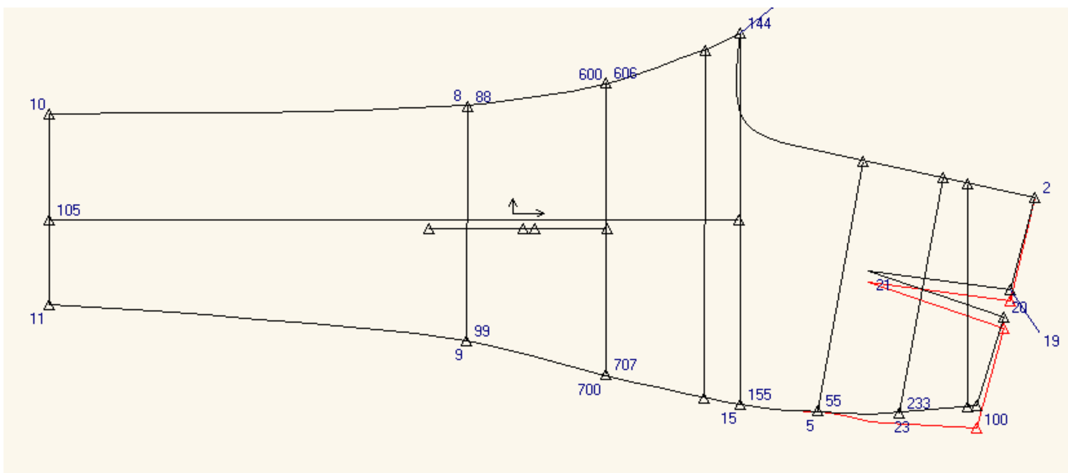


Figure 3-14. Alteration rule at back waist girth.

In order to have a smooth shaped side seam line from hip to thigh level, alterations for hip girth and thigh girth were not divided into front girth and back girth separately. At hip, each 25% of the alteration amount was allocated to a side hip point at front pattern and back pattern (25% × 2 front patterns + 25% × 2 back patterns = 100%) (Figure 3-15). For example, if the alteration amount was 5.1 cm (2 in), side hip points at front and back patterns were increased 1.3 cm (0.5 in).

At mid-thigh, knee, and ankle, each 50% of alteration amount was allocated to a side point of each level at front pattern and back pattern (Figure 3-16 and Figure 3-17).

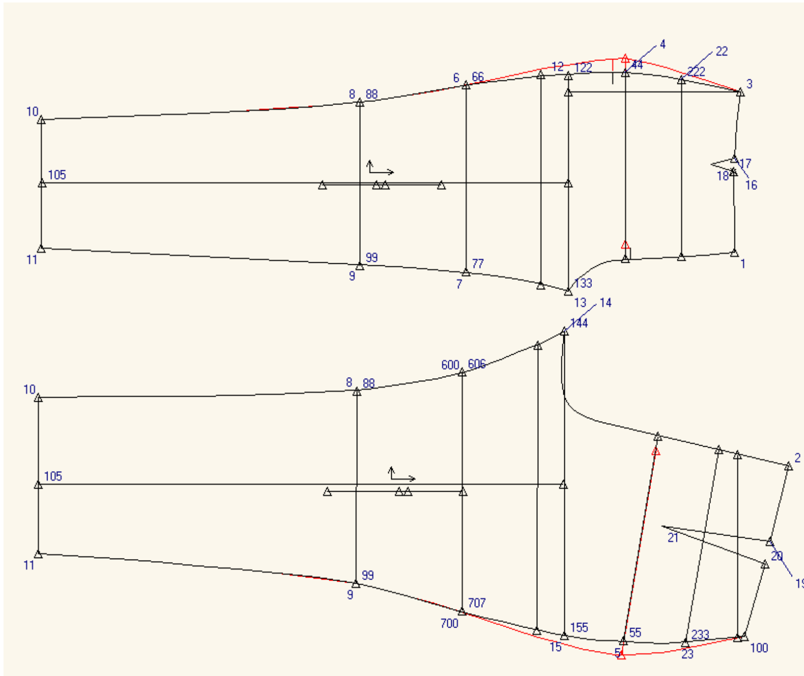


Figure 3-15. Alteration rule at hip girth.

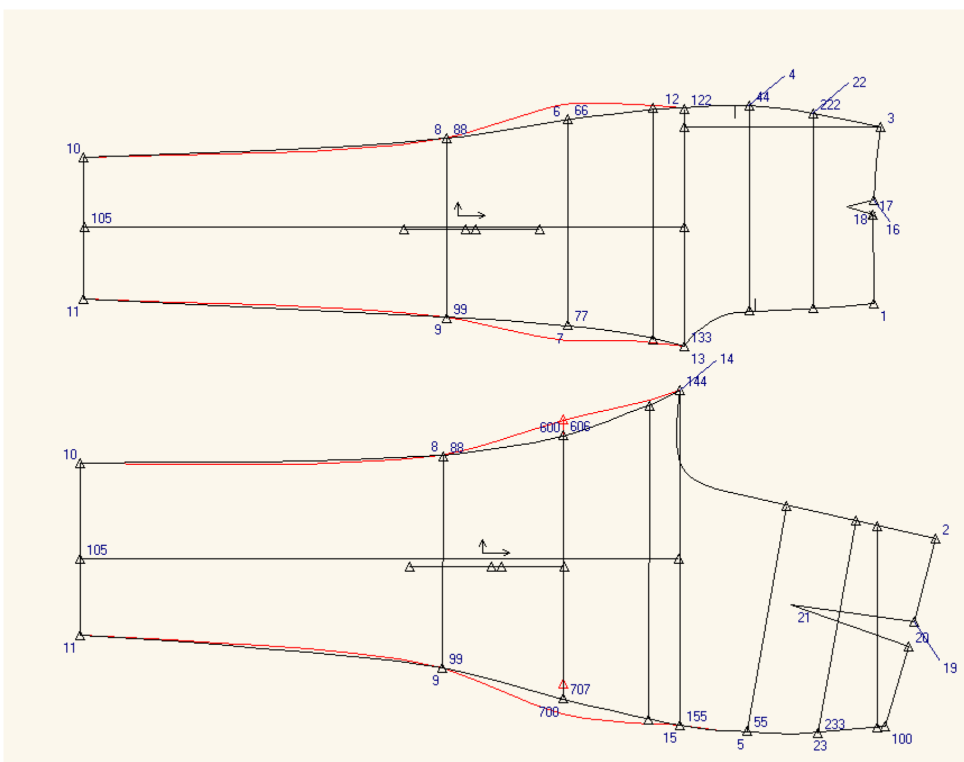


Figure 3-16. Alteration rule at thigh girth.

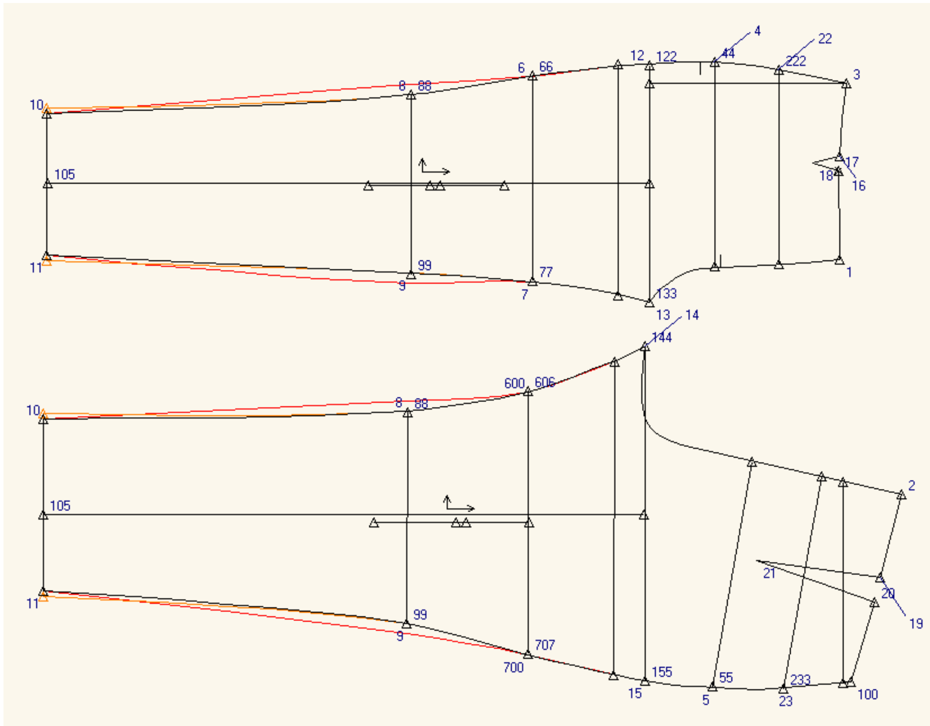


Figure 3-17. Alteration rules at knee girth (in red) and at ankle girth (in yellow).

Length alterations were relatively easier than girth alterations. For alteration of waist to crotch length, 100% of the alteration amount was allocated to points on the waist line toward the positive x direction (Figure 3-18). For alteration of inseam length, 100% of the alteration amount was allocated to points on the hem line toward the negative x direction (Figure 3-19). The patterns did not need to be graded and the body chart did not need to be fully developed from size 2 to 20, since this stage was only for fitting pants on fit models with hip girth size 101.6 cm (40 in). Only slight alterations were expected to be made from the base pattern, since fit models' measurements were close to the base size in the body chart. Grading is necessary to prevent extreme alterations or disproportional pattern shapes when there are extreme alterations, so this stage did not need graded patterns. The patterns and alteration rules were imported to AccuMark MtM program. Three body charts (group 1, group 2, and

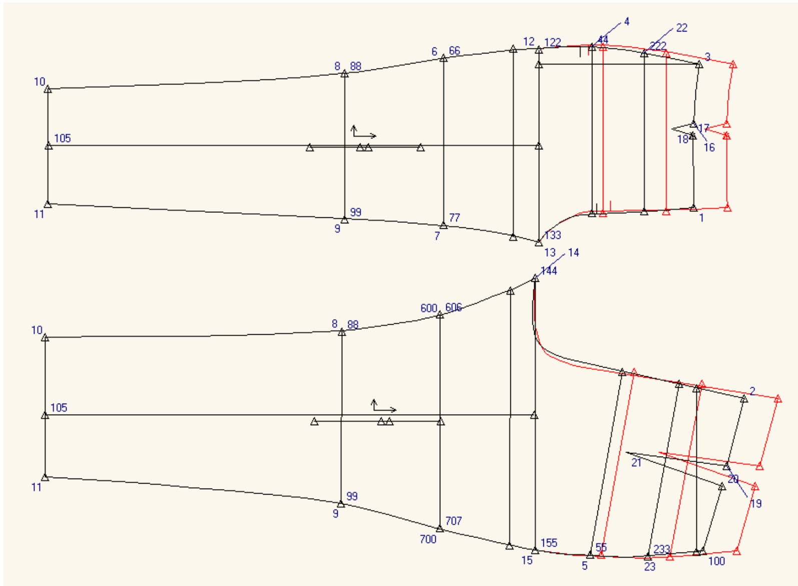


Figure 3-18. Alteration rule at crotch to waist length.

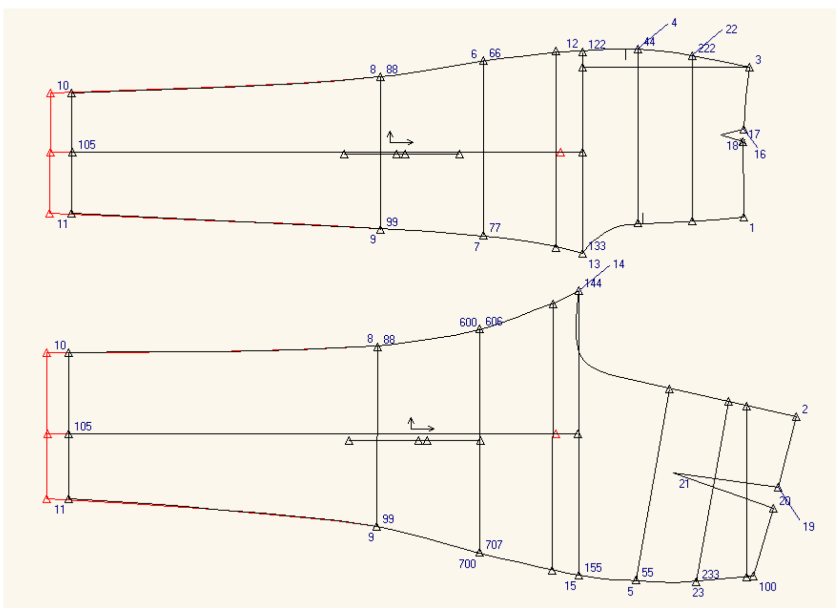
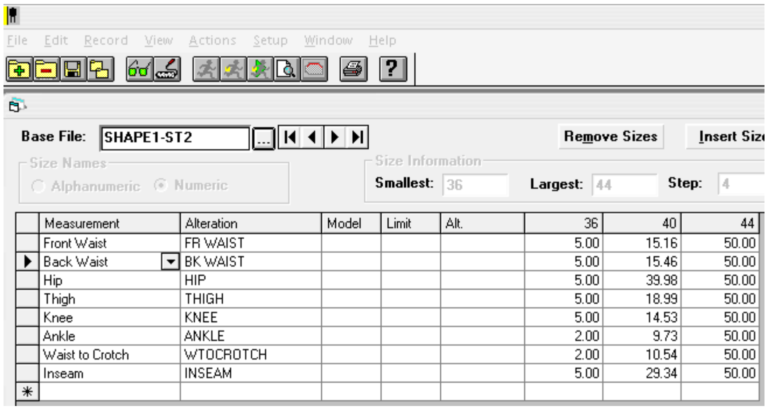


Figure 3-19. Alteration rule at inseam length.

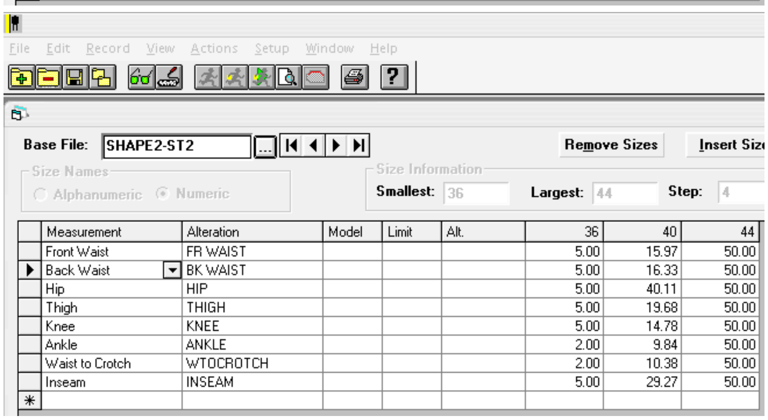
group 3) with measurements of the smallest size (size 36 – this was arbitrary size coding), base size (size 40), and the largest size (size 44) were stored. Alteration rules stored in Pattern Design 8.3 and body measurements in body chart were connected

(Figure 3-20). Before generating the fit models' custom pants, a pilot custom garment was made using my measurements, in order to test the made-to-measure system.



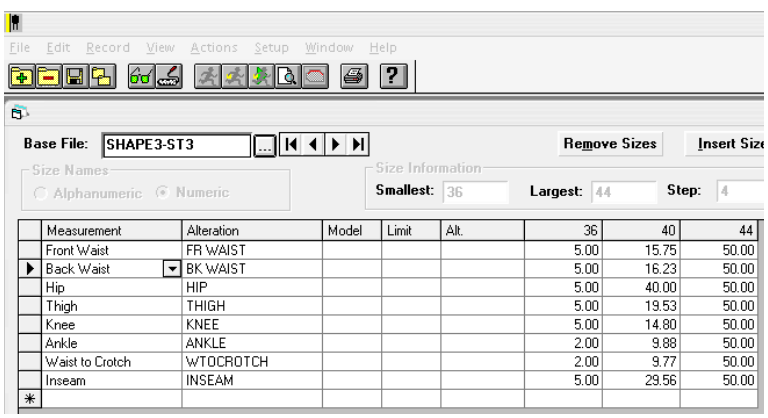
Measurement	Alteration	Model	Limit	Alt.	36	40	44
Front Waist	FR WAIST				5.00	15.16	50.00
Back Waist	BK WAIST				5.00	15.46	50.00
Hip	HIP				5.00	39.98	50.00
Thigh	THIGH				5.00	18.99	50.00
Knee	KNEE				5.00	14.53	50.00
Ankle	ANKLE				2.00	9.73	50.00
Waist to Crotch	WTOCROTCH				2.00	10.54	50.00
Inseam	INSEAM				5.00	29.34	50.00

Group 1



Measurement	Alteration	Model	Limit	Alt.	36	40	44
Front Waist	FR WAIST				5.00	15.97	50.00
Back Waist	BK WAIST				5.00	16.33	50.00
Hip	HIP				5.00	40.11	50.00
Thigh	THIGH				5.00	19.68	50.00
Knee	KNEE				5.00	14.78	50.00
Ankle	ANKLE				2.00	9.84	50.00
Waist to Crotch	WTOCROTCH				2.00	10.38	50.00
Inseam	INSEAM				5.00	29.27	50.00

Group 2



Measurement	Alteration	Model	Limit	Alt.	36	40	44
Front Waist	FR WAIST				5.00	15.75	50.00
Back Waist	BK WAIST				5.00	16.23	50.00
Hip	HIP				5.00	40.00	50.00
Thigh	THIGH				5.00	19.53	50.00
Knee	KNEE				5.00	14.80	50.00
Ankle	ANKLE				2.00	9.88	50.00
Waist to Crotch	WTOCROTCH				2.00	9.77	50.00
Inseam	INSEAM				5.00	29.56	50.00

Group 3

Figure 3-20. Body charts for stage 2.

Determination of the Final Block Patterns in Each Body Shape Group

Three fit models were selected for development of the block patterns in each body shape group (the process of selecting fit models is presented in the 'Results' section). Multiple fittings were conducted on each fit model to perfect the block patterns. Patterns were compared within each body shape group and among body shape groups to identify and validate differences. One participant from each body shape group was selected to represent the group as a whole, and to be the final fit model. These final fit models were invited for one additional meeting, and photographs and 3D scans were obtained of their fitted pants.

The final fit model's measurements including waist girth, top hip girth, hip girth, thigh girth, knee girth, ankle girth, waist to crotch length, inseam length, buttocks angle, and abdomen depth were compared with the median values of their body shape group. Fit models will never have perfect median measurements of their body shape group. If their body measurements and median values were not very different, I did not alter the pattern since fittings were conducted to perfect fit on the fit models. When the differences were relatively large, patterns were altered to meet either the median values, or between the median value and the fit model's measurement. In each case, I used my judgment to decide the appropriate action.

Validation of the Use of the Basic Block Patterns in a Custom Fit Process (Stage 3)

The purpose of stage 3 was to compare appearance and fit of a pair of pants created from the automated custom-made system using a single pattern (*standard customization method)* with pants developed from the automated custom-made system using multiple patterns driven by body shape *(body shape driven customization method)*. Alterations in the standard customization method started from a single pattern (industry pattern). Alterations in the body shape driven customization method started from one of the three different block patterns developed in stage 2 for each body shape group.

Setting up Alteration Rules for Stage 3

An automated custom-made system was developed to generate fit testers' custom patterns. In stage 3, the alteration rules needed be developed more carefully than those for stage 2. The purpose of alteration process in the stage 2 was just to reduce the time and numbers of fittings. However, alteration rules for stage 3 should be perfectly set up because in this stage my purpose was to analyze the influence of the block patterns on the fit of the custom made clothing. Therefore eliminating problems with the alteration rules was essential so that the influence of the alteration rules on the generation of custom made clothing would be decreased or eliminated.

Waist girth, hip girth, thigh girth, waist to crotch length, and inseam length were identified as the alteration locations needed. In Pattern Design 8.3, alteration points corresponding to the five locations were determined, and points were numbered. Before setting up alteration rules in the alteration rule file in AcuuMark Explore, a linear regression analysis was conducted between the front waist girth and full waist girth, between the back waist girth and full waist girth, between the front hip girth and full hip girth, between the back hip girth and full hip girth, and between the full hip girth and max-thigh girth using SPSS 18.0, in order to identify how alteration amounts should be distributed into points between the front or back patterns. The dataset for the regression analysis was the same as that for the body shape analysis (stage 1).

In the linear regression model between front waist girth and full waist girth, R^2 said 98.6 % of the variability in front waist girth measurements was accounted for by variation in full waist girth measurements. R^2 showed that the regression was successfully explained at fitting the data. The slope was 0.501. This meant that the front waist girth measurement increases about 1.273 cm (0.501 in) per inch of full waist girth measurement increase (Table 3-7). It was found that the back waist girth measurement increases about 1.267 cm (0.499 in) per inch of full waist girth measurement (Table 3-8) (R^2 = 98.5%). Accordingly, the alteration amount of full waist girth could be divided into approximately 50% (exactly 50.1%) in the front pattern and approximately 50% (exactly 49.9%) in the back pattern. The pants consisted of symmetric left and right patterns, one side (front and back patterns) were stored in the system. Therefore 25% of the alteration amounts were allocated to the side waist point in the front pattern, and 25% to side waist point in the back pattern (Figure 3-22).

Table 3-6. Model Summary of regression model between front waist girth and full waist girth.

Model	R	R^2	Adjusted R^2	Std. Error of the Estimate
1	.993(a)	**.986**	.985	.20845

Note. Predictors: (Constant), Waist

Table 3-7. Coefficients table (predictor: full waist girth, dependent variable: front waist girth).

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig
	B	Std. Error	Beta		
1 (Constant)	-.215	.039		-5.571	.000
Waist Girth	**.501**	.001	.993	411.107	.000

Note. Dependent variable: Front waist girth

Table 3-8. Coefficients table (predictor: full waist girth, dependent variable: back waist girth).

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig
	B	Std. Error	Beta		
1 (Constant)	.215	.039		5.571	.000
Waist Girth	**.499**	.001	.993	419.145	.000

Note. Dependent variable: Back waist girth

In linear regression model between the front hip girth and full hip girth, R^2 said

89.7 % of the variability in front hip girth measurements was accounted for by variation in full hip girth measurements. The front hip girth measurement increases about 0.416 inches per inch of full hip girth measurement (Table 3-9). It was found that the back hip girth measurement increases about 0.584 inches per inch of full hip girth measurement (Table 3-10) (R^2 = 94.3%). This meant that the alteration amount of the full hip girth could be divided into approximately 42% (exactly 41.6%) for the front pattern and approximately 58% (exactly 58.4%) for the back pattern. Therefore 21% at side hip point in front pattern and 28% at side hip point in back pattern were determined as the alteration amount percentage (Figure 3-23).

Table 3-9. Coefficients table (predictor: full hip girth, dependent variable: front hip girth).

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig
	B	Std. Error	Beta		
1 (Constant)	2.218	.125		17.751	.000
Hip Girth	**.416**	.003	.938	132.971	.000

Note. Dependent variable: Front hip girth

Table 3-10. Coefficients table (predictor: full waist girth, dependent variable: back hip girth).

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig
	B	Std. Error	Beta		
1 (Constant)	-2.218	.125		-17.751	.000
Hip Girth	**.584**	.003	.966	186.778	.000

Note. Dependent variable: Back hip girth

Determining alteration rules at the thigh was not easy since the side seam at thigh level was automatically altered when alteration rules at the hip were applied to patterns (See Figure 3-24). In the linear regression model between the hip girth and thigh girth, it was found that the thigh girth measurement increases about 1.608 cm (0.633 in) per inch of hip girth measurement (Table 3-11). According to the calculation shown in Table 3-12, 21% (front pattern) of hip girth was equivalent to

Table 3-11. Coefficients table (predictor: full hip girth, dependent variable: max-thigh girth).

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig
	B	Std. Error	Beta		
1 (Constant)	-1.584	.204		-7.777	.000
Hip Girth	**.633**	.005	.928	124.264	.000

Note. Dependent variable: Thigh girth

Table 3-12. Calculation for alteration amount at thigh level.

< Front pattern>

Hip girth × 0.633 (63.3%) = Thigh girth
Hip girth = Thigh girth / 0.633 = Thigh girth × 1.58

Hip girth × 21% = Thigh girth × 1.58 × 21%
= Thigh girth × 0.33 (33%)

< Back pattern>

Hip girth × 29% = Thigh girth × 1.58 × 29%
= Thigh girth × 0.46 (46%)

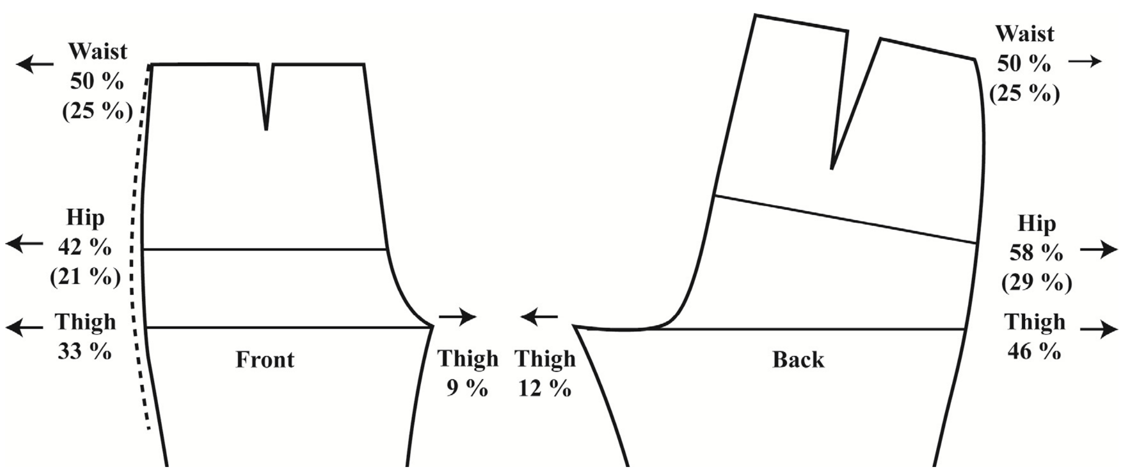


Figure 3-21. Waist, hip and thigh alteration rules.

33% of thigh girth and 29% (back pattern) of hip girth was the same amount of 46% of thigh girth. 100% of the alteration amount at thigh level was divided into 33% at the side thigh point in the front pattern, 46% at the side thigh point in the back, and 21% at the crotch points. The 21% of alteration amount at the crotch points was divided into 9% in the front pattern and 12% in the back pattern. For the waist to crotch length, 100% of alteration amount was allocated to points on the waist line (Figure 3-25). For the inseam length alteration, 100% of alteration amount was allocated to points at hem line (Figure 3-26).

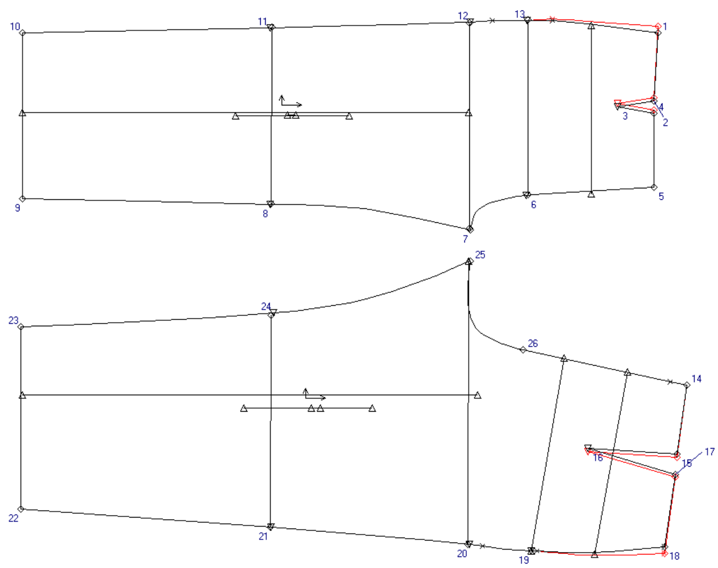


Figure 3-22. Alteration rules at waist girth.

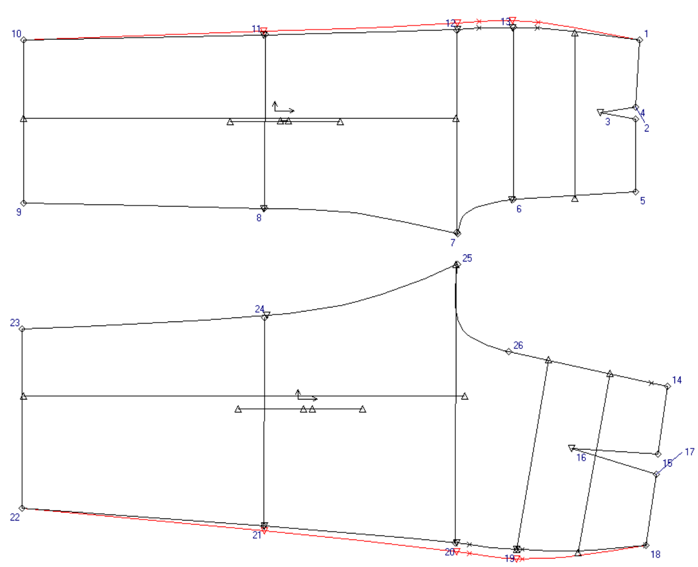


Figure 3-23. Alteration rules at hip girth.

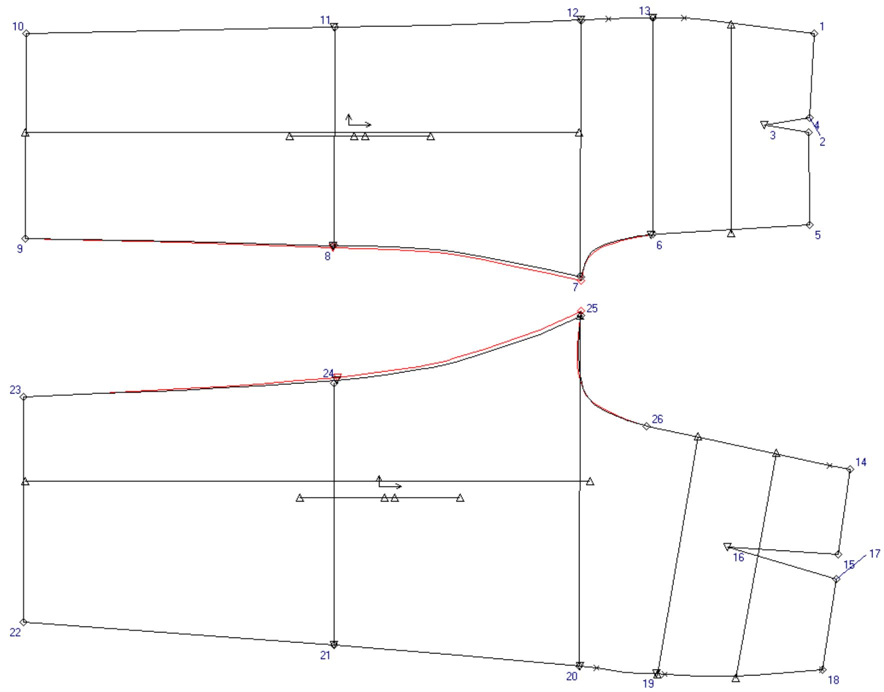


Figure 3-24. Alteration rules at thigh girth.

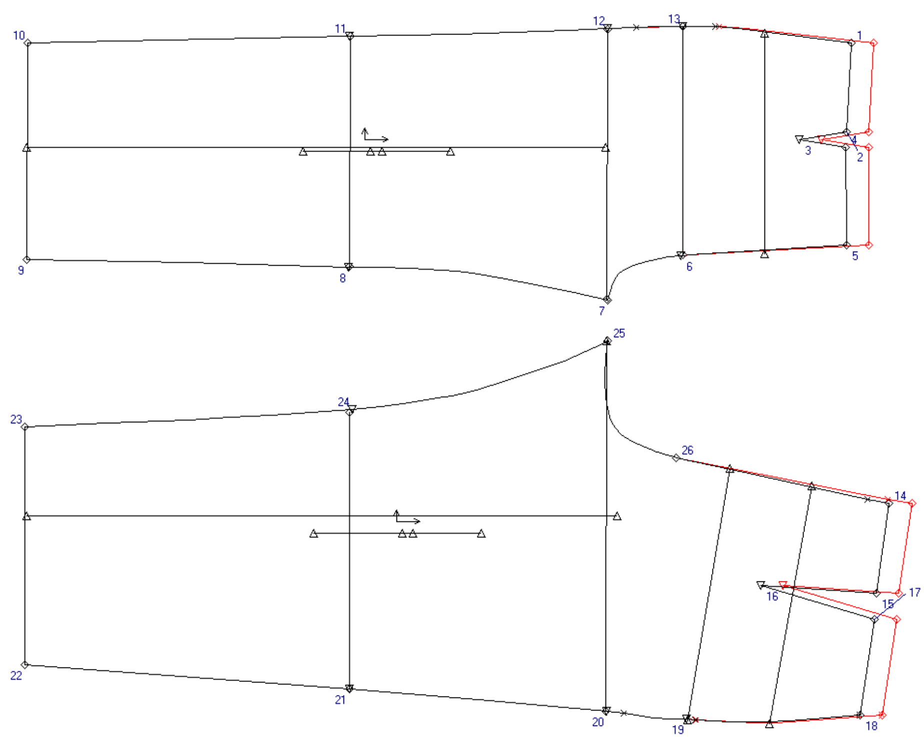


Figure 3-25. Alteration rules at waist to crotch length.

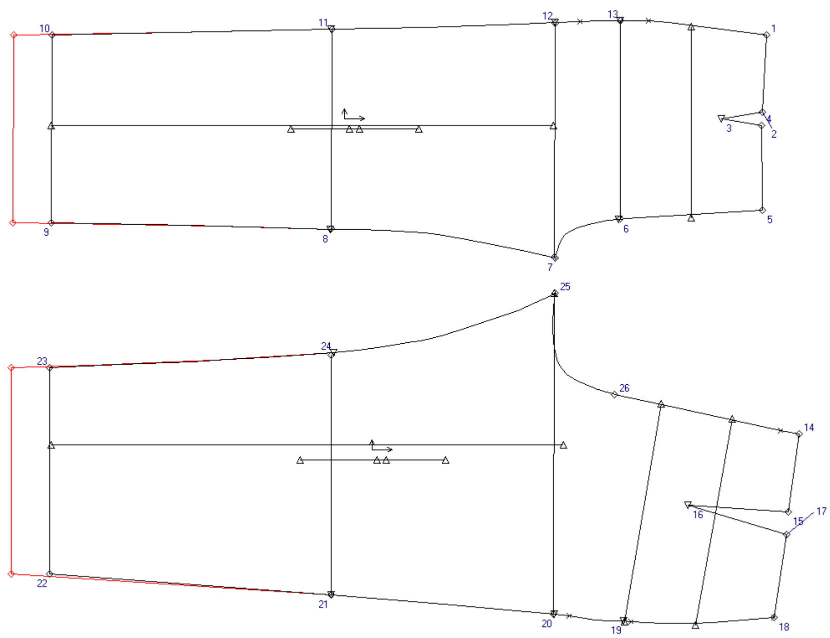


Figure 3-26. Alteration rules at inseam length.

Creation of Body Size Charts and Grading Patterns

For this study, I adopted a grading method from a grading class provided by Gerber Scientific in New York (Figure 3-27). In spring 2009, I took a class on grading from Gerber Scientific in New York, designed to teach apparel professionals. They taught the most common grading method which is used in the apparel industry.

Grading was done in a traditional proportional manner following the grade distribution among pattern pieces. The grade distribution determines in what areas the pattern takes the change from one size to the next, for example, the proportion of a circumference grade that is applied to the front and the proportion that is applied to the back. In this study, waist girth, hip girth, thigh girth, knee girth, ankle girth, and waist to crotch length were graded. The intersize intervals used in the Gerber Scientific method and ASTM D5585-95 were the same (Table 3-13). At the waist girth and hip girth, the intersize intervals were 2.5 cm (1 in) in the size range 2 to 10, 3.8 cm (1.5 in) in the size range 10 to 16, and 5.1 cm (2 in) in the size range 16 to 20. At the thigh girth, the intersize intervals were 1.9 cm (3/4 in) in the size range 2 to 10, 2.5 cm (1 in) in the size range 10 to 16, and 3.2 cm (1 1/4 in) in the size range 16 to 20. At the knee girth, the intersize intervals are 1.0 cm (3/8 in) in the size range 2 to 10, and 1.3 cm (1/2 in) in the size range 10 to 20. At the ankle girth, the intersize intervals are 0.6 cm (1/4 in) for the full size range. At the waist to crotch length, the intersize intervals are 0.6 cm (1/4 in) for the full size range, but the intersize intervals at the inseam length was zero. The total amount of increase between two body sizes (intersize interval or body grade) was applied to the garment in order to change it to the next size.

Table 3-13. Size interval in ASTM D 5585-95.

	2-4	4-6	6-8	8-10	10-12	12-14	14-16	16-18	18-20
Waist girth	1	1	1	1	1 1/2	1 1/2	1 1/2	2	2
Hip girth	1	1	1	1	1 1/2	1 1/2	1 1/2	2	2
Thigh girth (max)	3/4	3/4	3/4	3/4	1	1	1	1 1/4	1 1/4
Knee girth	3/8	3/8	3/8	3/8	1/2	1/2	1/2	1/2	1/2
Ankle girth	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4
Waist to crotch length	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4	1/4
Crotch height	0	0	0	0	0	0	0	0	0

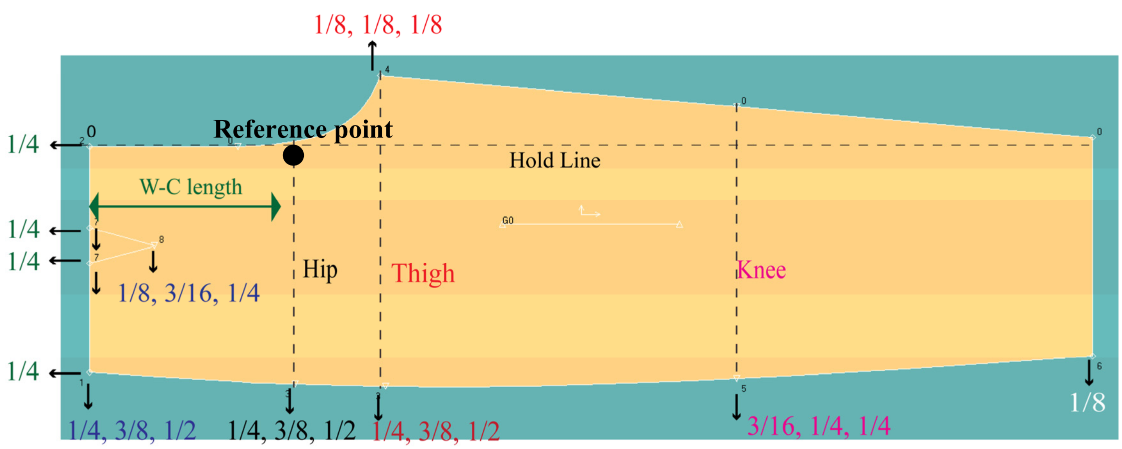
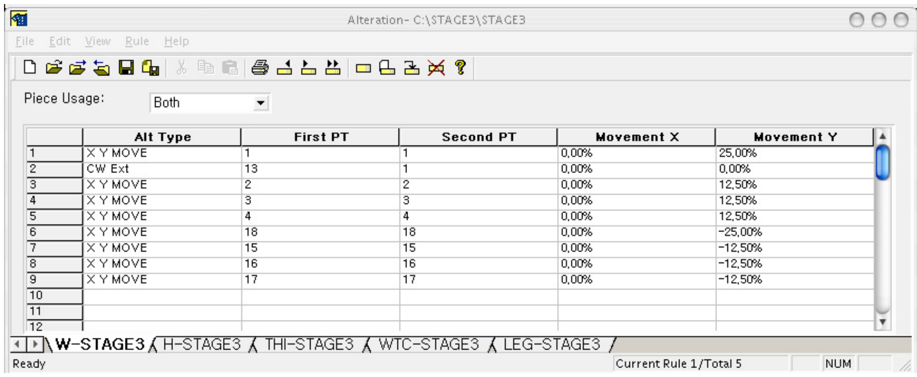


Figure 3-27. Grading method (values for waist to crotch length in green, waist girth in blue, hip girth in black, thigh girth in red, and knee girth in pink, and ankle girth in white).

For grading at waist girth and hip girth, the grade amount was evenly divided into four (two front patterns and two back patters which consisted of the whole girth), for example, for grading of waist girth, 0.6 cm (1/4 in) was graded up from size 2 to 4 at side waist points in each front pattern and back pattern. For grading of the thigh girth, knee girth, and ankle girth, the grade amount was evenly divided into two (a front pattern and a back pattern which consisted of the whole girth). The reference point (fixed point) for grading was set on a cross point of the vertical line starting from the side hip point and the horizontal line starting from the center waist point. The grading of all girth measurements was conducted on points located on the side seam line except for thigh grading. To create a smooth side seam line from hip to thigh, the graded amount at the side hip point (0.6 cm (1/4 in) in the size range 2 to 10, 1.0 cm (3/8 in) in the size range 10 to 16, and 1.3 cm (1/2 in) in the size range 16 to 20) was also applied to the side thigh point. But the total amount of grade for thigh was 1.9 cm (3/4 in) in the size range 2 to 10, 2.5 cm (1 in) in the size range 10 to 16, and 3.2 cm (1 1/4 in) in the size range 16 to 20, so 0.3 cm (1/8 in) in the whole size range was additionally applied at crotch point (3/8 minus 1/4 inches in the size range 2 to 10, 1/2 minus 3/8 inches the size range 10 to 16, and 5/8 minus 1/2 inches in the size range 16 to 20). The waist to crotch length grade was applied to points located on the waist line.

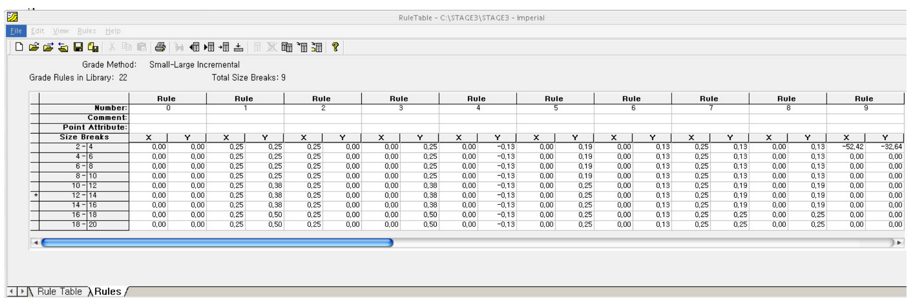
Setting up Made-to-Measure System

An alteration rule file and a grading rule file were developed in AccuMark Explore. In Pattern Design 8.3, points where grading rules and alteration rules were applied were numbered. All files (alteration rule file, grading rule file and patterns) were imported for storage in AccuMark MtM software. Three body charts (one for each body shape group) were made from the smallest size (size 2) to largest size (size 20). Since the system could not determine which alteration rule should be connected to



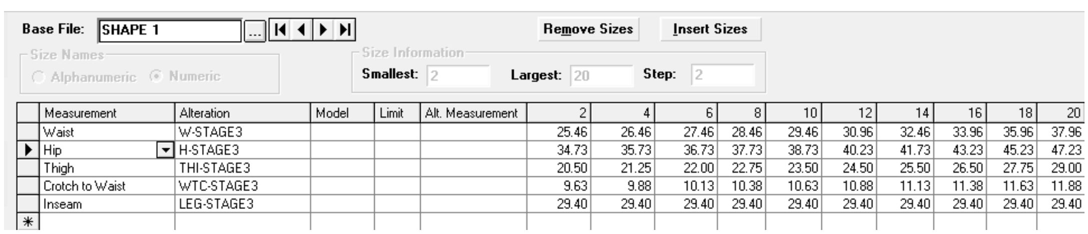
	Alt Type	First PT	Second PT	Movement X	Movement Y
1	X Y MOVE	1	1	0,00%	25,00%
2	CW Ext	13	1	0,00%	0,00%
3	X Y MOVE	2	2	0,00%	12,50%
4	X Y MOVE	3	3	0,00%	12,50%
5	X Y MOVE	4	4	0,00%	12,50%
6	X Y MOVE	18	18	0,00%	-25,00%
7	X Y MOVE	15	15	0,00%	-12,50%
8	X Y MOVE	16	16	0,00%	-12,50%
9	X Y MOVE	17	17	0,00%	-12,50%
10					
11					
12					

Figure 3-28. Alteration rule file.

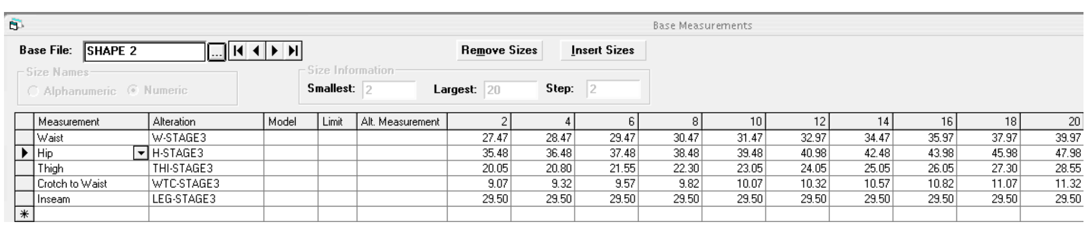


Rule Number:	0		1		2		3		4		5		6		7		8		9	
Comment:																				
Point Attribute:																				
Size Breaks	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
2 - 4	0,00	0,00	0,25	0,25	0,25	0,00	0,00	0,25	0,00	-0,13	0,00	0,19	0,00	0,13	0,25	0,13	0,00	0,13	-52,42	-32,64
4 - 6	0,00	0,00	0,25	0,25	0,25	0,00	0,00	0,25	0,00	-0,13	0,00	0,19	0,00	0,13	0,25	0,13	0,00	0,13	0,00	0,00
6 - 8	0,00	0,00	0,25	0,25	0,25	0,00	0,00	0,25	0,00	-0,13	0,00	0,19	0,00	0,13	0,25	0,13	0,00	0,13	0,00	0,00
8 - 10	0,00	0,00	0,25	0,25	0,25	0,00	0,00	0,25	0,00	-0,13	0,00	0,19	0,00	0,13	0,25	0,13	0,00	0,13	0,00	0,00
10 - 12	0,00	0,00	0,25	0,38	0,25	0,00	0,00	0,38	0,00	-0,13	0,00	0,25	0,00	0,13	0,25	0,19	0,00	0,19	0,00	0,00
* 12 - 14	0,00	0,00	0,25	0,38	0,25	0,00	0,00	0,38	0,00	-0,13	0,00	0,25	0,00	0,13	0,25	0,19	0,00	0,19	0,00	0,00
14 - 16	0,00	0,00	0,25	0,38	0,25	0,00	0,00	0,38	0,00	-0,13	0,00	0,25	0,00	0,13	0,25	0,19	0,00	0,19	0,00	0,00
16 - 18	0,00	0,00	0,25	0,50	0,25	0,00	0,00	0,50	0,00	-0,13	0,00	0,25	0,00	0,13	0,25	0,25	0,00	0,25	0,00	0,00
18 - 20	0,00	0,00	0,25	0,50	0,25	0,00	0,00	0,50	0,00	-0,13	0,00	0,25	0,00	0,13	0,25	0,25	0,00	0,25	0,00	0,00

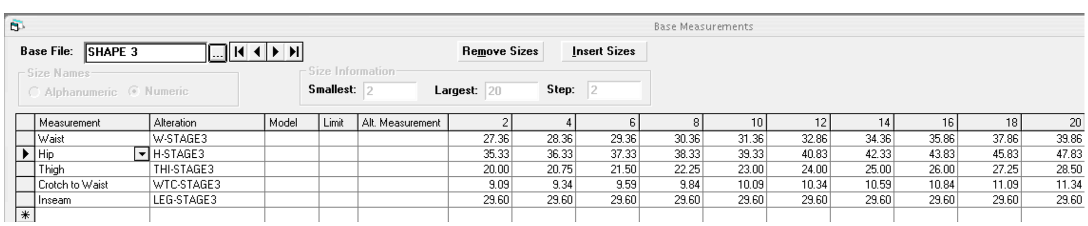
Figure 3-29. Grading rule file.



Measurement	Alteration	Model	Limit	Alt. Measurement	2	4	6	8	10	12	14	16	18	20
Waist	W-STAGE3				25.46	26.46	27.46	28.46	29.46	30.96	32.46	33.96	35.96	37.96
Hip	H-STAGE3				34.73	35.73	36.73	37.73	38.73	40.23	41.73	43.23	45.23	47.23
Thigh	THI-STAGE3				20.50	21.25	22.00	22.75	23.50	24.50	25.50	26.50	27.75	29.00
Crotch to Waist	WTC-STAGE3				9.63	9.88	10.13	10.38	10.63	10.88	11.13	11.38	11.63	11.88
Inseam	LEG-STAGE3				29.40	29.40	29.40	29.40	29.40	29.40	29.40	29.40	29.40	29.40



Measurement	Alteration	Model	Limit	Alt. Measurement	2	4	6	8	10	12	14	16	18	20
Waist	W-STAGE3				27.47	28.47	29.47	30.47	31.47	32.97	34.47	35.97	37.97	39.97
Hip	H-STAGE3				35.48	36.48	37.48	38.48	39.48	40.98	42.48	43.98	45.98	47.98
Thigh	THI-STAGE3				20.05	20.80	21.55	22.30	23.05	24.05	25.05	26.05	27.30	28.55
Crotch to Waist	WTC-STAGE3				9.07	9.32	9.57	9.82	10.07	10.32	10.57	10.82	11.07	11.32
Inseam	LEG-STAGE3				29.50	29.50	29.50	29.50	29.50	29.50	29.50	29.50	29.50	29.50



Measurement	Alteration	Model	Limit	Alt. Measurement	2	4	6	8	10	12	14	16	18	20
Waist	W-STAGE3				27.36	28.36	29.36	30.36	31.36	32.86	34.36	35.86	37.86	39.86
Hip	H-STAGE3				35.33	36.33	37.33	38.33	39.33	40.83	42.33	43.83	45.83	47.83
Thigh	THI-STAGE3				20.00	20.75	21.50	22.25	23.00	24.00	25.00	26.00	27.25	28.50
Crotch to Waist	WTC-STAGE3				9.09	9.34	9.59	9.84	10.09	10.34	10.59	10.84	11.09	11.34
Inseam	LEG-STAGE3				29.60	29.60	29.60	29.60	29.60	29.60	29.60	29.60	29.60	29.60

Figure 3-30. Body charts.

which body measurement, it was necessary to connect body measurements in the body chart to alteration locations in the alteration rule file (Figure 3-30).

In this study, the hip girth measurement was used as a primary body measurement for selecting the base size for an individual. When generating custom-made patterns for the individual, the system first selected a base size pattern of the individual by comparing her primary body measurement (hip girth) with that in the body chart. After selecting the base size pattern for that individual from the graded nest, the system compared the rest of her measurements with those in the body chart for the size pattern chosen, and calculated the alteration amounts at each location. In Pattern Design 8.3, her base pattern was then selected and each alteration was made according to the alteration rules. All of the alterations were combined, and the final custom pants patterns were generated. The process within each program of Gerber Scientific is summarized in Figure 3-31.

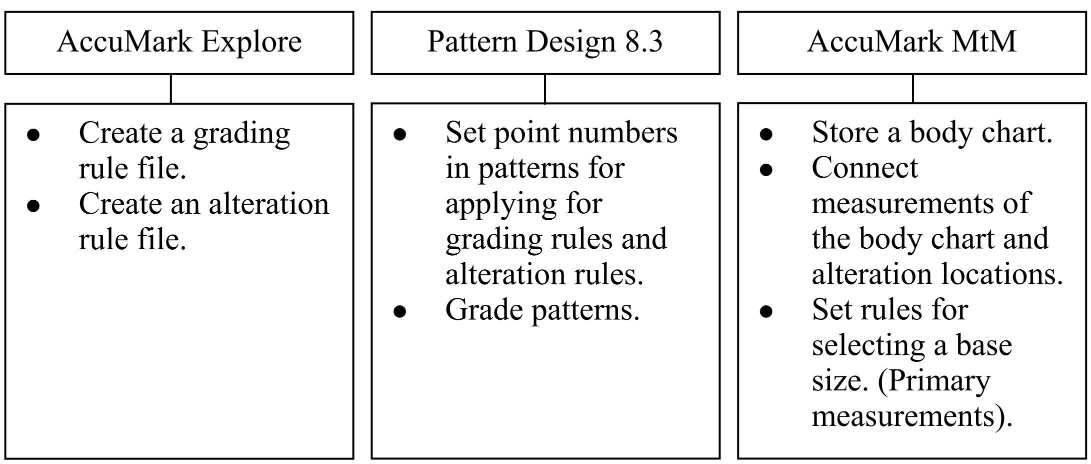


Figure 3-31. Made-to-measure system of Gerber Scientific.

Wearers' Fit Test

Twenty seven participants (fit testers) in the three body shape groups were selected from the 83 participants. Subjects' sizes were not controlled at this stage except that all were less than 123.4 cm (48.6 in) hip girth measurement (90th percentile of the hip girth distribution in SizeUSA). To identify fit variations, fit testers were selected across the full range of body sizes as proportionally as possible. They were invited to try on two pairs of pants, and to compare them. A fit test with four postures was conducted with each pair of pants. After the fit test, they were asked to judge the fit of the two sets of pants, and their fit satisfaction at twelve body locations; waist ease, abdomen ease, hip ease, thigh ease, knee ease, crotch ease, front waist placement, back waist placement, crotch placement, hip placement, side seam placement, and inseam length. A five-point scale was used for this study. The end points of each scale varied depending on the fit location, for example very tight (1) – very loose (5) or very short (1) – very long (5). The middle value of the scale, 3, represented good fit. The participants rated overall fit satisfaction on a 5-point Likert scale, ranging from 1 (very dissatisfied) to 5 (very satisfied). They were also asked to select the pair of pants they preferred. They were then scanned, and photographs of the front, side, and back views of each pair of pants in standard posture, and side view in sitting posture were taken.

Expert Judges' Fit Analysis

Three expert fit judges working in the women's apparel industry performed visual analysis of the fit of the pants. Each fit judge had worked as a designer or technical designer in the women's woven apparel industry for eight years or more. Each judge was provided with 27 questionnaires for 27 sets of pants for each set of test pants (A – made by standard alteration method, B –made by body shape driven alteration method, 54 pair of pants total) for fit analysis. The questionnaire consisted of four sections; front view (front waist ease, abdomen ease, front thigh ease, front crotch ease, crotch length, and inseam length), back view (back waist ease, back hip ease, back thigh ease, and back crotch ease), side view (front waist placement, back waist placement, and side seam placement), and overall fit. A five-point scale was used for this study. The end points of each scale varied depending on the fit location, for example very tight (1) – very loose (5), very short (1) – very long (5), very low (1) – very high (5), or very forward (1) – very backward (5). The middle value of the scale, 3, represented good fit. The fit of the pants was judged from photographs that were provided with the questionnaire. For analyzing the fit of the front view, a side view photograph was also provided next to the front view photograph. For analyzing the fit of the back view, a side view photograph was also provided next to the back view photograph. The side view photograph helped judges to identify gaps between the body and pants, or wrinkles caused by tight fit. Judges also rated overall fit on a 5-point Likert scale, ranging from 1 (very bad) to 5 (very good). At the end of the questionnaire, judges ranked the two pair of pants for each subject, choosing the best fitting pair overall.

In order to reduce a bias caused by each expert's different judging ability, I developed a training instruction including a fit checklist and examples of good fitted pants and poor fitted pants (Appendix 4). Before they started to fill out the questionnaire, they were asked to read the instruction.

Analysis Method for Comparison of Two Made-to-Measure Systems

Wearers' Fit Test

The questionnaire for judging the fit of two types of pants was constructed using a five-point scale. The middle value of the scale, 3, represented good fit. The end points of each scale varied depending on the fit location, for example very tight (1) – very loose (5), very short (1) – very long (5), very low (1) – very high (5), or very forward (1) – very backward (5). For the first step of the analysis to judge which type of pants provided better fit in each body area, the scale 3 was re-coded as '1 (good fit)', and the rest of scales (1, 2, 4, and 5) as '0 (poor fit)'. A generalized estimating equation (GEE) was performed to test whether the body shape driven customization method (A pants type) can generate custom-made pants with better fit than the standard customization method (B pants type). This analysis assessed 12 locations for the two main effects (pants type and body shape group) and one two-way interaction (pants type by body shape group) at 95% confidence level using SPSS 17.0. If no significant interaction was found, GEE was re-performed with only the two main effects. F-values and means for each location were examined. In locations where both a 'pants type' main effect and a 'pants type' by 'shape group' interaction were found, means of type A and B were compared depending on shape groups using pairwise comparison analysis at 95% confidence level.

Then, I returned to the data coded by a five-point scale [e.g., very tight (1) – very loose (5)], and cross-tabulations of frequencies of fit scores were calculated to identify which fit problems each pants type had depending on body shape group.

Regarding analysis of fit satisfaction at 12 locations and overall fit satisfaction judged by a five-point scale, Linear mixed models (LMM) was utilized for the two main effects (type and shape group) and a two-way interaction (type by shape group). Pairwise comparisons (A-B) of fit satisfaction at each location were conducted by shape group. For the last question in which wearers chose the best fitting pair, frequencies were calculated.

Expert Judges' Fit Analysis

The questionnaire for judging the fit of two types of pants was constructed using a five-point scale. As for the wearers' fit analysis methods, a five-point scale was transformed to a two-point scale. A generalized estimating equation (GEE) was performed to test whether the body shape driven customization method (A pants type) can generate custom-made pants with better fit than the standard customization method (B pants type). This analysis assessed 13 locations for the three main effects (pants type, body shape group, and judge) and three two-way interactions (pants type by body shape group, pants type by judge, body shape group by judge) at 95% confidence level using SPSS 17.0. If no significant interaction was found, GEE was re-performed with only the three main effects. But if certain significant interactions were found, GEE was re-performed with the three main effects and the interactions which had significance. F-values and means for each location were examined. In locations where both a 'pants type' main effect and a 'pants type' by 'judge' interaction were found, means of type A and B were compared depending on judges using pairwise comparison analysis at 95% confidence level.

In order to identify whether A pants type can generate custom-made pants with better fit than B pants type depending on body shape groups, pairwise t-test was performed after splitting the data by body shape group. Then, I returned to the data coded by a five-point scale (e.g., very tight (1) – very loose (5)), and cross-tabulations of frequencies of fit scores were calculated to identify which fit problems each pants type had depending on body shape group.

Regarding analysis of overall fit judged by a five-point Likert scale, Linear mixed models (LMM) was utilized for the three main effects (type, shape group, and judge) and three two-way interactions (type by shape group, type by judge, and shape group by judge). Pairwise comparisons (A-B) of overall fit were conducted by judge and by shape group. About the last question which judges chose the best fitting pair, frequencies were calculated.

CHAPTER 4. RESULTS

Lower Body Shape Analysis

Pre-Principal Component Analysis

As a first step to create a new method for categorizing body shape principal component analysis (PCA) was conducted using fourteen drops and a buttocks angle. The total amount of variations in the sample was 15. Five principal components (PCs) with eigenvalues greater than 1.0 were extracted (*Pre-PCA1)*. Table 4-1 shows that 87.7% of the variation of the fifteen variables was explained by 5 PCs. As presented in Table 4-2, the first PC had high loadings with seven drops: top hip girth to waist girth, front top hip arc to front waist arc, back top hip arc to back waist arc, hip width to waist width, hip girth to waist girth, front hip arc to front waist arc, and back hip arc to back waist arc. The second PC had a high correlation with five drops: hip girth to top hip girth, front hip arc to front top hip arc, back hip arc to back top hip arc, hip to waist girth, and front hip to waist arc. The third PC had a high correlation with the buttocks angle and two drops: back hip depth to back waist depth, and hip depth to waist back depth. The last two PCs have only a single variable: PC4 – drop of front abdomen depth to front waist depth, and PC5 - drop of front abdomen depth to front hip depth.

Table 4-1. Total variance explained from Pre-PCA1.

Principal component	Rotation sums of squared loading		
	Eigenvalue	% of Variance	Cumulative %
1	**4.2**	**28.0**	28.0
2	**3.3**	**21.9**	50.0
3	**3.0**	**19.9**	69.8
4	1.4	9.3	79.2
5	1.3	8.5	87.7

Note. The total amount of variations in the sample is 15.

Table 4-2. Rotated component matrix of Pre-PCA1.

	Principal component					
Variable	1	2	3	4	5	6
Girth: Top Hip – Waist	**.934**	-.139	.283	.118	-.024	.000
Width: Hip – Waist	**.827**	.297	.119	-.043	.145	-.101
Front arc: Top Hip – Waist	**.773**	-.072	-.154	.453	-.155	-.133
Girth: Hip – Waist	**.718**	**.586**	.305	.110	-.051	.156
Front arc: Hip – Waist	**.716**	**.505**	-.102	.256	-.194	-.036
Back arc: Top Hip – Waist	**.704**	-.142	**.545**	-.215	.097	.086
Back arc: Hip –- Waist	**.603**	.346	**.586**	-.072	.114	-.051
Girth: Hip – Top Hip	.072	**.966**	.145	.036	-.048	.016
Front arc: Hip – Top Hip	.147	**.860**	.032	-.165	-.106	-.081
Back arc: Hip – Top Hip	-.022	**.820**	.191	.202	.052	.122
Buttocks angle	-.018	.125	**.893**	-.083	.113	.262
Back Depth: Hip – Waist	.207	.131	**.844**	-.066	.235	-.400
Depth: Hip – Waist	.275	.229	**.712**	.376	-.412	.085
Front Depth: Abdomen – Waist	.122	.057	-.052	**.907**	.085	-.013
Front Depth: Abdomen – Hip	.016	-.079	.202	.083	**.954**	.069

Each variable should have high component loadings with a single PC in order to sort into distinct shapes most effectively, but four of the drops (hip girth to waist girth, front hip arc to front waist arc, back hip arc to back waist arc, and back top hip arc to back waist arc) were highly correlated with two PCs (Table 4-2). As shown in Table 4-3, after the removal of three drops (hip girth to waist girth, back hip arc to back waist arc, and back top hip arc to back waist arc) from the PCA, the five PCs with eigenvalues of 1.0 and more (with 12 total variations in the sample) had variables with high loadings for only a single PC (*Pre-PCA2)*. Interpretation of the PCs was based on variables with high component loadings.

Even though 5 PCs were extracted since their eigenvalues were greater than 1.0, only the first three PCs (PC1, PC2, and PC3) were found to make a strong contribution to variance explained: PC1 = 25.5%, PC2 =23.3%, PC3 = 19.6 %. The

Table 4-3. Rotated component matrix of Pre-PCA2 with 12 variables retained.

	Principal component				
Variable	1	2	3	4	5
Girth: Top Hip – Waist	**.890**	-.142	.296	.015	.066
Front arc: Top Hip – Waist	**.882**	-.097	-.075	-.117	.288
Width: Hip – Waist	**.806**	.298	.146	.183	-.108
Front arc: Hip – Waist	**.798**	.495	-.030	-.152	.118
Girth: Hip – Top Hip	.064	**.962**	.146	-.047	.047
Front arc: Hip – Top Hip	.140	**.876**	.045	-.089	-.173
Back arc: Hip – Top Hip	-.014	**.805**	.178	.035	.220
Buttocks angle	-.063	.121	**.898**	.142	-.087
Back Depth: Hip – Waist	.204	.125	**.881**	.283	-.145
Depth: Hip – Waist	.317	.225	**.746**	-.381	.322
Front Depth: Abdomen – Hip	-.006	-.078	.190	**.966**	.074
Front Depth: Abdomen – Waist	.174	.064	-.076	.064	**.950**

contribution of the next two PC values was much less: PC4 = 10.5 % and PC5 = 10.3 %. In addition, each PC should have minimum of three variables, but the last two PCs had a single variable, which was not enough to provide adequate information about that component.

Therefore, the first three PCs were only considered as true PCs, and the last two PCs were removed from the final PCA. However, since the variables from PC4 and PC5 were also critical components that represent distinctive shapes from silhouette and profile views of the lower body, these variables were calculated as z-scores, and their z-scores were used in the cluster analysis as independent variables (z-score 1: ‘drop of front abdomen depth to waist front depth’, and z-score 2: ‘drop of front abdomen depth to front hip depth’).

Consideration of Length Variables

Previous to this, I also tested length measurements for inclusion in the PCA, including 'waist to hip height’, 'waist to abdomen height’ and 'waist to crotch height’. All three length measurements were collected under one PC, since they were highly correlated with each other. Therefore, I concluded that these measurements would not be useful for sorting into body shape groups. This is the same reason that I excluded body size-related measurements such as girths, front arcs, back arcs and inseam length.

I then tried a PCA that included length proportions: 'waist to hip height / waist to crotch height’, and 'waist to abdomen height / waist to crotch height’. The results showed that the first two variables were included in the ‘waist to hip silhouette’ PC with relatively low loadings (.620, .562). Since no specific PC related to a specific vertical descriptor was found, I used only horizontal measurements in the final PCA.

Final Principal Component Analysis

Once all of the final variables were chosen, an additional PCA was performed with the two variables corresponding to PC4 and PC5 removed. Analysis of the remaining variables yielded 82.1% of the variations explained by three PCs with eigenvalues 1.0 and greater (with 10 total variations in the sample): PC1 = 30.7%, PC2 = 27.8% and PC3 = 23.6%. The three PCs were considered as appropriate for the cluster analysis since each PC had three or four variables which had high loadings for only their PC, as shown in Table 4-4. PC1 can be interpreted as measurements that relate to ‘waist to top hip silhouette’, PC2 as ‘top hip to hip silhouette’, and PC3 as ‘buttocks prominence’. As shown in Figure 4-1, each PC can clearly represent a distinctive shape from either the silhouette or profile view of the body. These PC scores were saved in the dataset, and used for the cluster analysis.

Table 4-4. Rotated component matrix of Final PCA.

	Principal component		
Variable	1	2	3
Front arc: Top Hip – Waist	**.931**	-.083	-.086
Girth: Top Hip – Waist	**.880**	-.148	.318
Front arc: Hip – Waist	**.815**	.507	-.030
Width: Hip – Waist	**.755**	.273	.209
Girth: Hip – Top Hip	.068	**.962**	.154
Front arc: Hip – Top Hip	.105	**.878**	.059
Back arc: Hip – Top Hip	.021	**.801**	.181
Buttocks angle	-.099	.103	**.914**
Back Depth: Hip – Waist	.151	.098	**.913**
Depth: Hip – Waist	.379	.253	**.694**

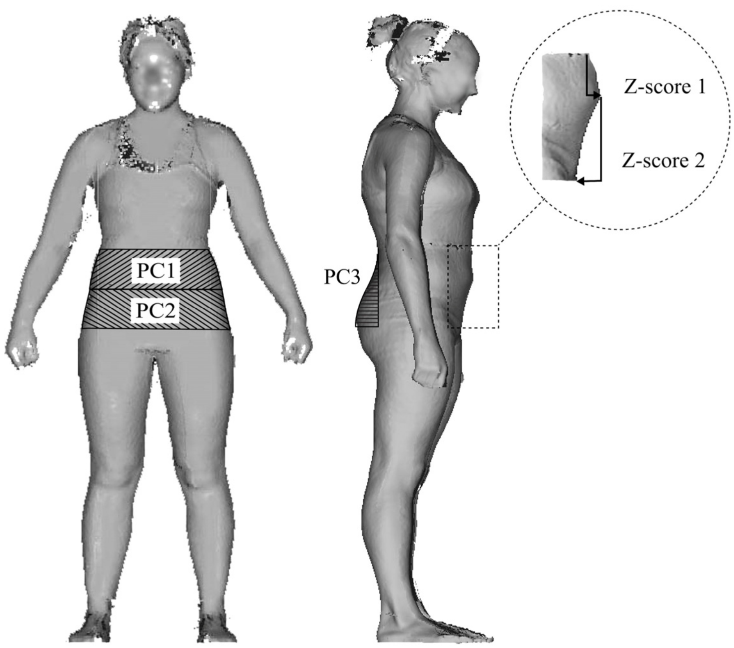


Figure 4-1. Five variables identified for the cluster analysis.

Cluster Analysis

K-means cluster analysis was performed using PC1 score, PC2 score, PC3 score, and z-scores 1 and 2 as independent variables to categorize lower body shapes. I experimented with different numbers of clusters, dividing the 2, 488 women into two, three, four and five clusters, and analyzed each set of clusters. I concluded that three clusters were the most efficient and appropriate to represent complex lower body shapes for this study. The reasons are as follows:

When 2, 3, or 4 clusters were categorized, the data were judged to be relatively evenly divided into each cluster as follows; in 2-cluster model (cluster 1: n=1,186, 47.7%, cluster 2: n=1,302, 52.3%), in the 3-cluster model (cluster 1: n=727, 29.2%, cluster 2: n=867, 34.9%, cluster 3: n=894, 35.9%), and in the 4-cluster model (cluster 1: 639, 25.7 %, cluster 2: 575, 23.1 %, cluster 3: 721, 29.0 %, cluster 4: 553, 22.2 %), However, in the 5-cluster model, cluster 3 only represented 10% of the total data (cluster 1: 461, 18.5%, cluster 2: 646, 26.0%, cluster 3: 251, 10.1%, cluster 4: 531, 21.3%, cluster 5: 599, 24.1%). Therefore I concluded that 5-cluster model was not appropriate for lower body shape analysis for this purpose of my study. Finding study participants for the testing phase of this study from such a small percentage of the population would limit the effectiveness of this phase.

In the 2-cluster model, cluster 1 had a straight front silhouette, flat abdomen, and prominent buttocks, and cluster 2 had a curvy front silhouette, prominent abdomen and flat buttocks. The 'Straight' shape in both front and side views, which existed in the 3-cluster model, did not exist in the 2-cluster model. I concluded that two clusters were not enough to represent complex lower body shapes, and the 3-cluster model was more appropriate to represent lower body shapes than the 2-cluster model.

The 4-cluster model was also considered as a possible choice for this study. However, in this model though cluster 1 and cluster 2 had obvious shape differences when compared to the other two clusters, cluster 3 and 4 had shapes similar to each other. Since this research was considered as an early stage of these kinds of shape analysis studies using PCA and cluster analysis, the 4-cluster model did not have much merit when compared to the 3-cluster model. Therefore, I chose three clusters as the final number.

In the 3-cluster model, a one-way ANOVA was conducted based on 95% confidence level to compare the mean scores on the five variables used in the cluster analysis. Table 4-5 shows that the overall F for the one-way ANOVA was statistically different ($p<.05$). As a post-hoc analysis, Duncan's multiple range test showed that the means of all possible pairwise comparisons on the five variables were significantly different at the 0.05 level, except for the z-score of 'drop of front abdomen depth to waist front depth' (z-score 1) between group 2 and group 3. This means that each group is in a subset by itself in four variables, but regarding the fifth variable, the z-score 1, two subsets were identified as group 1 and group 2/3.

Table 4-5. Mean and standard deviation of PC and z-score variables for three body shape groups, and ANOVA comparison of the scores.

Variables for cluster analysis	Body shape group 1 (n=727) Curvy shape		2 (n=867) Hip tilt shape		3 (n=894) Straight shape		F	Sig.
	Mean	S.D.	Mean	S.D.	Mean	S.D.		
PC1: Waist to top hip silhouette	**.967 a**	.731	-.356 b	.814	-.440 c	.793	784.636	.000 *
PC2: Top hip to hip silhouette	.008 b	.970	-.367 c	.965	**.349 a**	.929	124.186	.000*
PC3: Buttocks prominence	-.151 b	.832	**.730 a**	.836	-.585 c	.816	572.582	.000*
Z1: Abdomen prominence	**.894 a**	.816	-.403 c	.746	-.337 b	.884	614.963	.000*
Z2: Slope from abdomen to hip	-.023 b	.775	**.720 a**	.847	-.679 c	.797	659.569	.000*

Note. Means were ranked by a, b, and c ordered by the magnitude of the value.
* $p < .05$

Table 4-5 also presents the means and standard deviations of the PCs and z-scores of each body shape group on five variables, ranked by a, b, and c, and ordered by the magnitude of the mean value. Considering the waist to top hip silhouette (PC1), group 1 is the curviest (.967), while group 2 (-.356) and 3 (-.440) have rather straight silhouettes. With respect to top hip to hip silhouette (PC2), group 1 has a somewhat straight silhouette (.008), group 2 is the straightest (-.367), and group 3 has the curviest shape (.349). Regarding buttocks prominence (PC3), group 1 has somewhat flat buttocks (-.151), group 2 has the most prominent buttocks (.730) with a large difference from the other two groups, and group 3 has the flattest buttocks (-.585). For the abdomen prominence (z-score 1), group 1 has the most prominent abdomen (.894) with a large difference from the other two groups, group 2 (-.403) and 3 (-.337). Regarding the slope of the abdomen prominence point to the front point at hip level (z-score 2), group 1 has a somewhat vertical profile (-.023), group 2 is the most sloped and tilted toward the back (.720), and group 3 has the most vertical profile (-.679).

Table 4-6 presents means and standard deviations of each body shape group on 12 variables. The overall F for the one-way ANOVA was statistically different on all variables, and the means of most variables demonstrated the same relationships as the means of their PCS. Figure 4-2 shows how the means of each principal component and z-scores compare among the three body shape groups.

To sum up characteristics of each body shape, group 1 (curvy shape) has the curviest silhouette between waist level and top hip level, and the most prominent abdomen among the three groups. The most notable characteristic of group 2 (hip tilt shape) is that this group has the most prominent buttocks, and their lower body is tilted toward the back. Group 2 also has a rather straight silhouette between the waist level and top hip level similar to group 3. However, group 2 has a fuller top hip than group 3. Group 3 (straight shape) has a non-curvy silhouette and non-prominent buttocks.

Table 4-6. Mean and standard deviation of three body shape groups on twelve body measurements.

	Variables	Body shape group 1 (n=727) Curvy shape Mean	S.D.	2 (n=867) Hip tilt shape Mean	S.D.	3 (n=894) Straight shape Mean	S.D.	F	Sig.
PC1	Front arc: Top Hip – Waist	6.93 (2.73) **a**	.60	4.09 (1.61) b	.70	4.09 (1.61) b	.65	755.85	.000*
	Girth: Top Hip – Waist	17.81 (7.01) **a**	1.12	14.88 (5.86) b	1.23	12.65 (4.98) c	1.14	606.47	.000*
	Front arc: Hip – Waist	10.24 (4.03) **a**	.81	6.83 (2.69) **c**	.92	7.75 (3.05) **b**	.90	477.52	.000*
	Width: Hip – Waist	9.32 (3.67) **a**	.66	7.98 (3.14) b	.70	7.39 (2.91) c	.69	252.10	.000*
PC2	Girth: Hip – Top Hip	8.43 (3.32) b	1.38	7.21 (2.84) c	1.40	8.97 (3.53) **a**	1.37	56.63	.000*
	Front arc: Hip – Top Hip	3.28 (1.29) b	.68	2.74 (1.08) c	.69	3.66 (1.44) **a**	.62	66.57	.000*
	Back arc: Hip – Top Hip	3.00 (1.18) **a**	.61	2.62 (1.03) **b**	.65	3.10 (1.22) **a**	.64	20.81	.000*
PC3	Buttocks angle	21.69 b	3.46	25.35 **a**	3.38	20.84 c	3.51	415.09	.000*
	Back Depth: Hip – Waist	6.65 (2.62) b	.52	8.00 (3.15) **a**	.55	5.74 (2.26) c	.52	629.38	.000*
	Depth: Hip – Waist	5.56 (2.19) **a**	.54	4.93 (1.94) **b**	.62	4.34 (1.71) c	.58	137.74	.000*
Z1	Front Depth: Abdomen – Hip	1.54 (.57) **a**	.28	0.30 (.12) c	.26	0.36 (.14) b	.30	614.96	.000*
Z2	Front Depth: Abdomen – Waist	2.54 (1.00) b	.35	3.40 (1.34) **a**	.39	1.78 (.70) c	.36	659.57	.000*

Note. Means were ranked by a, b, and c ordered by the magnitude of the value.
Note. For mean of 12 variables (except for buttocks angle), 'inch' unit is also added in parentheses next to 'centimeter' unit.
* $p < .05$

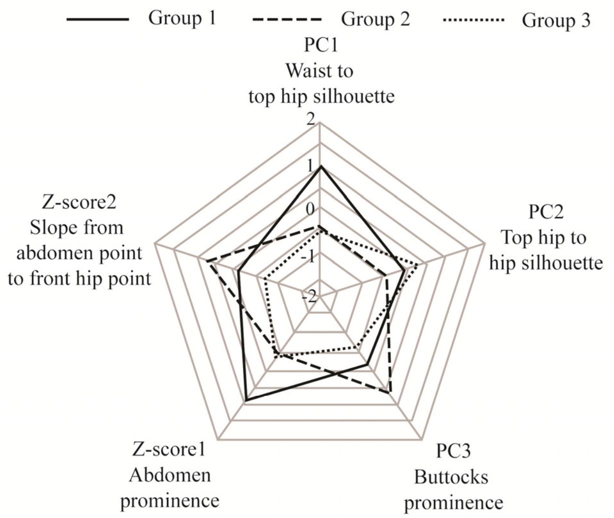


Figure 4-2. Graph showing the means of the PC and z-score variables used for cluster analysis across three body shape groups.

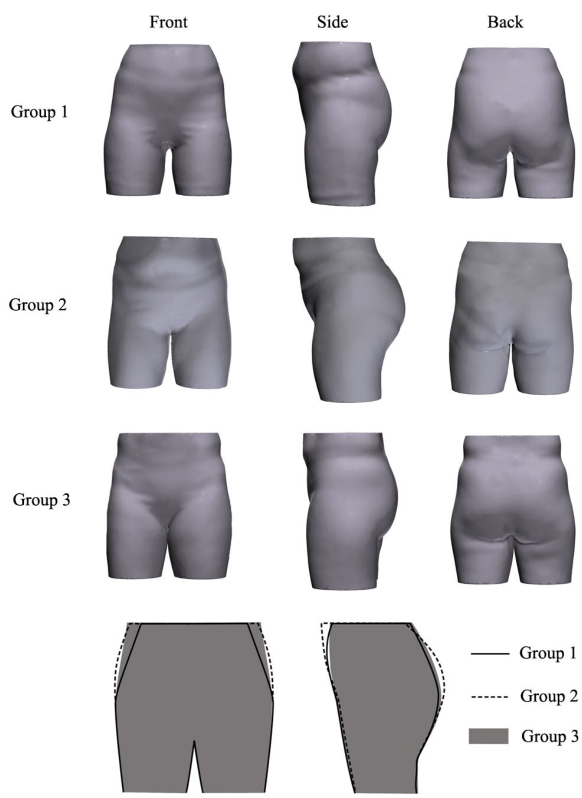


Figure 4-3. Front and side silhouettes of three body shape groups.

From the SizeUSA database of scans, I tried to identify fit models for each of the three body shape groups. The perfect fit model for a body shape group would have median values for all five variables. However, it was impossible to find perfect fit models, a normal outcome given the fallacy of the average man (McConville, 1978). Therefore, I identified some individuals that generally represent each body shape group, and their 3D scans were provided from $[TC]^2$. To generate the fit model examples in Figure 4-3, I selected 3D scan files (.obj format) which could most closely represent each body shape. Then using the 3D tools in Photoshop CS4, I manipulated and refined the 3D images in order to represent each silhouette in the three directions (front/side/back) most effectively. These silhouettes were adjusted to match the calculated average key measurements for each group. Front silhouettes and profile sketches of each lower body shape group are also shown in Figure 4-3 for comparison.

The population distribution of each of the three body shape groups was analyzed according to two age groups (Table 4-7). For women aged 18 to 25, group 3 (straight shape) is the largest group (43.8%), group 2 (hip tilt shape) follows with 35.9%, and group 1 (curvy shape) is least represented with 20.3%. On the other hand, in women aged 25 to 35, group 1 (curvy shape) was the largest group (39.9%), group 2 (hip tilt shape) follows with 22.6% and group 3 (straight shape) with 26.5%. It is speculated that this is due to an increase in abdomen prominence as the age increases.

Table 4-8 shows that there is also a difference in lower body shapes according to ethnicity. Caucasians were classified into the three body shape groups more evenly than the other ethnicities. The Hispanic population was classified primarily as either group 2 (hip tilt shape) (42.4%) or group 3 (straight shape) (40.3%); only 17.3% were identified as group 1 (curvy shape). Almost half of African American women were classified into group 2 (hip tilt shape) (50.2%), and only 19.5% into group 1 (curvy

Table 4-7. Crosstabulation of age group and body shape group.

			Body shape group			
			1 Curvy shape	2 Hip tilt shape	3 Straight shape	Total
Age group	18 to 25	Count	276	488	595	1,359
		%	20.3%	35.9%	**43.8%**	100.0%
	26 to 35	Count	451	379	299	1,129
		%	**39.9%**	33.6%	26.5%	100.0%
	Total	Count	727	869	894	2,488
		%	29.2%	34.8%	35.9%	100.0%

shape). Others including Asians were classified fairly evenly into body shape group 1 (38.4%), group 2 (hip tilt shape) (33.4%), and group 3 (straight shape) (28.2%). The results showed that African American and Hispanic people tend to have more prominent buttocks and a less prominent abdomen than Caucasians and Asians.

Table 4-8. Crosstabulation of ethnic group and body shape group.

			Body shape group			
			1 Curvy shape	2 Hip tilt shape	3 Straight shape	Total
Ethnic group	Caucasian	Count	438	318	413	1,169
		%	**37.5%**	27.2%	**35.3%**	100.0%
	Hispanic	Count	74	181	172	427
		%	17.3%	**42.4%**	**40.3%**	100.0%
	African American	Count	81	209	126	416
		%	19.5%	**50.2%**	30.3%	100.0%
	Others	Count	134	159	183	476
		%	28.2%	33.4%	**38.4%**	100.0%
	Total	Total	727	867	894	2,488
		%	29.2%	34.8%	35.9%	100.0%

Discriminant Analysis

The discriminant analysis was performed with three body shape group memberships coded by the cluster analysis as a grouping variable, and twelve variables used for the PCA and the cluster analysis in order to develop a means to classify individuals in the study shape groups. The discriminant analysis extracted nine out of twelve variables as key measurements, which discriminate three groups identified from the cluster analysis. Three variables not represented included the front arc and back arc hip to top hip and back depth hip to waist.

Two discriminant functions (DFs) were found. The first row in Table 4-9 (Wilks's Lambda), '1 through 2' provides information about the statistical significance of the entire model using DF 1 and DF 2 combined. Since a chi-square statistic is χ^2 (18) = 4094.96, $p<.001$, the overall model, including both DF 1 and DF 2, significantly predicted group membership. The second row of the table shows the significance of DF 2 alone. Since a chi-square statistic is χ^2 (8) =1904.46, $p<.001$, thus, the overall model with the only DF 2 significantly predicted group membership.

Table 4-9. Wilks' Lambda.

Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
1 through 2	.192	4094.964	18	.000
2	.464	1904.455	8	.000

In Table 4-10, additional information about the relative predictive usefulness of DF 1 and DF 2 is presented. Here it can be seen that 55.1% of the variance was predicted by DF 1, and 44.9% of the variance was predicted by DF 2. Thus, it is clear that the entire model should combine both DF 1 and DF 2 to explain 100% of the variance.

Table 4-10. Eigenvalues of functions.

Function	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
1	1.418	55.1	55.1	.766
2	1.155	44.9	100.0	.732

Table 4-11 reports the coefficients that were used to construct DFs, and shows the correlation of each variable with each DF. The two DFs are as follows:

DF 1= (a×-.143) + (b×-.011) + (c×-.386) + (d×-.197) + (e×-.165) + (f×.089) + (g×.858) + (h×-2.324) + (i×2.158) + (-2.493)

DF 2= (a×.357) + (b×-.327) + (c×.023) + (d×.191) + (e×-.258) + (f×.017) + (g×.544) + (h×1.522) + (i×1.420) + (-5.740)

Table 4-11. Canonical discriminant function coefficients.

	Variable	Function	
		1	2
a	Front arc: Top Hip – Waist	-.143	.357
b	Girth: Top Hip – Waist	-.011	.327
c	Front arc: Hip – Waist	-.386	.023
d	Width: Hip – Waist	-.197	.191
e	Girth: Hip – Top Hip	-.165	-.258
f	Buttocks angle	.089	.017
g	Depth: Hip – Waist	.858	.544
h	Front Depth: Abdomen – Waist	-2.324	1.522
i	Front Depth: Abdomen – Hip	2.158	1.420
	Constant	-2.493	-5.740

A new person's group membership can be predicted by calculating her DF1 score and DF2 score, and comparing these scores with the scatterplot in Figure 4-4. Group 1 tends to have a positive DF1 score and a positive DF2 score. Group 2 has a negative DF1 score, but the DF2 score can be either positive or negative. Group 3 can have either a positive or negative DF1 score, but a negative DF2 score.

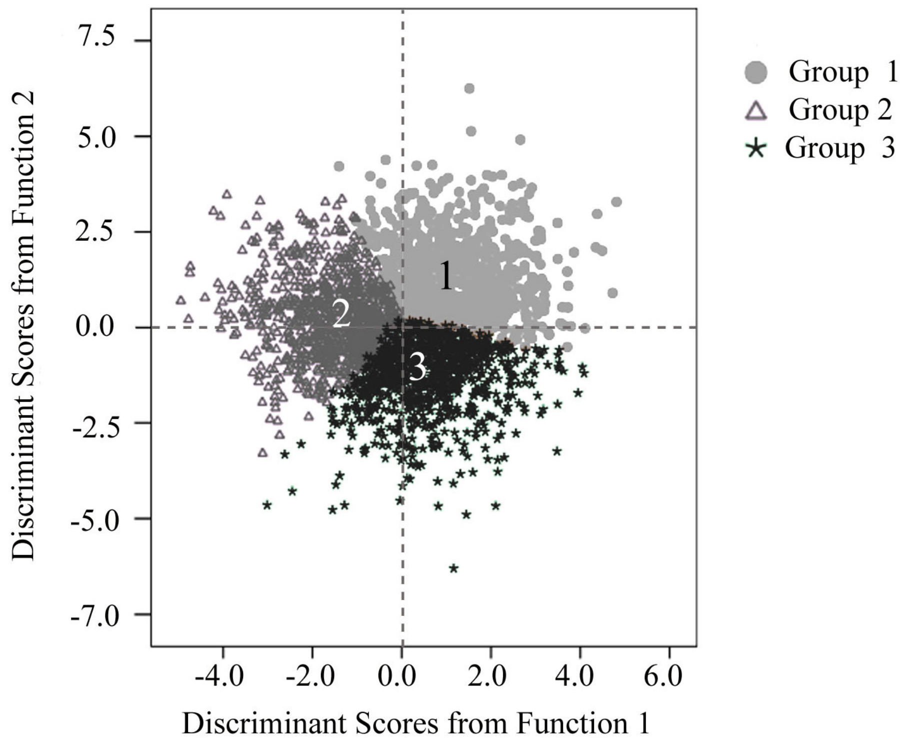


Figure 4-4. Scatterplot of discriminant function 1 and 2 scores.

Table 4-12. Classification results.

			Predicted group membership			Total
			1	2	3	
Original group membership	Count	1	703	10	14	727
		2	4	853	10	867
		3	11	13	870	894
	%	1	**96.7**	1.4	1.9	100.0
		2	.5	**98.4**	1.2	100.0
		3	1.2	1.5	**97.3**	100.0

Note. Overall 97.5% of original grouped cases were correctly classified.

In order to identify the degree of predictive accuracy of the DFs in classifying women to one of the three body shapes, the original group memberships were identified from cluster analysis and predicted group memberships were classified from the DFs, and the two results were compared. Results can be seen in Table 4-12; 97.5% of the women were classified in the same body shape group by the two methods. It is considered that classification by calculation of the two DFs is accurate enough to predict body shape groups.

Development of Final Block Patterns

Modification of Industry Pattern for Three Prototype Patterns

Three prototype patterns were developed by manipulating the modified Lands' End pattern (Figure 3-11) developed to represent an industry base pattern for use in the automated custom fit system. Median values of critical body measurements needed to develop the patterns were calculated based on measurements of women with hip girths between 100.3 to 102.9 cm (39.5 to 40.5 in) from SizeUSA data used in the body shape analysis (stage 1). The median values are presented in Table 4-13. The three prototype patterns were developed to provide ease amounts [1.3 cm (1/2 in) at waist (1.7% of the waist girth), 5.1 cm (2 in) at hip (4.8% of the hip girth), 2.5 cm (1 in) at top hip (2.7% of the top hip girth), 7.6 cm (3 in) at mid-thigh (15.8% of the mid-thigh girth)], plus the median values of each body shape group. The variance in shape was addressed in following areas of the pattern: inseam length, waist to crotch length, front and back waist girths, front and back hip girths, max-thigh girth, mid-thigh girth, center front seam slope, center back seam slope, front and back dart lengths, and back crotch extension.

Table 4-13. Median values of women with hip girth 39.5 to 40.5 inch in SizeUSA data

Body Measurements	Body Shape Group			Note
	1	2	3	
Lengths				
Inseam (Crotch Height)	29.3	29.3	29.6	=
Waist to Crotch Length	**10.7**	**10.7**	**10.0**	
Crotch to Thigh Length	1.5	1.5	1.5	=
Crotch to Knee Length	11.7	11.7	11.7	=
Waist - Hip Length / Waist - Crotch Length	0.7	0.7	0.7	=
Waist - Hip Length / Inseam Length	0.3	0.3	0.3	=
Back pattern				
Back Waist Girth	**7.7**	**8.2**	**8.1**	Firstly, front and back girths at waist and hip were matched, and then total girth of top hip girth was matched since each side seam location was not the same.
Back Top Hip Girth	**9.9**	**10.3**	**9.9**	
Back Hip Girth	**10.4**	**10.7**	**10.5**	
Back Hip - Back Waist Girth	**2.7**	**2.5**	**2.4**	Back dart amount
Waist - Hip Height	**7.5**	**7.3**	**6.7**	Back Dart Length: W-H Height – 1”
Buttocks Angle	**21.3**	**25.8**	**20.6**	Center back seam slope: Angle/2 + 2.5 Industry pattern: 10.4° (1) **13.15°**, (2) **15.40°**, (3) **12.80°**
Back Hip Depth	**5.5**	**5.8**	**5.4**	Back crotch extension (group 2 - 0.4” longer than the other groups)
Total Crotch Length	**27.4**	**28.0**	**26.0**	Ease: 0.7”
Front pattern				
Front Waist Girth	**7.7**	**8.2**	**8.1**	
Front Top Hip Girth	**8.9**	**8.8**	**8.7**	
Front Hip Girth	**9.6**	**9.3**	**9.5**	
Waist to Abdomen Height	**3.3**	**2.0**	**2.5**	Front dart length: Waist to abdomen height – 0.5”
Front Depth: Abdomen-Waist	**0.6**	**0.14**	**0.17**	Front seam slope
Front Abdomen Depth	**5.5**	**5.8**	**5.4**	
Girth				
Ease amount: Waist 1.7% (1/2”), Hip 4.8% (2”), High hip 2.7% (1”), Mid-thigh 15.8% (3”)				
Waist girth (half side)	**15.4**	**16.1**	**16.0**	
Top Hip Girth (half side)	**18.8**	**19.0**	**18.7**	
Hip Girth (half side)	**20.0**	**20.1**	**20.0**	
Max – Thigh Girth	23.5	23.9	23.8	
Mid – Thigh Girth	**19.0**	**19.7**	**19.5**	
Knee Girth	14.5	14.8	14.8	=
Ankle Girth	9.7	9.8	9.9	=

Note. Areas with different measurements across the body shape groups were marked in bold font. Unit = inch

Median values of inseam lengths of all three shape groups were almost the same 74.4 to 75.2 cm (29.3 to 29.6 in). The inseam length of the industry pattern was longer than these median values, so inseam lengths of all the three prototype patterns were decreased to 74.9 cm (29.5 in). The industry pattern had a low waist location, so crotch to waist lengths of the group 1 and 2 patterns were increased to 27.2 cm (10.7) and to 25.4 cm (10.0 in) for group 3.

Regarding front waist girth and back waist girth, group 2 (20.8 cm, 8.2 in) and 3 (20.6 cm, 8.1 in) had similar measurements while group 1 (19.6 cm, 7.7 in) had smaller one. About back hip girth measurement, group 2 (27.2 cm, 10.7 in) had larger measurement than the other groups (26.4 cm, 10.4 in – group 1, and 26.7 cm, 10.5 in). With respect to mid-thigh girth, group 1 had the smallest (48.3 cm, 19.0 in), while group 2 (50.0 cm, 19.7 in) and 3 (49.5 cm, 19.5 in) had similar measurements. Regarding ease amounts, a quarter of the 1.7% of the whole waist girth (1.27 cm, 0.5 in) were allocated to each pattern at waist level, 4.8% (5.08 cm, 2.0 in) of the whole hip girth at hip level, and 15.8% (7.62 cm, 3.0 in) of the whole thigh girth at thigh level (Petrova & Ashdown, 2008).

Back dart length was determined by waist to hip vertical length minus 5.0 cm (2.0 in). Back dart lengths of group 1 and 2 were 14.0 cm (5.5 in) and 13.5 cm (5.3 in), while that of group 3 was relatively short: 11.9 cm (4.7 in). Since the waist to crotch length of group 3 was also shorter than the other groups, the proportion of waist to hip length by waist to crotch length was the same across the body shape groups (0.7). Front dart length was determined by waist to abdomen vertical height minus 1.27 cm (0.5 in). The front dart length of group 1 was the longest (7.1 cm, 2.8 in), while group 2 had 3.8 cm (1.5 in), and group 3 had 5 cm (2 in).

To determine the center back seam slope, a finding by Cho (1993) applied for this study (buttocks angle/2 + 2.5° = center back seam slope). The industry pattern had rather vertical center back seam slope (10.4°) suitable for women with relatively flat buttocks. The proposed three patterns had more tilted slopes: group 2 (15.40°), group 1 (13.15°), and group 3 (12.80°) (Figure 4-5). For center front seam slope, drop value of front abdomen depth to front waist depth was applied. A method for developing the center front seam slope was not found in the literature, so the slopes were developed using my assumptions about how to provide good fit. Group 2 (0.4 cm, 0.14 in) and 3 (0.4 cm, 0.17 in) had almost flat abdomens, while group 1 had fuller abdomens (1.3 cm, 0.5 in). Therefore, center front seam slopes of group 2 and 3 were almost vertical to the hip line, while that of group 1 was tilted by 1.3 cm (0.5 in). Regarding back hip depth, group 2 was deeper (14.7 cm, 5.8 in) by about 1 cm (0.4 in) than the other groups [group 1: 14.0 cm (5.5 in) and group 3: 13.7 cm (5.4 in)], so the back crotch extension was made longer by this amount than the other groups. The three draft patterns are shown in Figure 4-5. The patterns were not expected to provide good fit at this stage, since they were made based on my hypothesized theoretical concepts. The main purpose of developing these draft patterns at this time was to reduce the number of fittings on fit models in stage 2.

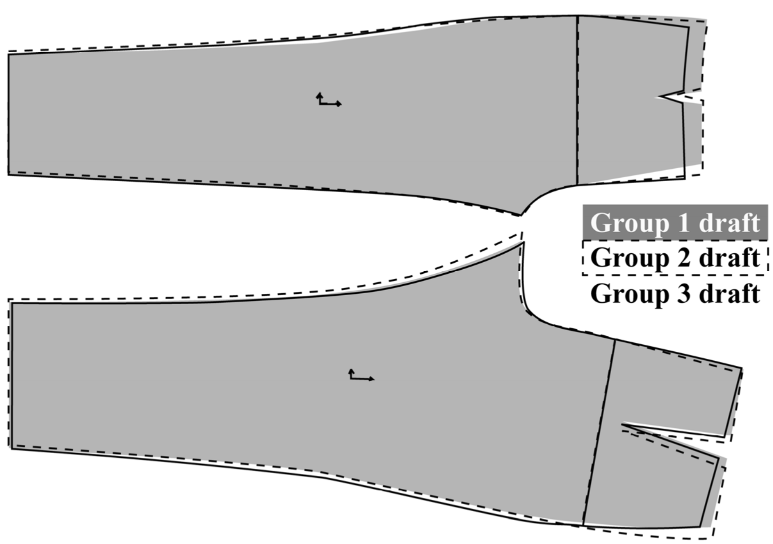


Figure 4-5. Proposed three draft patterns of group 1, 2, and 3.

Selecting Fit Models for Each Body Shape Group for Refinement, Fitting, and Comparison of the Base Patterns (for Stage 2)

Eighty three women with waist girths from 61.2 to 98.6 cm (24.1 to 38.8 in) and hip girths from 87.6 to 138.7 cm (34.5 to 54.6 in) were recruited for this stage of the study. As shown in Figure 4-6, two participants had greater than 48.6 in (90th percentile of SizeUSA data) hip girth, so they were not included in this study. As a first step three fit models for each body shape group were chosen from this group to refine the base pattern. In order to identify each participant's five variable scores (three PCs and two z-scores), their measurements were added into the original SizeUSA dataset, and the PCA and cluster analysis were re-performed. The discriminant analysis could be used to identify each person's body shape group, and to show their position within the group generally, but it did not provide information on her position in each variable. Therefore, PCA was necessary in order to find fit models that could represent their body shape group across the five variables.

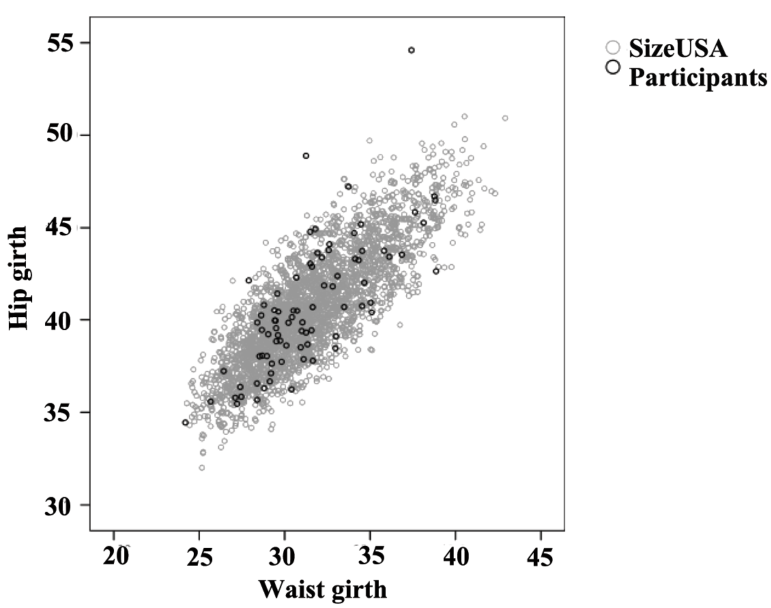


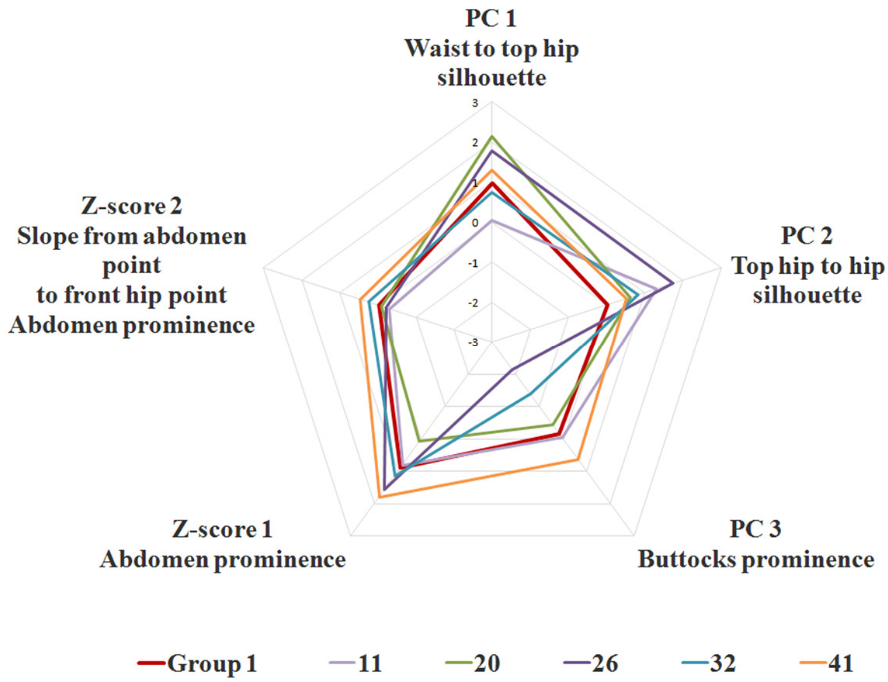
Figure 4-6. Distribution of waist and hip girth measurements of participants compared to 90th percentile SizeUSA.

From the cluster analysis, 26 participants (31.3%) were included in group 1, 18 participants (21.7%) in group 2, and 39 participants (47.0%) in group 3. In each group, all the participants' pentagonal graphs showing their five variable scores were plotted. Those participants, who had a hip girth measurement from 100.3 to 102.9 cm (39.5 to 40.5 in) and with five scores close to the median values of their group were first considered as candidates for fit models. However if there were not enough fit models who could represent their group across the five variables within this hip range, fit models were selected even if they had hip girth somewhat below 100.3 cm (39.5 in) or above 102.9 cm (40.5 in).

The pentagonal graphs of 19 best fit model candidates (based on their measurements) among 26 participants from group 1 are shown in Figure 4-7.

Among them, eight participants had hip girth measurements within the range of 100.3 to 102.9 cm (39.5 to 40.5 in): #11, #20, #26, #32, #41, #42, #50, and #52. Their graphs were compared with the graph of 'group 1' depicted by median values. It was impossible to find perfect fit models that had median values of the group 1 in all five variables. The main criteria of selection of fit models were PC3 (buttocks prominence), z-score 1 (abdomen prominence) and z-score 2 (slope from abdomen point to front hip point). The three variables were related to abdomen and hip size and shape which were critical elements to develop center front seam slope, center back seam slope and crotch extension. These locations in patterns are difficult to develop from measurements alone, so fittings on live fit models with median values of these three variables are preferred. On the other hand, PC1 (waist to hip silhouette) and PC2 (top hip to hip silhouette) were related to girth measurements, which could be relatively easily applied for pattern making.

Regarding PC3 (buttocks prominence), the scores of participants #26, #32, #41, #42, and #50 were located far away from the median values of group 1, so they were



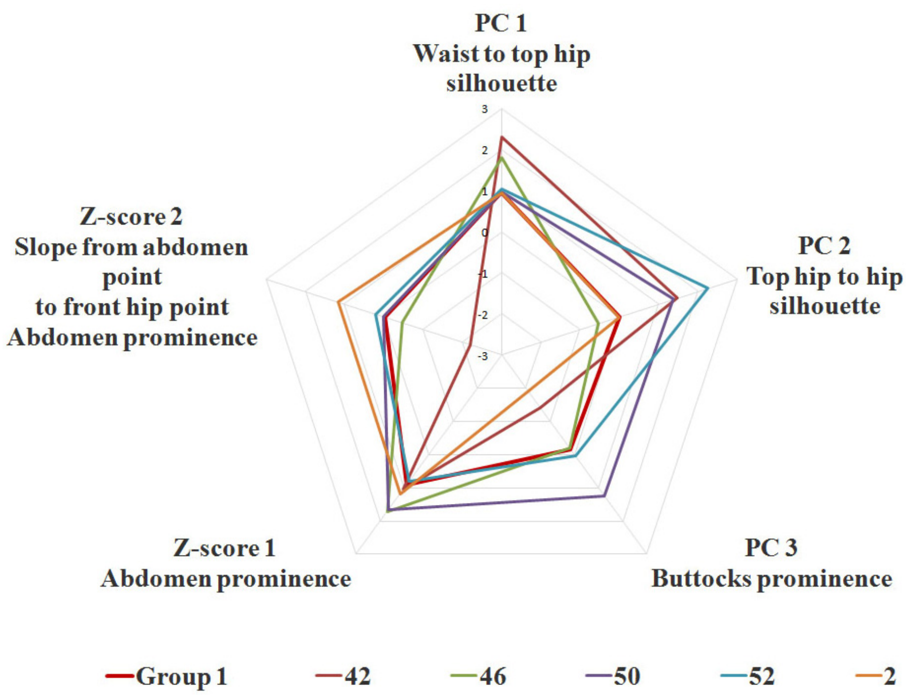
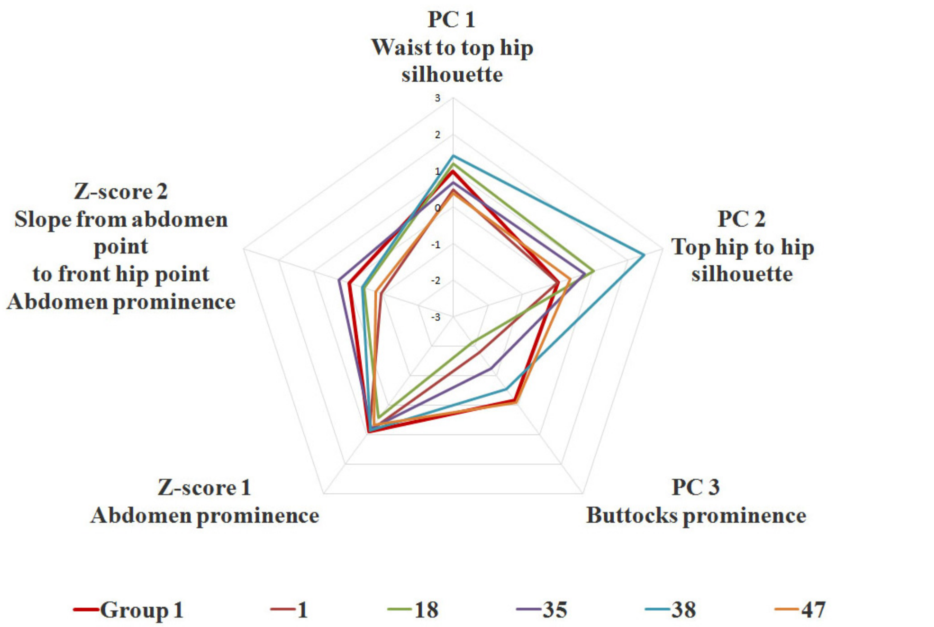
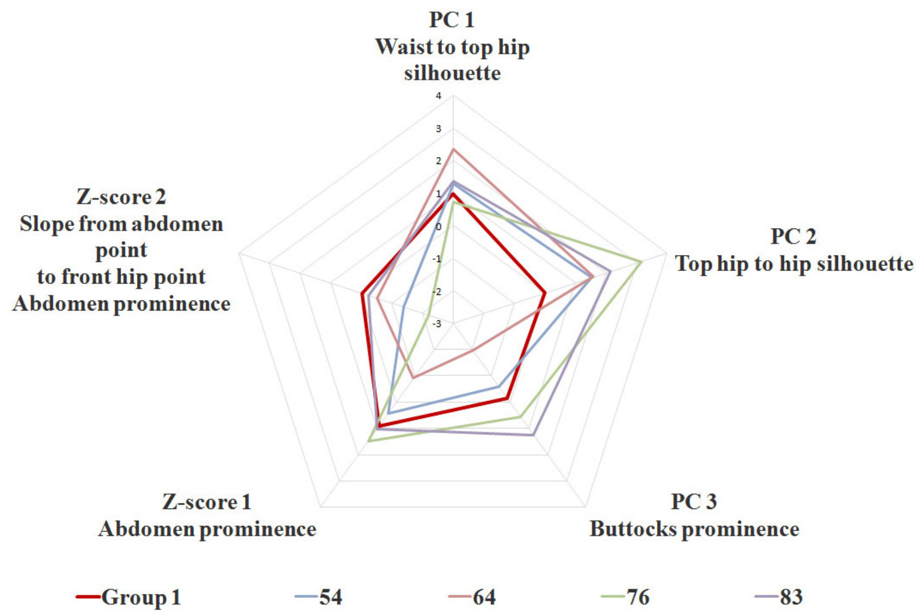


Figure 4-7. Pentagonal graphs of 19 fit model candidates among participants in group 1.

Figure 4-7 (Continued)





removed from the candidate list. #11 had almost median values in all three critical variables: PC3 (buttocks prominence), z-score 1 (abdomen prominence), and z-score 2 (slope from abdomen point to front hip point). She had a slightly smaller top hip girth than the median value, resulting in a smaller PC1 (waist to hip silhouette) score and a larger PC2 (top hip to hip silhouette) score. Increasing top hip girth in her pattern was relatively easy, so she became a fit model for group 1. #52 had also median values in four variables: PC1, PC3, z-score 1 and z-score 2, while PC2 (top hip to hip silhouette) score was larger than the median value, which means hip width is wider than the median value. This person was also determined as a fit model. The last fit model was selected between participant #20 and #46. For the values of PC1, PC2 and z-score 1, neither #20 nor #46 had scores which were very close to the median values by similar amounts. But #20 had almost median values in PC3 (buttocks prominence) and z-score 2 (slope from abdomen point to front hip point), while #46 had median value in only PC3 (buttocks prominence). Therefore #20 was selected as the last fit

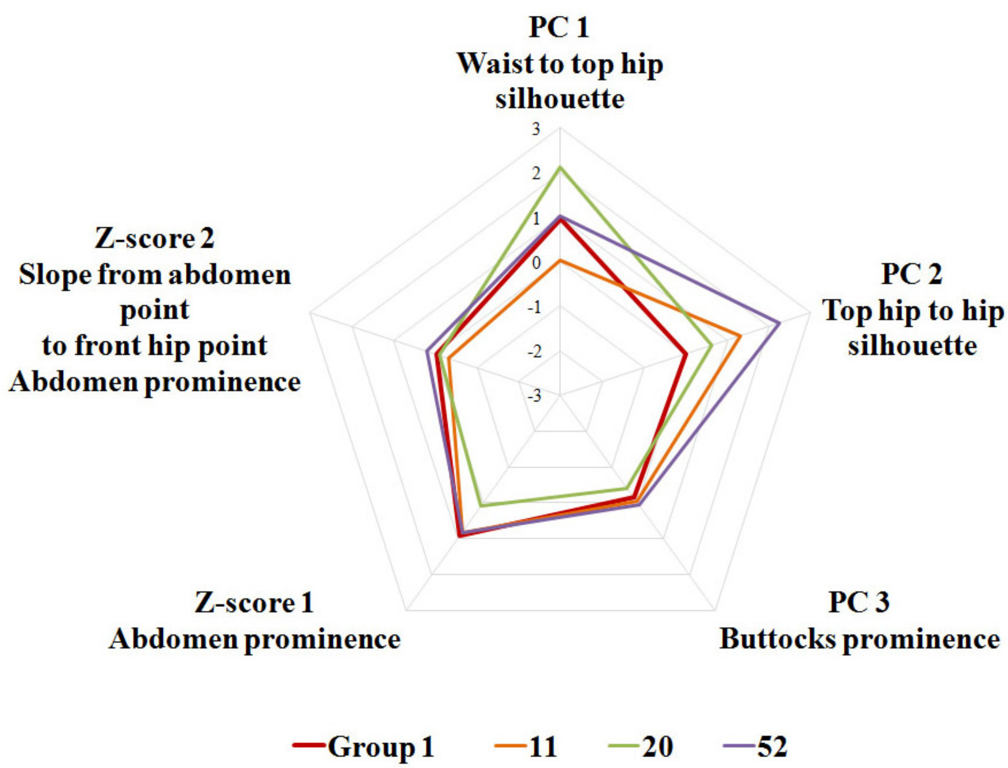


Figure 4-8. Pentagonal graph of fit models of body group 1.

model. From participants who had hip girth measurements below 100.3 cm (39.5 in) or above 102.9 cm (40.5 in), #38 and #47 could be fit models, but their hip measurements were much bigger than the size for this stage (#38 – 110.8 cm, 43.64 in, # 47 – 110.0 cm, 43.32 in). Therefore the three participants #11, #20 and #52 were chosen to be fit models for Group 1 (Figure 4-8). The most representative model was identified as #11, and additional fittings for final refinements to the pattern were conducted on this model.

Selecting fit models for group 2 was more difficult than for group 1, since only 18 participants were included in group 2. The primary characteristics of group 2 were a prominent buttocks shape and a tilted posture toward the back: the smallest z-score 2 (slope from abdomen point to front hip point) and the largest PC3 (buttocks prominence). Therefore these two variables were main criteria for selecting fit models for group 2.

Even though #8 and #66 had hip girth beyond the range for becoming fit models, they had median values in all three important variables for this group: PC3 (buttocks prominence), z-score 1 (abdomen prominence), and z-score 2 (slope from abdomen point to front hip point). Therefore they were chosen as group 2 fit models. Since these two fit models' hip sizes were 109.0 cm (42.9 in) and 96.5 cm (38.0 in), the last fit model was selected from the six participants who had hip girth measurements within the range of 100.3 to 102.9 cm (39.5 to 40.5 in): #12, #21, #58, #61, #65, and #72. #12 and #21 had extremely large score in z-score 2 (slope from abdomen point to front hip point), and #65 had much large score than the median value in PC3 (buttocks prominence). Therefore they were removed from the candidate list. From #58, #61 and #72, #72 was selected as the last fit model because she had median values in all of the important variables except for PC3 (buttocks prominence). The most representative fit model was determined to be #72, and fitting for final

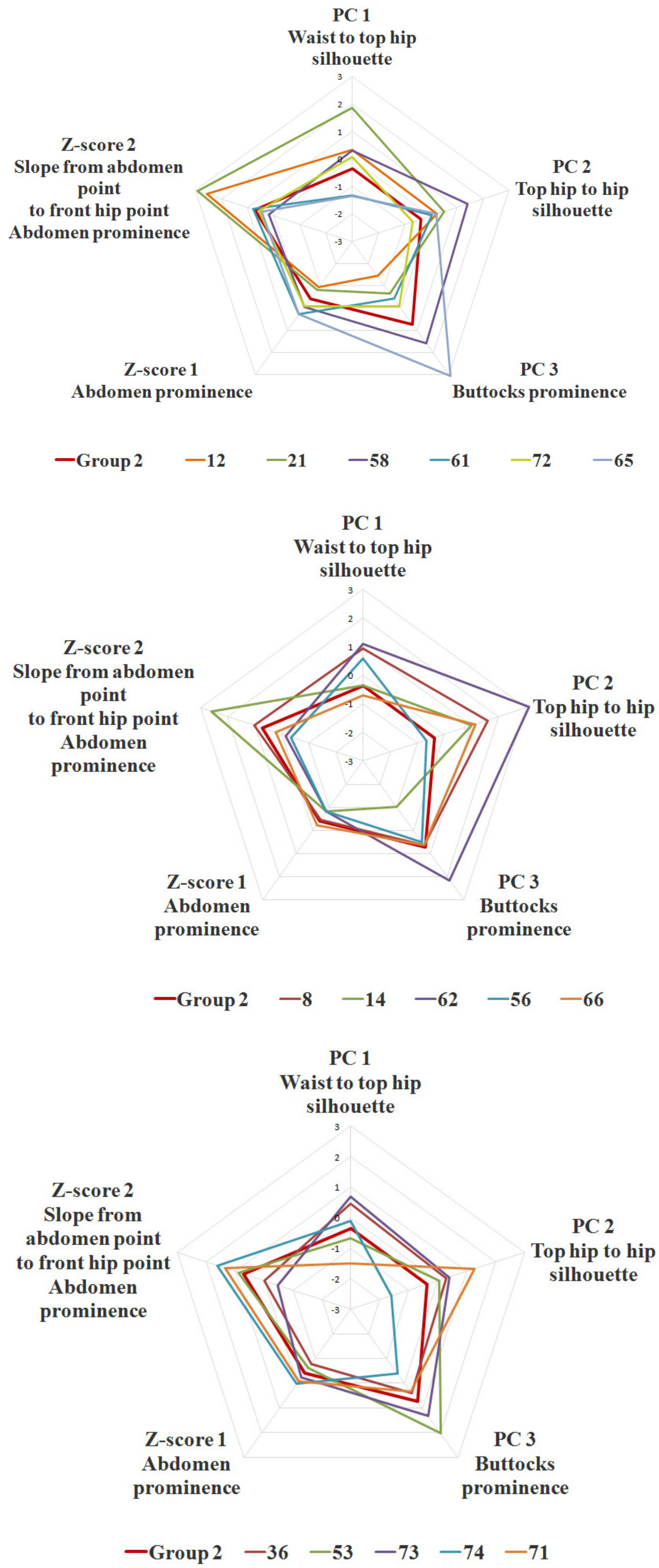


Figure 4-9. Pentagonal graphs of 16 fit model candidates among group 2 participants.

refinement of the pattern was conducted on this model. The three fit models' pentagonal graphs were shown in Figure 4-10.

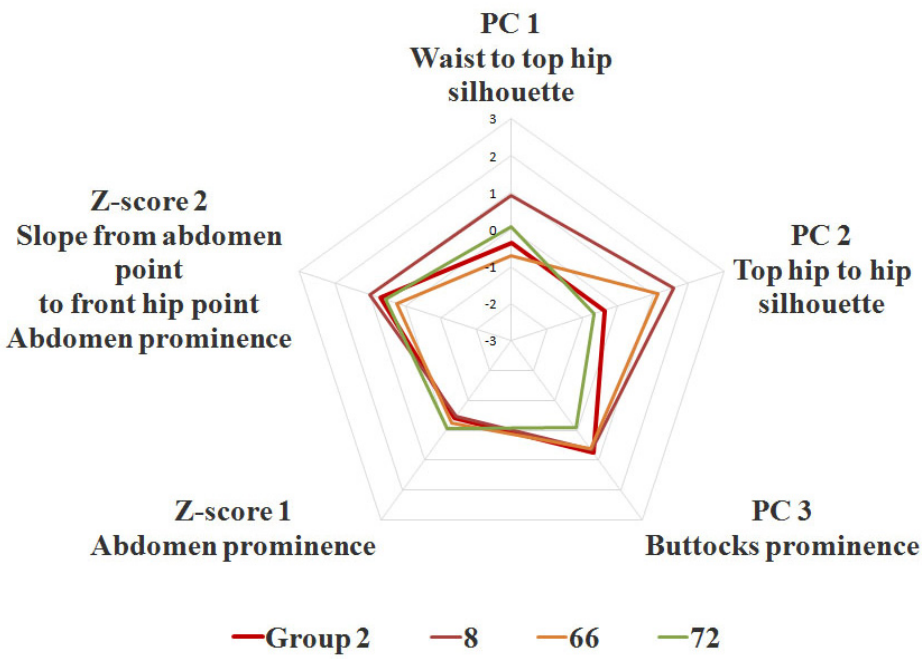
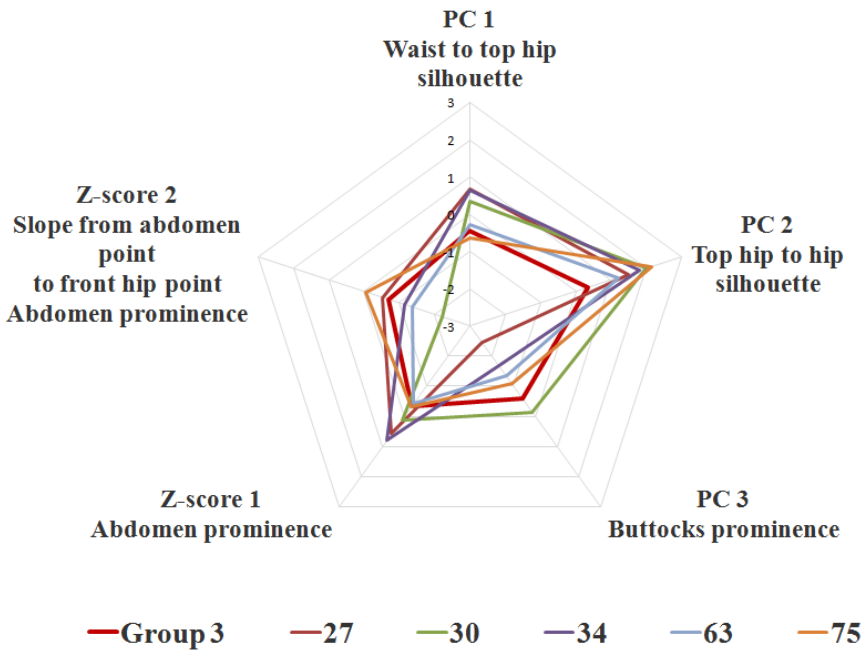


Figure 4-10. Pentagonal graphs of fit models of group 2.

In group 3, eight participants out of 39 participants had hip girth measurements within the range of 100.3 to 102.9 cm (39.5 to 40.5 in): #27, #30, #34, #45, #63, #75, #79, and #81. Like group 1, the main criteria of selection of fit models for group 3 were PC3 (buttocks prominence), z-score 1 (abdomen prominence) and z-score 2 (slope from abdomen point to front hip point). #27, #30, #34, and #81 had scores that varied greatly from one of these three variables. Even though #63 had values closer to the median, both her PC3 and z-score 2 were smaller than the median values. #79 had median values in all the three variables, so she was selected as the first fit model.



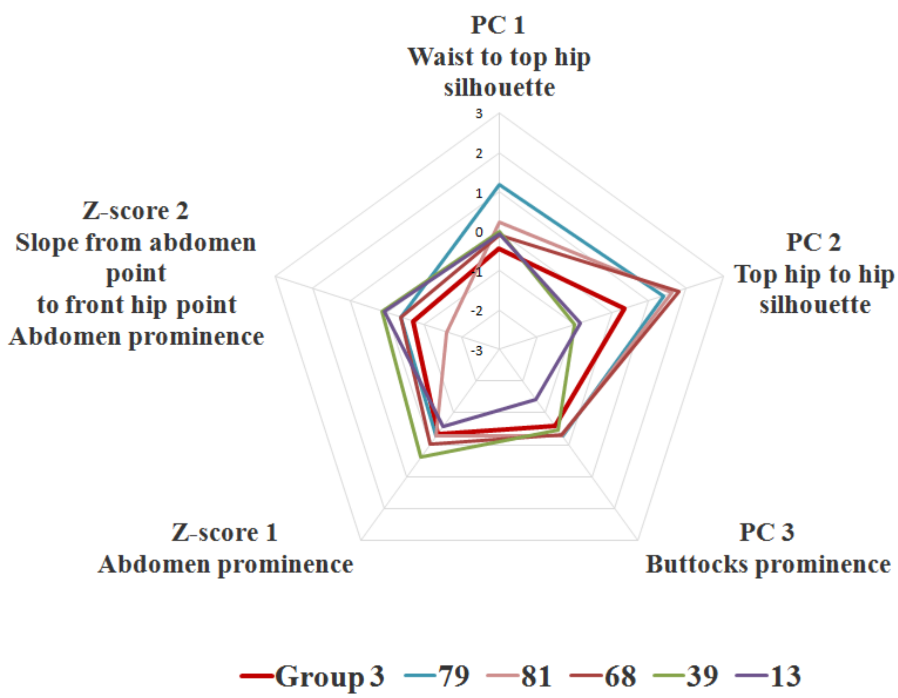
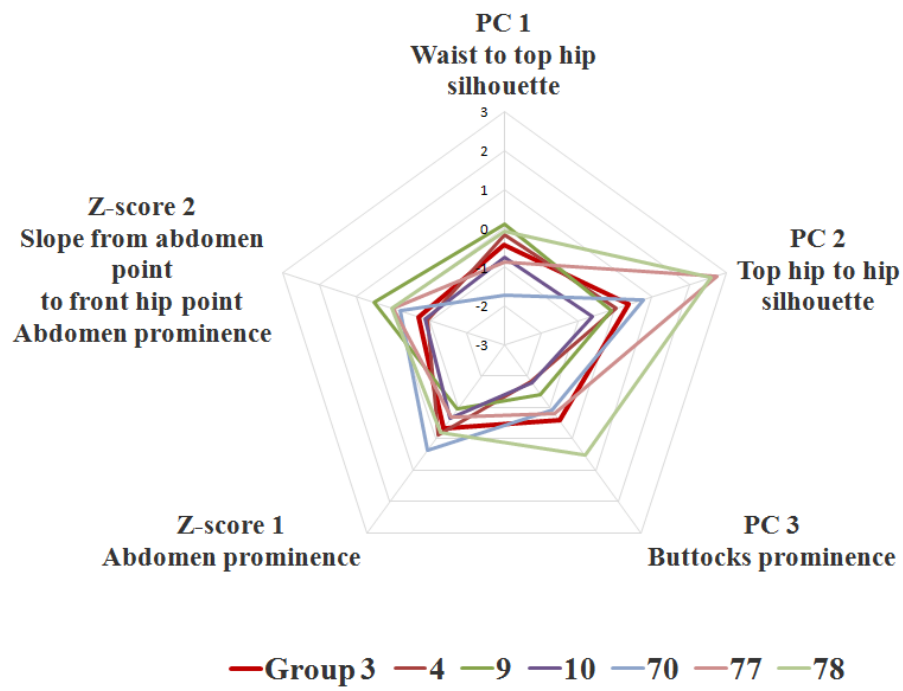
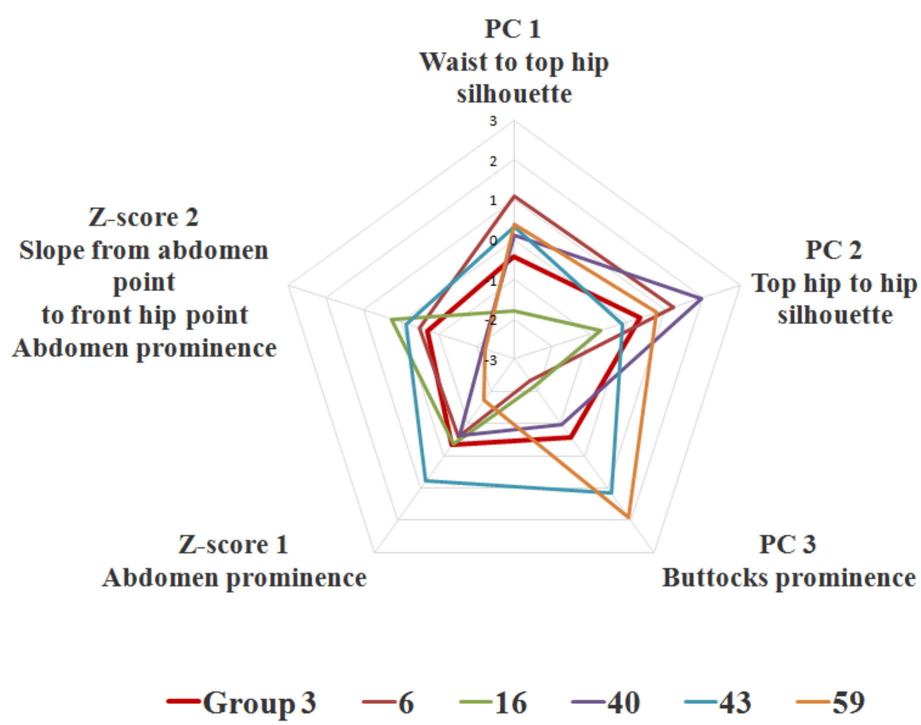


Figure 4-11. Pentagonal graphs of 21 participants who were candidates as fit models from group 3.

Figure 4-11 (Continued)





Since there were no more participants who could represent the three variables within the hip range of 100.3 cm (39.5 in) to 102.9 cm (40.5 in), the participants who had hip girth below 100.3 cm (39.5 in) or above 102.9 cm (40.5 in) were considered to select the other two fit models. #68 had median values in all three variables, so she was selected as the second fit model. For the last fit model, the rest of the participants were reexamined regardless of the hip size. #75 and # 77 were considered as candidates. Both #75 and #77 had similar patterns in their graphs: larger PC2, slightly smaller PC3, and larger z-score 2 than the median values. Therefore #75 was selected as the final fit model since she had 101.4 cm (40.3 in) hip girth which was closer to the base size (101.6 cm, 40.0 in), while #77 had 106.2 cm (41.8 in). The most representative model was determined as #79, and the additional fitting was conducted on this model. The three fit model's graphs were depicted in Figure 4-12.

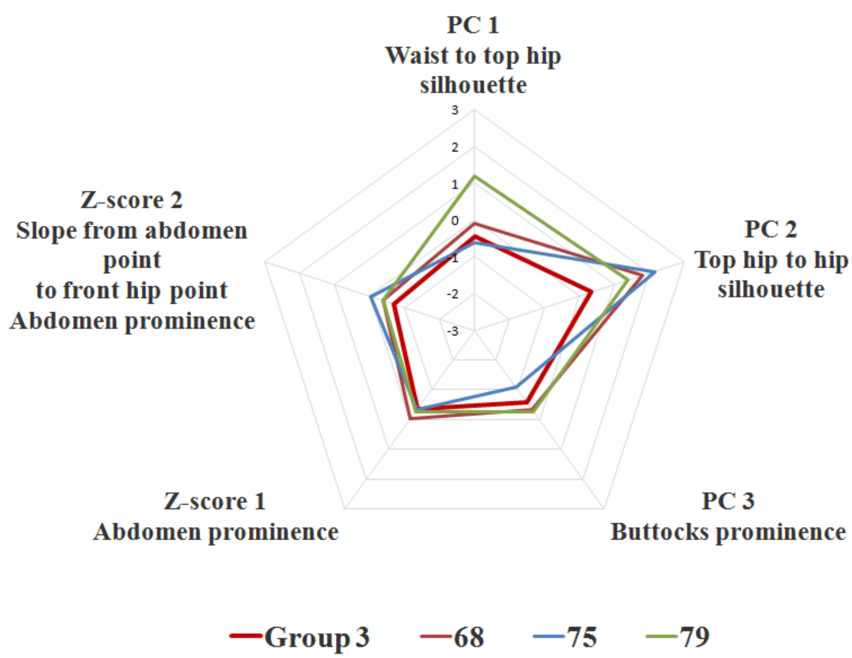


Figure 4-12. Fit Pentagonal graphs of fit models of group 3.

Fitting on Nine Fit Models

The three participants (fit models) in each body shape group were invited to come for fittings to develop the base pattern for their respective groups. A pair of custom-made pants was made for each participant by altering the draft of the pattern for their respective group to their individual body measurements, using the Gerber made to measure pattern system. After each fitting session, the areas that were altered during the fitting were transferred back to patterns using Pattern Design 8.3 of Gerber Scientific. The patterns were altered and plotted, and a new pair of custom pants with refined fit was sewn for the next fitting.

At the 1st fitting, common fit problems were found across the participants: hip circumferences were tight, hem circumferences were small, and inseam lengths were long (Figure 4-13). The reason for the tight fit at the hip and crotch areas was that the hip ease amount of the base prototype patterns had been decreased by 2.5 cm (1 in) based on results from the original test of the base pants (using my size) made in setting up the pilot made-to-measure system. The ease amount was probably decreased too much at that time. Since the participants' custom pants were altered and generated from these base patterns (with an incorrect hip ease amount), most of the participants' pants had tight fit at the hip area.

It was found that the style of the base prototype pants was much more tapered than the style that was originally intended for this study. The fabric used for this study was stiff and thick, so wrinkles appeared more visibly than thin or stretch fabrics if the style of the pants was tapered. The level of fit refinement to perfect this style in this fabric was beyond the scope of the study. Therefore, the style was changed to a straight silhouette from the abdomen and buttocks to the hem level (The 'Trouser style' described in Armstrong's patternmaking book, 2006). All except two of the participants' pants were a longer length than their leg length. The reason might be that the pants were made using the crotch height measurement taken from the 3D body scanner. The crotch area is a difficult measurement to derive automatically from a body scan as the cameras cannot catch this area. Therefore, the crotch height measurements were likely measured longer than the actual measurements. Therefore, for stage 3 of this study I took all crotch height measurements manually.

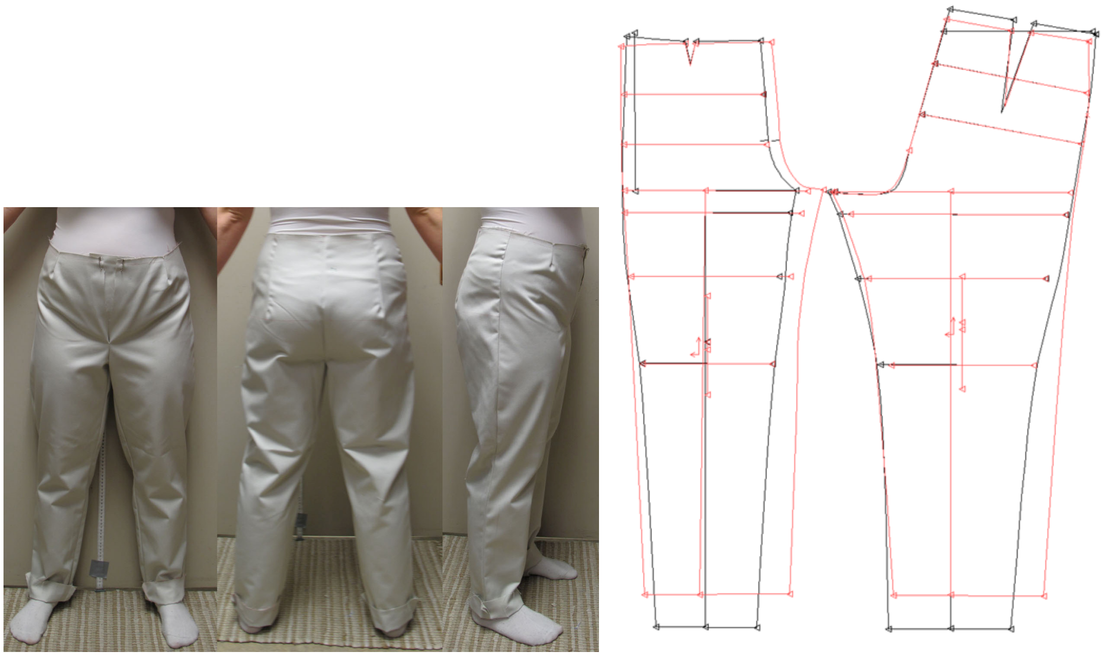


Figure 4-13. Common fit problems found at the 1st fitting (left), and the 1st patterns in black and the final patterns in red (right).

Three to five fittings were conducted for each participant. Since fitting pants perfectly is difficult, five fittings were sometimes not enough to refine the patterns. However it was not possible to invite the participants more than five times. Therefore in that case, any minor remaining changes from the 5th fitting were marked on the pants and transferred to the patterns in the Pattern Design 8.3 program. The final patterns were then created. Pictures taken at the final fitting are shown in Figure 4-14 to Figure 4-22. If there were additional corrections after the picture was taken at the final fitting, the areas that were altered are described in each caption.

Figure 4-14. #52 - group 1.

Figure 4-15. #11 (the final fit model) - group1. The front dart was moved to a point midway between the center front and the side. The side seam was moved toward the front by 1.3 cm (0.5 in). The back dart length was shortened by 1.3 cm (0.5 in). The back crotch extension was increased by 0.6 cm (0.25 in). The inseam was shortened by 0.6 cm (0.25 in).

Figure 4-16. #20 - group 1. The side seam was moved toward the front by 0.6 cm (0.25 in). The back crotch extension was increased by 1.3 cm (0.5 in).

Figure 4-17. #72 (the final fit model) - group 2.

Figure 4-18. #66 - group 2. The back crotch extension was increased by 1.3 cm (0.5 in), and the crotch curve was scooped toward the outside.

Figure 4-19. #8 - group 2. The front crotch extension was increased by 1.3 cm (0.5 in).

Figure 4-20. #79 (the final fit model) - group 3. The inseam length was shortened by 0.6 cm (0.25 in). The side seam was moved toward the back by 0.6 cm (0.25 in).

Figure 4-21. #68 - group 3. The front crotch length was extended by 2.5 cm (1 in).

Figure 4-22. #75 - group 3. The inseam length was decreased by 1.3 cm (0.5 in).

Comparison of Patterns and Finalizing the Block Patterns

For development of the block pattern for group 1, patterns for participants #11, #20, and #52 were compared. Participant #11 had a smaller top hip, #20 had a smaller waist and abdomen, and #52 had a smaller waist and top hip than the median measurements of group 1 (see the pentagonal graphs in Figure 4-23). Their measurements critical to pattern comparisons are shown in Table 4-14. Drop of front top hip girth to front waist girth, and drop of front hip girth to front waist girth, which were retained in PC1, are related to center front seam slope. #11 had the smallest drops, resulting in the most vertical center seam slope. Drop of front abdomen depth to front hip depth (z-score 2) is also related to center front seam slope. Even though the differences among the fit models were small, #11 had the smallest drop, resulting in the least slope, while #52 had the largest drop and the most tilted slope. Drop of front abdomen depth to front waist depth (z-score 1) was related to front dart amount.

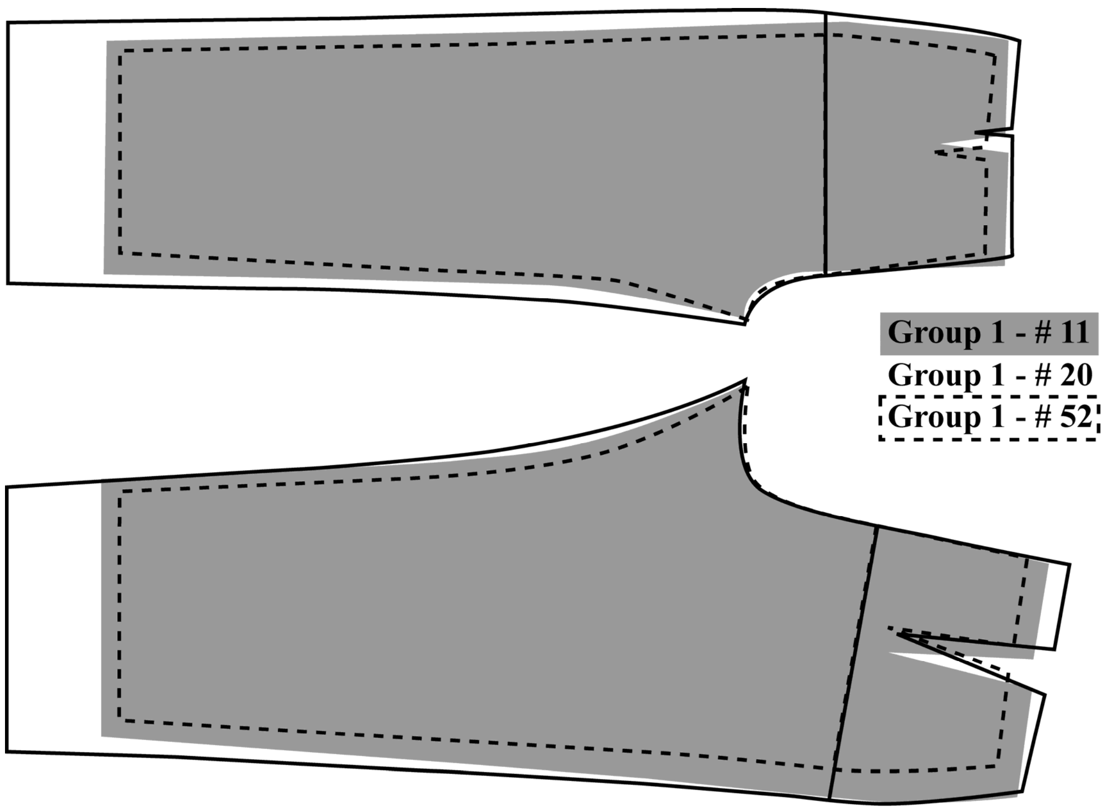


Figure 4-23. Group 1 - fit models' patterns.

Table 4-14. Group 1 - fit models' measurements critical to pattern comparisons.

		#11 – fit model (small Th)	#20 (small W & Ab)	#52 (small W & Th)	Note
	Hip girth	40.23	**41.27**	39.38	
PC1	Front girth: th – w	**2.00**	3.73	2.68	- CF seam angle (#11 was the most vertical)
	Front girth: h – w	**3.51**	5.59	5.46	
PC3	Buttocks angle	21.72	20.0	**22.35**	- CB seam angle (#52 was the most tilted)
Z 1	Front depth: ab – w	0.54	**0.29**	0.54	- Front dart amount (#20 was the smallest dart)
Z2	Front depth: ab – h	0.87	0.97	1.10	- Relatively related to CF seam slope (#52 was the most tilted)
	Max-thigh girth	24.05	25.37	22.30	

#20 had the smallest abdomen prominence, so the dart amount was the smallest. Her front dart length was the shortest since she had larger front top hip girth in proportion to waist and hip than the other fit models. Since the side seams of the three fit models were parallel at top hip level, shortening the dart length was an effective way to increase top hip girth circumference, rather than by moving the side seam out. The center back seam slopes of the three fit models were similar since their buttocks angles were similar.

Overall, #11 had scores close to median values across the five variables, so her pattern was considered as a standard to compare with the other fit models' patterns. #11 and #52 had similar body size and lower body shapes with similar patterns in the pentagonal graph. Regarding body size, the main differences between the two fit models were that #11 had larger waist and hip girths than #52. Figure 4-24 shows where pattern pieces were changed when waist and hip girths increased in group 1.

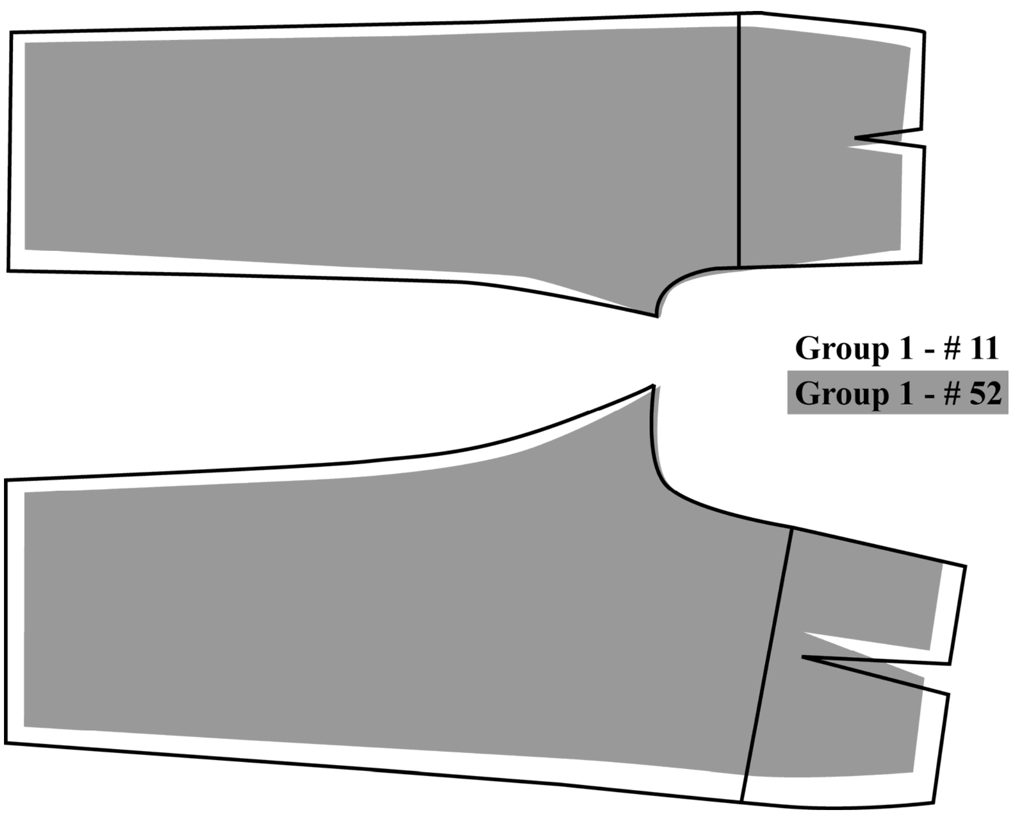


Figure 4-24. Group 1 - comparison of #11 and #52 patterns.

When the waist girth decreased, the front waist point and side waist point in the front pattern, and the side point in the back pattern were moved. In terms of body group, #11 had a more prominent abdomen, and smaller drop of front top hip girth to waist girth than #52, resulting in a smaller and longer front dart. This information was helpful to alter `#11's pattern to refine and finalize the block pattern for group 1.

To create the final block pattern, #11's measurements at waist girth, top hip girth, hip girth, max-thigh girth, waist to crotch length, crotch height, and buttocks angle were compared with the median values of the group 1 (Table 4-15). Rather than altering #11's pattern to meet the median values of the group 1 in all areas, the pattern shape was not altered especially from hip to thigh level to prevent distortion of the silhouette or of the pattern proportions. #11's hip girth (40.23 in) and thigh girth (24.05 in) were not much different from the median values (hip: 39.98 in and thigh: 23.50 in), so the two girth measurements in the pattern were not changed. However, #11 had much smaller waist and top hip girths than the median values, so it was necessary to alter her pattern to meet sizes of an imaginary fit model with hip girth of 40.23 in. By adding the difference between #11's hip girth and the median hip girth of group 1 (40.23 – 39.98 = 0.25 in) to the median waist girth measurement (30.71 in), a new waist girth measurement (37.75 in) was calculated for a perfect fit model with hip girth measurement 40.23 in. Using the same calculation method, a new top hip girth was determined to be 37.75 in. The differences between the new measurements and #11's measurements at the waist and top hip were calculated, and they were applied to change #11's pattern (Table 4-15 and Figure 4-25).

Regarding the length measurements, crotch to waist length measurement in #11's pattern was kept since changing the waist location influenced the front dart amount and length. However, when the inseam length was changed, the hem location only was changed and the proportion of the pattern was not distorted. Therefore, the

Table 4-15. Mean, fit model, and new fit model's measurements of Group 1.

	Median of group 1	#11	New fit model	Alteration amounts (new fit model – #11)	
Waist girth	30.71	32.04	**30.96 (30.71+0.25)**	- 1.08	Decreased at center front point and back side point.
Top hip girth	37.5	35.64	**37.75 (37.5+0.25)**	+ 2.11	The dart length was shortened to increase top hip girth.
Hip girth	39.98	**40.23**	40.23 (39.98+0.25)	0	
Thigh girth (max)	23.50	**24.05**	24.05	0	
Waist to crotch length	10.54	**10.88**	10.88	0	
Crotch height	**29.4**	27.70	29.4	+ 1.7	
Hip angle	**21.3**	21.7	21.3	0°	

Note: A new fit model's measurements were determined as [#11 (fit model)'s measurement + difference between #11's hip girth and median hip girth of group 1].

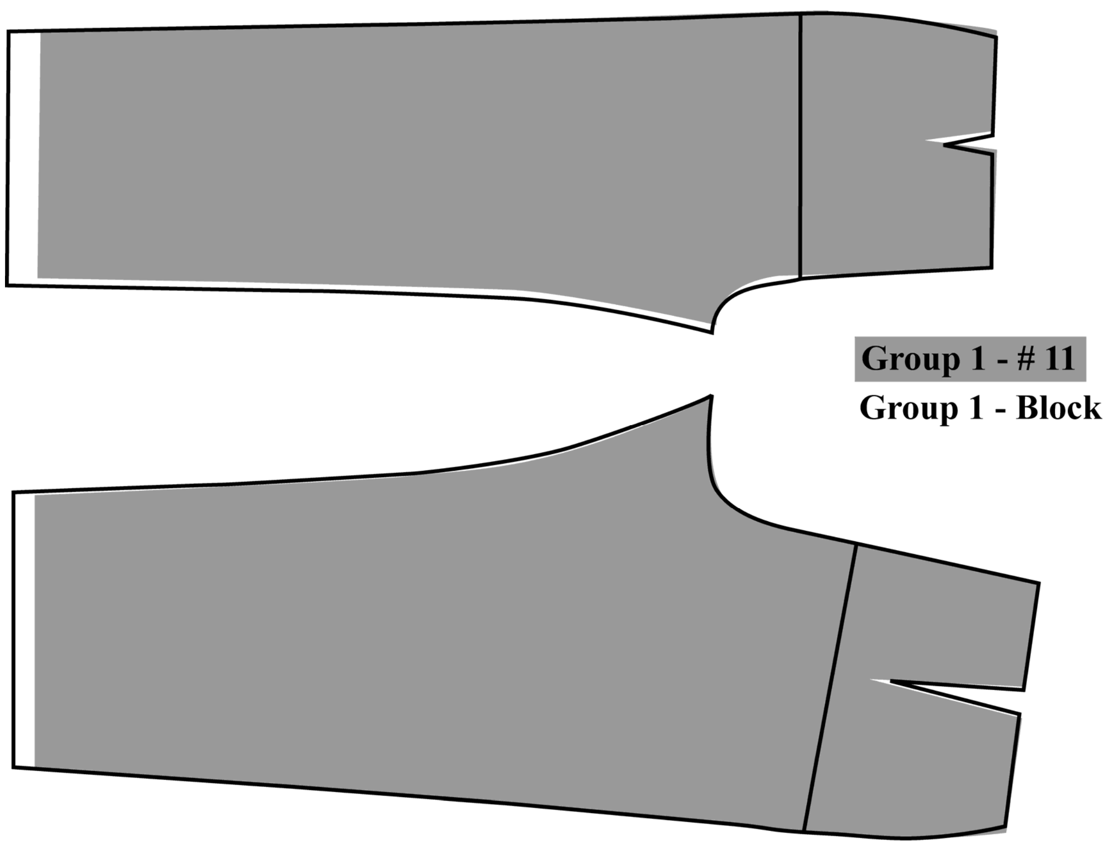


Figure 4-25. #11's pattern and block pattern for group 1.

inseam length of the #11's pattern was increased to meet the median value (29.4 in). For development of the block pattern for group 2, participant #8, #66, and #72's patterns were compared. It was found that #8 had smaller waist and top hip (much smaller waist in proportion to top hip), #66 had smaller top hip, and #72 had smaller buttocks than the median person of the group 2 (see pentagonal graphs in Figure 4-26). Their measurements critical to pattern comparisons are presented in Table 4-16. Drop of front top hip girth to front waist girth, and drop of front hip girth to front waist girth, which were retained in PC1, is related to center front seam slope. #8 had the largest drops, resulting in the most tilted slope. Drop of front abdomen depth to front hip depth (z-score 2) is also related to center front seam slope. Even though the differences among the fit models were small, #8 had the largest drop, showing the most tilted slope. Drops of front abdomen depth to front waist depth (z-score 1) were similar among fit models. In group 1, this drop is related to front dart amount, but in group 2 drop of front top hip girth to front waist girth is related to front dart amount. #66 had the smallest difference between front top hip girth to front waist girth, so the dart amount was the smallest. The center back seam slope for #66 was the most tilted since she had the largest buttocks angle (28.61°) compared to #8 at 25.86° and #72 at 22.64°.

Overall, #72 had scores closest to median values except for PC3 (buttocks prominence), so her pattern was considered as the standard to compare with the other fit models' patterns. Participant #72's pattern was compared with that of #66, since #66 had median values in four variables while #8 had median values in three variables (see the pentagonal graphs in Figure 4-26). The difference between the two fit models was that #66 had larger drop of hip girth to waist girth than #72. Figure 4-27 showed where pattern pieces were changed as waist and hip girths increased in group 2. When the waist girth decreased, the front waist point and side waist point in the front pattern,

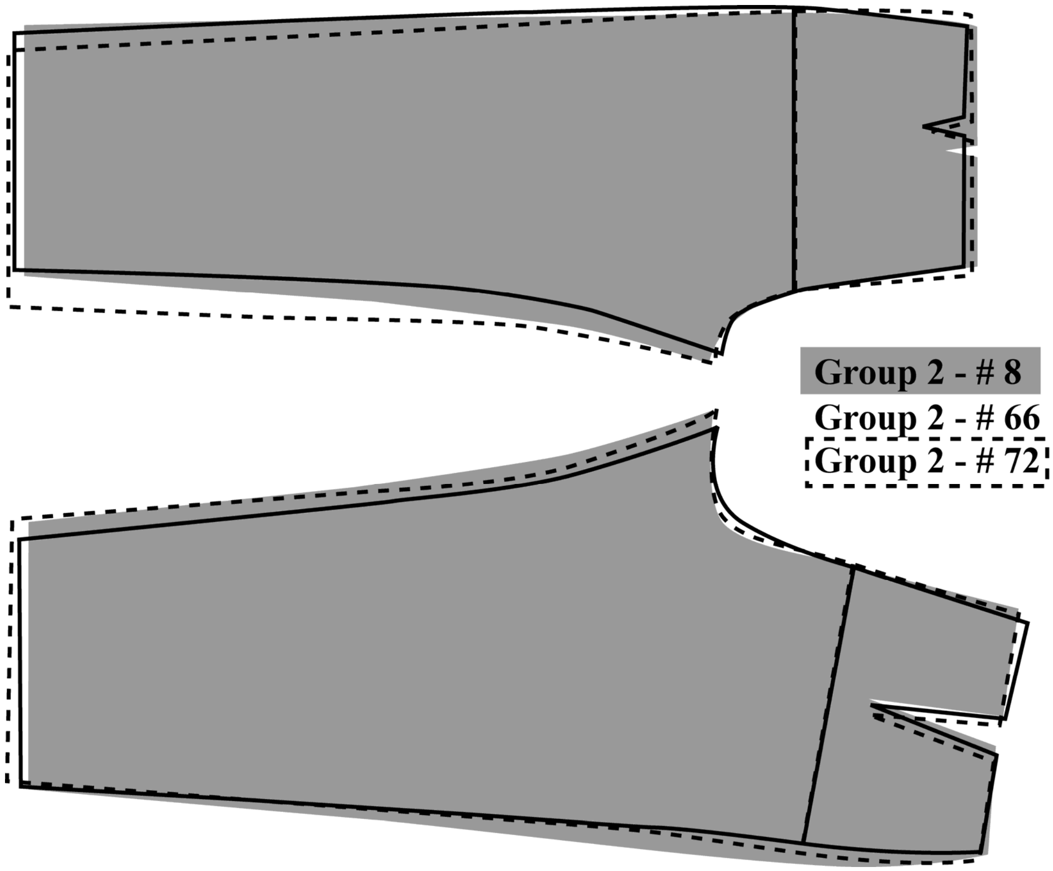


Figure 4-26. Group 2 - fit models' patterns.

Table 4-16. Group 2 - fit models' measurements critical to pattern comparisons.

		#8 (small w & th)	#66 (small th)	#72 – fit model (small buttocks)	Note
	Hip girth	42.9	38.04	40.98	
PC1	Front girth: th – w	**1.98**	0.93	1.44	**- CF seam angle (#8 is the most tilted.)**
	Front girth: h – w	**4.48**	3.51	2.53	
PC3	Buttocks angle	25.86	**28.61**	22.64	**- CB seam angle (#66 is the most tilted.)**
Z 1	Front depth: ab – w	**0.10**	0.18	0.24	**- Front dart amount (#8 is the smallest.)**
Z2	Front depth: ab – h	**2.03**	1.01	1.42	**- CF seam angle (#8 is the most tilted.)**
	Max-thigh girth	26.01	**23.08**	25.62	

and the side point in the back pattern were moved. The second difference between the two fit models was the degree of buttocks prominence. #72 had less prominence than the median person, while #66 had a representative buttocks prominence for group 2. #66's center back seam slope was more tilted than #72, and so her center back seam slope was used as a guide when #66's pattern was altered to finalize the block pattern for group 2.

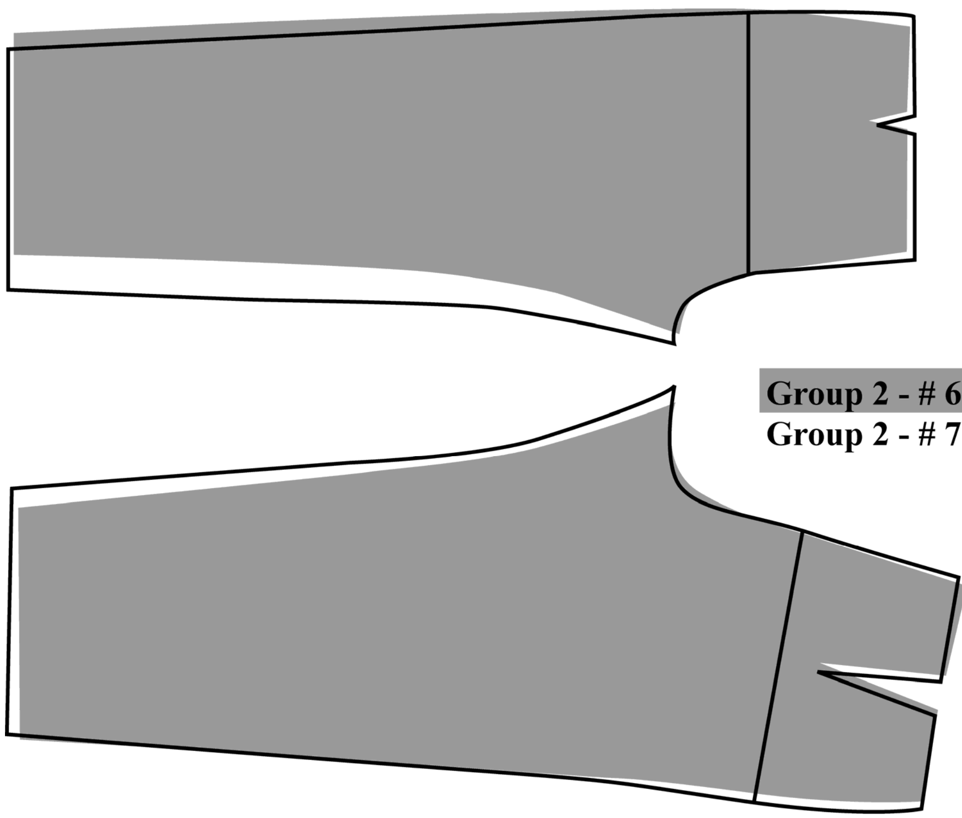


Figure 4-27. Group 2 - comparisons of patterns of #66 and #72.

To create the final block pattern, #72's measurements at waist girth, top hip girth, hip girth, max-thigh girth, waist to crotch length, crotch height, and buttocks angle were compared with the median values of the group 1 (Table 4-17). Rather than altering #72's pattern to meet the median values of the group 1 in all areas, her pattern shape was kept as much as possible especially from hip to thigh level to prevent distortion of the silhouette or proportion of the pattern. Therefore the thigh girth and hip girth measurements in the pattern were not changed. However, #72 had larger waist and top hip girths than the median values, so it was necessary to alter her pattern to meet sizes of an imaginary fit model with hip girth 40.98 in. By adding the difference between #72's hip girth and median hip girth of group 2 (40.98 – 40.11 = 0.87 in) to median waist girth measurement (32.13 in), a new waist girth measurement (32.97 in) was calculated for a perfect fit model with hip girth 40.98 in. Using the same calculation method, a new top hip girth measurement was determined as 38.8 in. The differences between the new measurements and #72's measurements at the waist and top hip were calculated, and they were applied to change #72's pattern (Table 4-17 and Figure 4-28).

Regarding length measurements, the crotch to waist length measurement in #72's pattern was kept since changing the waist location influenced the front dart amount and length. However, changing the inseam length only affects, the hem location and the proportion of the patterns is not distorted. Therefore, the inseam length of #72's pattern was increased to meet the median value (29.3 in).

Table 4-17. Mean, fit model, and new fit model's measurements of group 2.

	Median of group 2	#72	New fit model	Alteration amounts (new fit model – #72)	
Waist girth	32.13	34.68	**32.97 (32.13+0.87)**	-1.71	Decreased at center front point and back side point.
Top hip girth	37.93	39.02	**38.8 (37.93+0.87)**	- 0.22	The dart length was shortened to increase top hip girth.
Hip girth	40.11	**40.98**	40.98	0	
Thigh girth (max)	23.89	**25.63**	25.63	0	
Waist to crotch length	10.38	**10.32**	10.32	0	
Crotch height	**29.3**	29.0	**29.3**	+ 0.3	
Hip angle	**25.8**	22.64	25.8	+ 2.36°	

Note: A new fit model's measurements were determined as [#72 (fit model)'s measurement + difference between #72's hip girth and median hip girth of group 2].

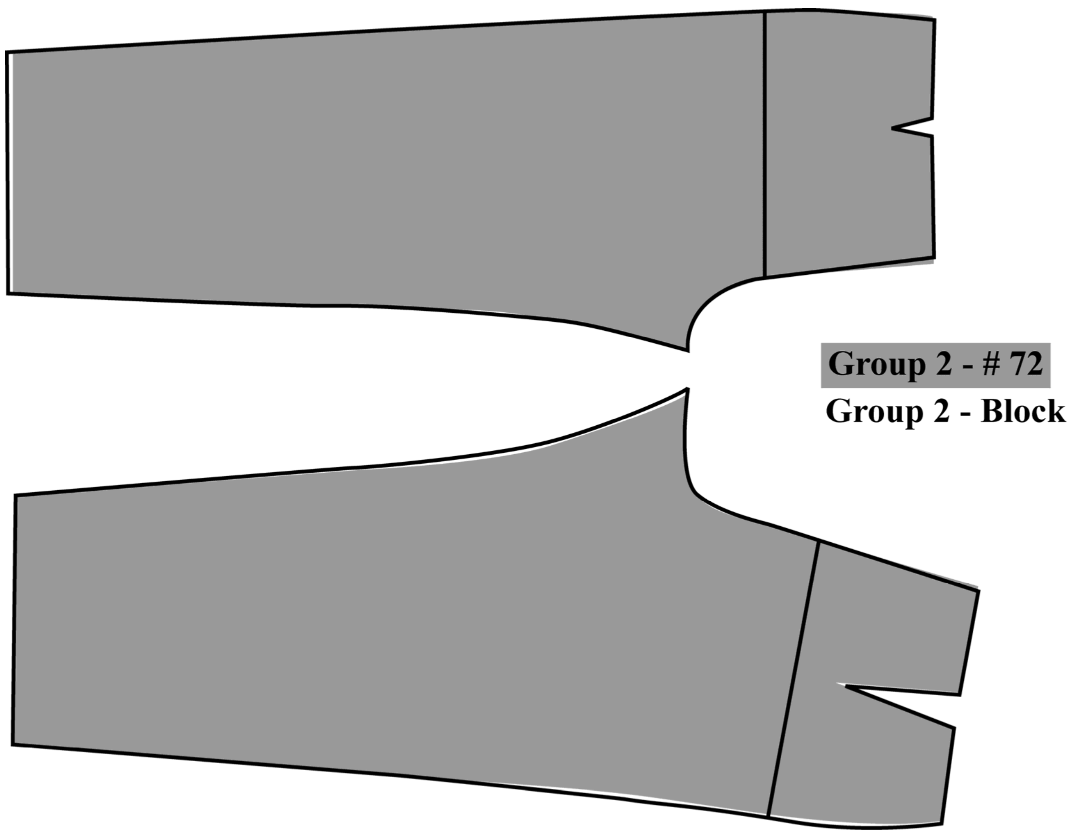


Figure 4-28. #72’s pattern and block pattern of group 2.

For development of the block pattern for group 3, patterns for participant #68, #75, and #79’s were compared. It was found that #68 had a flatter abdomen, #75 had smaller top hip, and #79 had smaller waist and top hip (smaller waist in proportion to top hip) than the median person of the group 3 (see the pentagonal graphs in Figure 4-29). Their measurements critical to pattern comparisons are shown in Table 4-18. Drop of front top hip girth to front waist girth, and drop of front hip girth to front waist girth, which were retained in PC1, are related to center front seam slope. #68 had the smallest drop, resulting in the most vertical center seam slope. However, even though #79 had the largest drop, she also had a vertical center seam slope. In group 3, an adjustment to change the waist girth was more effective when applied to the side seam, rather than in the center front seam (Figure 4-30). Drop of front abdomen depth

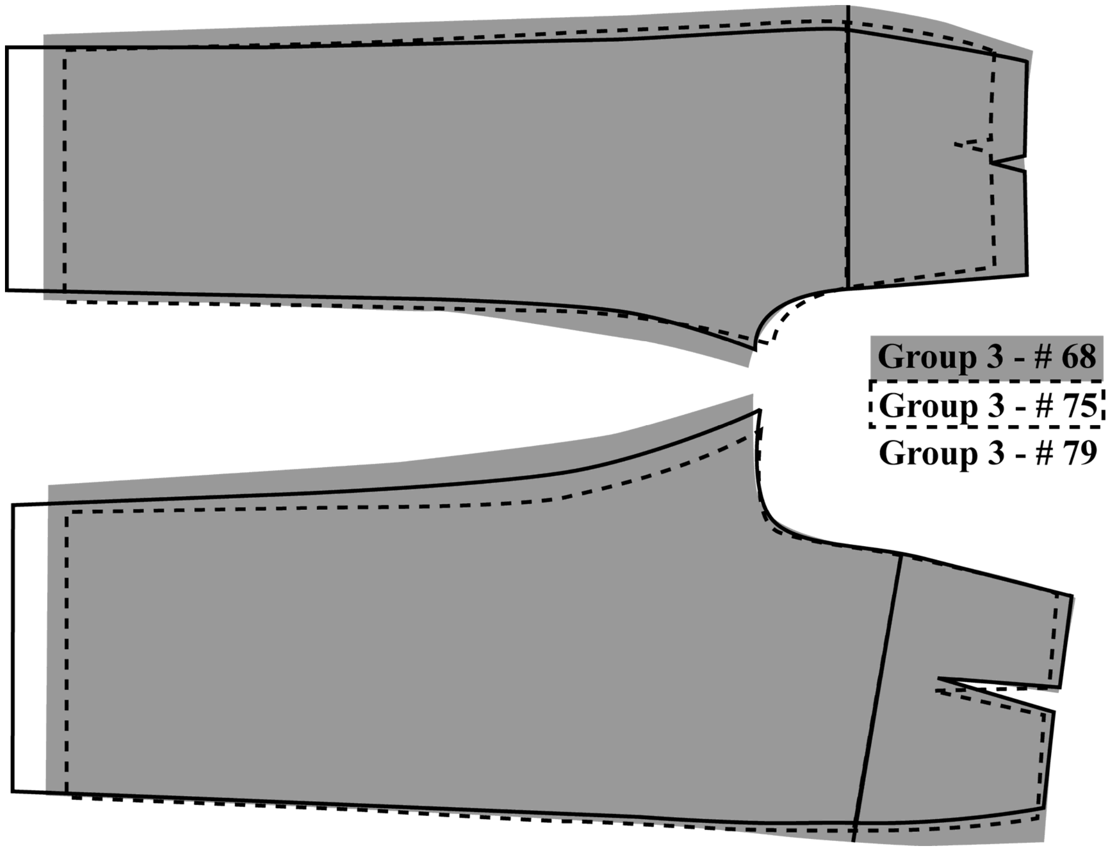


Figure 4-29. Group 3 - fit models' patterns.

Table 4-18. Group 3 - fit models' measurements critical to pattern comparisons.

		#68 (no abdomen)	#75 (small th)	#79 - fit model (small w & th)	Note
	Hip girth	42.95	40.34	40.83	
PC1	Front girth: th – w	1.67	1.08	**2.90**	- CF seam angle (#79 is the most tilted.)
	Front girth: h – w	3.74	4.08	**5.25**	
PC3	Buttocks angle	19.90	20.29	22.52	
Z 1	Front depth: ab – w	**-0.10**	0.15	0.17	- Front dart amount (#68 had no dart.)
Z2	Front depth: ab – h	**0.00**	0.99	0.84	- CF seam angle (#68 is the most vertical.)
	Max-thigh girth	25.91	24.56	23.98	

to front hip depth (z-score 2) is also related to center front seam slope. Even though the differences among the fit models were small, #68 had the smallest drop, resulting in the most vertical center front slope, especially in the area at hip and crotch level.

Drop of front abdomen depth to front waist depth (z-score 1) was related to the front dart amount. #68 had no abdomen prominence (-0.1), so the dart amount was zero. The center back seam slopes of the three fit models were similar since their buttock angles were relatively the same.

#79 was selected as the final fit model, so her pattern was considered as a standard to compare with the other fit models' patterns. Since #75 and #79 had similar waist and hip girth, #68 (hip girth: 42.95 in) and #79 (hip girth: 40.83) were compared each other to identify where patterns were changed as the waist and hip sizes increase or decrease (Figure 4-30). #68 had a flat abdomen (z score 1 = -.01), so instead of a front dart her pattern sloped in the side seam from waist to hip. The side waist point in the front pattern, and the side point in the back pattern were moved when the waist girth decreased.

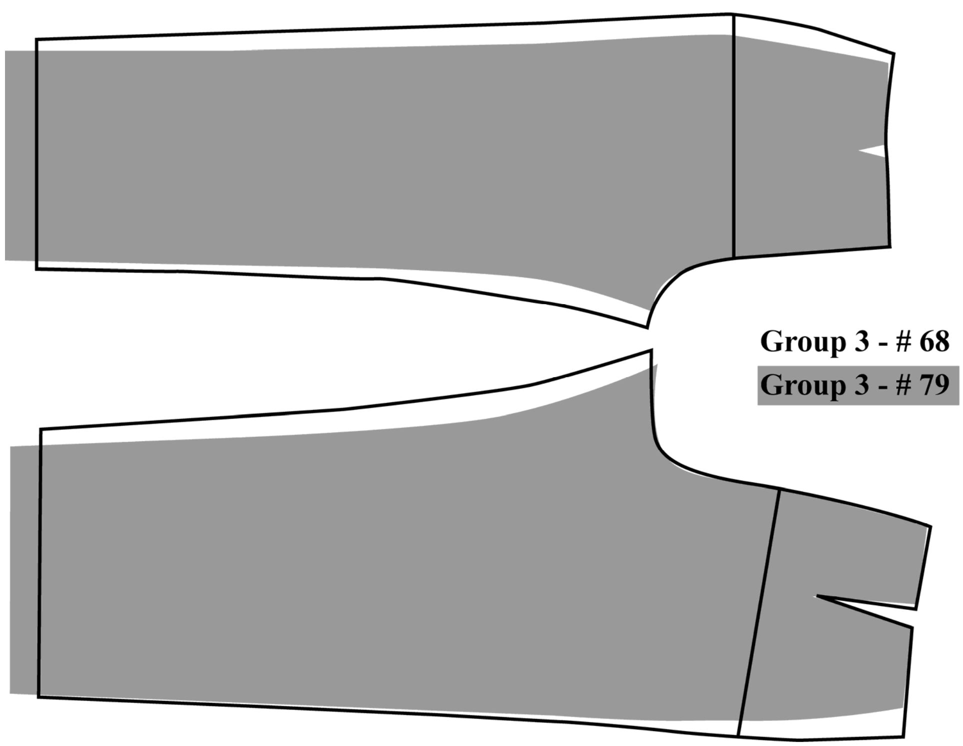


Figure 4-30. Group 3 - comparison of patterns for #68 and #79.

To create the final block pattern, #79's measurements at waist girth, top hip girth, hip girth, max-thigh girth, waist to crotch length, crotch height, and buttocks angle were compared with the median values for group 3. Rather than altering #79's pattern to meet the median values of the group 3 in all areas, her pattern was kept unchanged as much as possible especially from hip to thigh level to prevent distortion of the silhouette or proportions of the pattern. Two of the girth measurements in the pattern were not changed. However, #79 had much smaller waist and top hip girths than the median values, so it was necessary to alter her pattern to meet sizes of an imaginary fit model with a hip girth of 40.83 in. By adding the difference between #79's hip girth and the median hip girth (40.83 – 40.00 = 0.83 in) to median waist girth of group 3 (29.85 in), a new waist girth measurement (32.86 in) was calculated for a perfect fit model with hip girth 40.83 in. Using the same calculation method, the new top hip girth was determined to be 38.8 in. The differences between the new measurements and #79's measurements at the waist and top hip were calculated, and changes to #79's pattern were made in these areas (Table 4-19 and Figure 4-31). The slope of the center back seam was slightly decreased (22.52-20.62 + 2.5°).

Table 4-19. Mean, fit model, and new fit model's measurements of group 3.

	Median of group 3	#79	New fit model	Alteration amounts (new fit model – #79)	
Waist girth	32.03	29.85	**32.86 (32.03+0.83)**	+ 3.01	Decreased at front side point and back side point.
Top hip girth	37.33	36.47	**38.8 (37.33+0.83)**	+ 1.69	
Hip girth	40.00	**40.83**	40.83		
Thigh girth (max)	23.77	**24.00**	24.00		
Waist to crotch length	9.77	**10.34**	10.34		
Crotch height	**29.6**	32.2	**29.6**	-2.6	
Hip angle	**20.6**	22.52	20.6	-1.92	

Note: A new fit model's measurements were determined as [#79 (fit model)'s measurement + difference between #79's hip girth and median hip girth of group 3].

Regarding the length measurements, the crotch to waist length measurement in #79's pattern was kept since changing the waist location influenced the front dart amount and length. However, changing the inseam length did not affect the proportion of the pattern. Therefore, the inseam length of #79's pattern was increased to meet the median value (29.6 in).

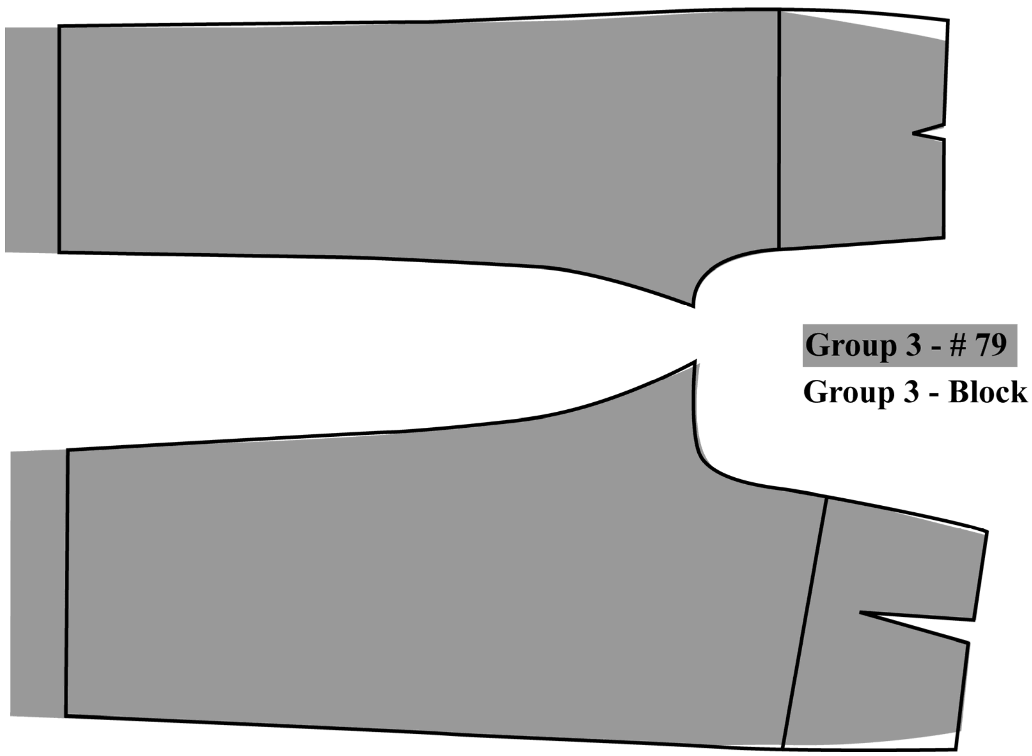


Figure 4-31. #79's pattern and block pattern for group 3.

In Figure 4-32, the three final block patterns and the industry pattern are superimposed for comparison, and the perfect fit models' measurements which were used for the body charts in the made-to-measure system are shown in Table 4-20. The most obvious difference in patterns is the center back seam slope. The buttocks of group 2 were the most prominent (25.8°), group 1 and 3 had a medium degree of prominence (21.3° and 20.6°), and the fit model for the industry pattern had the flattest

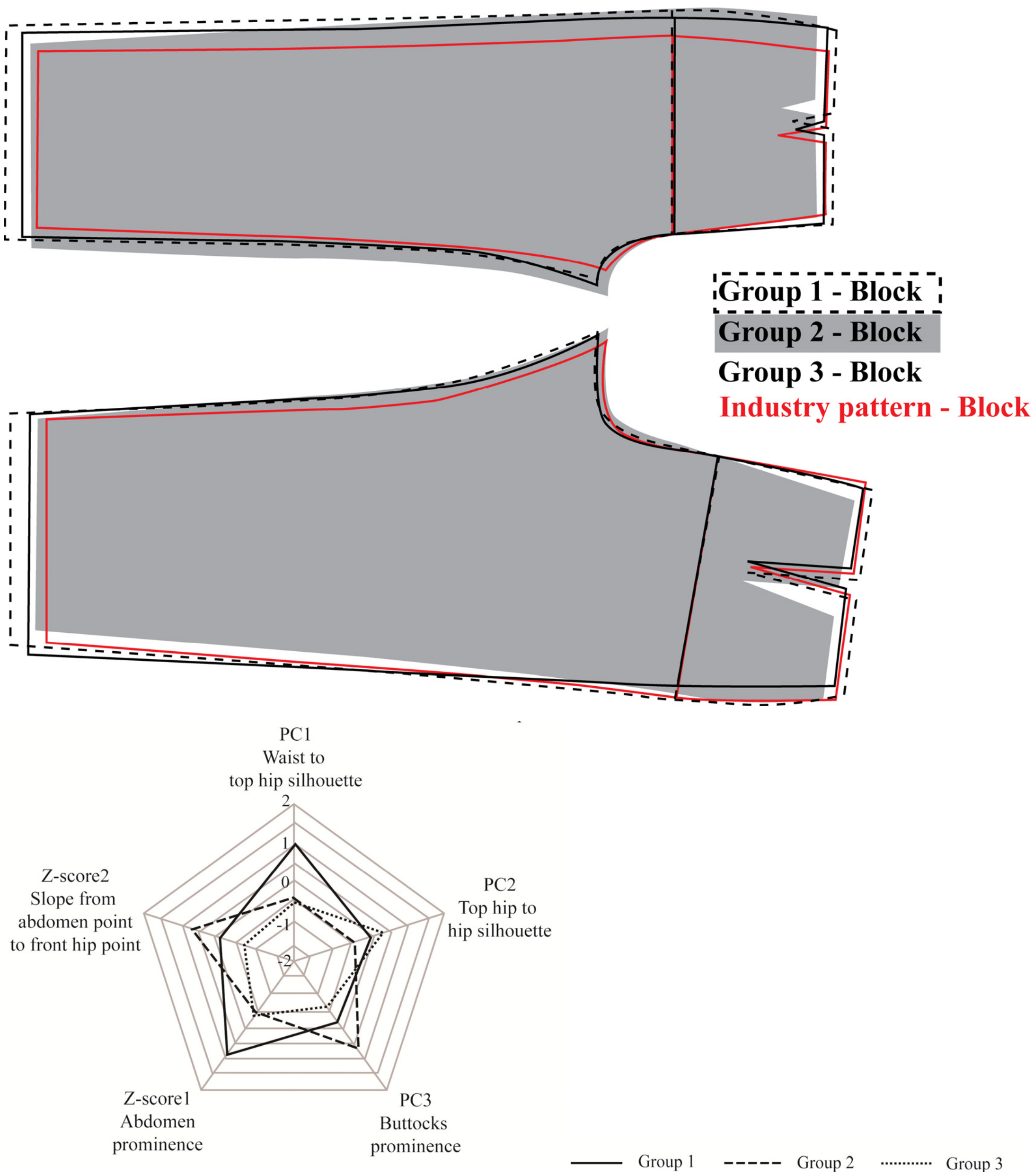


Figure 4-32. The final three block patterns and industry pattern.

Table 4-20. Fit models' primary body measurements.

	Group 1	Group 2	Group 3	Industry pattern
Waist girth	30.96	32.97	32.86	31.5
Hip girth	40.23	40.98	40.83	40
Thigh girth (max)	24.05	25.63	24.00	23.5
Waist to crotch length	10.88	10.32	10.34	10.5
Crotch height	29.4	29.3	29.6	29.50

Unit = inch

buttocks (15.5°). Accordingly, the center back seam slope of group 2 was the most tilted and that of the industry pattern was the most vertical. Another difference was the center front seam slope. The difference in center front seam slope was influenced by the drop of front abdomen depth to front hip depth. Group 2 had the largest drop (the posture is tilted toward the back), so the center front seam slope is the most tilted. The third difference was the silhouette of the side seams. Group 3 had a straight shape while group 1 had a curvy waist to hip shape and a prominent abdomen, and group 2 had prominent buttocks. Therefore, group 3 has straighter side seams from waist to hip level than the other groups. Group 1 has curvier side seams from waist to top hip level than the others. Regarding the proportion of front pattern to back pattern at waist level, group 1 proportion is 1:0.97, group is 2 1:1.08, and group 3 is 1:1.02. The front pattern piece of group 1 has a larger proportion compared to the back, while the others have smaller front patterns compared to the back. The proportion of the front pattern piece to the back pattern piece at the hip level is similar for all three groups (1:1.06 = front:back). The side seam of the industry pattern is located further toward the front than the other three group patterns (a smaller front pattern piece and larger back piece with proportions of 1:1.30 at waist level and 1:1.21 at hip level).

It was difficult to analyze crotch length in relation to body shape and size, since max-thigh girth, hip depth and abdomen depth were inter-related and influenced the pattern shapes simultaneously. One of the reasons that group 2 has the longest crotch extension was because the fit model of group 2 has the largest thigh girth. Another possible contributing factor is that group 2 has the most prominent buttocks, so this depth influenced the amount of the crotch extension. Group 1 and 2 have a similar thigh girth (24.05 and 24.00 in), so the amounts of their crotch extensions are similar. The proportion of front to back crotch extension was not quantified in relation to body shape differences.

Comparison of Two Made-to-Measure Systems

Setting up Made-to-Measure System

Based on idealized fit models' measurements, body charts for the three body shape groups were developed (Table 4-21). Hip girth was selected as the primary measurement for selection of each participant's base size (Table 4-22). The size intervals from ASTM D 5585-95 were used to develop the chart. Then the base patterns (size 12) for each body shape group were graded (Figure 4-33).

Table 4-21. Body charts for stage 3.

	Size									
Group 1	2	4	6	8	10	12	14	16	18	20
Waist girth	25.46	26.46	27.46	28.46	29.46	30.96	32.46	33.96	35.96	37.96
Hip girth	34.73	35.73	36.73	37.73	38.73	40.23	41.73	43.23	45.23	47.23
Thigh girth (max)	20.05	20.80	21.55	22.30	23.05	24.05	25.05	26.05	27.30	28.55
W-Crotch	9.63	9.88	10.13	10.38	10.63	10.88	11.13	11.38	11.63	11.88
Crotch height	29.40	29.40	29.40	29.40	29.40	29.40	29.40	29.40	29.40	29.40
Group 2	2	4	6	8	10	12	14	16	18	20
Waist girth	27.47	28.47	29.47	30.47	31.47	32.97	34.47	35.97	37.97	39.97
Hip girth	35.48	36.48	37.48	38.48	39.48	40.98	42.48	43.98	45.98	47.98
Thigh girth (max)	21.63	22.38	23.13	23.88	24.63	25.63	26.63	27.63	28.88	30.13
W-Crotch	9.07	9.32	9.57	9.82	10.07	10.32	10.57	10.82	11.07	11.32
Crotch height	29.30	29.30	29.30	29.30	29.30	29.30	29.30	29.30	29.30	29.30
Group 3	2	4	6	8	10	12	14	16	18	20
Waist girth	27.36	28.36	29.36	30.36	31.36	32.86	34.36	35.86	37.86	39.86
Hip girth	35.33	36.33	37.33	38.33	39.33	40.83	42.33	43.83	45.83	47.83
Thigh girth (max)	20.00	20.75	21.50	22.25	23.00	24.00	25.00	26.00	27.25	28.50
W-Crotch	9.09	9.34	9.59	9.84	10.09	10.34	10.59	10.84	11.09	11.34
Crotch height	29.60	29.60	29.60	29.60	29.60	29.60	29.60	29.60	29.60	29.60
Industry pattern	2	4	6	8	10	12	14	16	18	20
Waist girth	26	27	28	29	30	31.5	33	34.5	36.5	38.5
Hip girth	34.5	35.5	36.5	37.5	38.5	40.00	41.5	43	45	47
Thigh girth (max)	19.5	20.25	21	21.75	22.5	23.5	24.5	25.5	26.75	28
W-Crotch	9.25	9.5	9.75	10	10.25	10.5	10.75	11	11.25	11.5
Crotch height	29.5	29.5	29.5	29.5	29.5	29.50	29.5	29.5	29.5	29.5

Unit. Inch

Table 4-22. Hip measurement range for selecting a base size

		Size									
		2	4	6	8	10	12	14	16	18	20
Group 1	from	34.23	35.24	36.24	37.24	38.24	39.49	40.99	42.49	44.24	46.24
	to	35.23	36.23	37.23	38.23	39.48	40.98	42.48	44.23	46.23	48.23
Group 2	from	33.98	35.99	36.99	37.99	38.99	40.24	41.74	43.24	44.99	46.99
	to	35.98	36.98	37.98	38.98	40.23	41.73	43.23	44.98	46.98	48.99
Group 3	from	34.83	35.84	36.84	37.84	38.84	40.09	41.59	43.09	44.84	46.84
	to	35.83	36.83	37.83	38.83	40.08	41.58	43.08	44.83	46.83	48.84
Industry pattern	from	34.00	35.01	36.01	37.01	39.01	39.26	40.76	42.26	44.01	46.01
	to	35.00	36.00	37.00	38.00	39.25	40.75	42.25	44.00	46.00	48.00

Unit. Inch

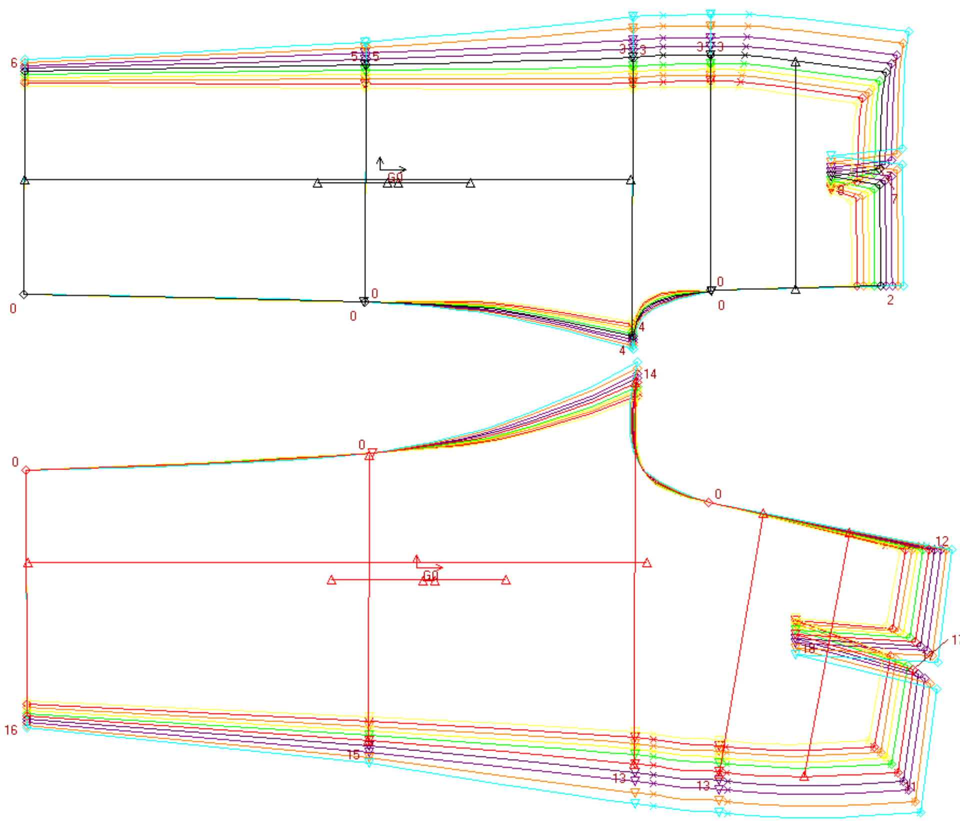


Figure 4-33. Example of a graded pattern.

A group of 27 participants were chosen for the fit analysis stage of the study from the remaining 74 participants who were left once the nine fit models were removed from the 83 participants originally recruited. I selected women from small to large sizes as evenly as possible, though medium sizes (size 10 and 12) were over-represented.

Table 4-23. Number of participants in each size and group.

	Size									
	2	4	6	8	10	12	14	16	18	20
Group 1			1		3	3		1	1	
Group 2		1		2	1	2	1	1		1
Group 3				2	2	2	3			

Comparison of Fit of the Pants Made by the Standard Customization System and the Body Shape Driven Customization System

Expert Judges' Fit Evaluation

Three expert judges rated fit of 13 areas of the pants and overall fit using a 5-point Likert scale by viewing front, side and back view pictures of each of the 27 participants. At the completion of the fit rating, they also ranked the two pairs of pants for each participant in order to choose the best fitting pair overall. A total of 81 comparisons of ratings (3 judges × 9 sets of pants × 3 shape groups) were made to choose the best fitting pants between the two types. 70.4% (n = 57) of the judges' ratings ranked type A the highest (shape driven customization system), and 24.7% (n = 20) ranked type B the highest (standard customization system). In 4.9% (n = 4) of the cases that the judges were not able to choose between type A and B indicating that in these cases they were the same overall fit. Within each of the body shape groups, type A was ranked higher than B as the best fitting pair more frequently (Table 4-24).

Table 4-24. Best fitting pair.

		Type			
		A	B	A = B	Total (3 fit judges × 9 pairs)
Body shape group	1	**18 (66.7%)**	8 (29.6%)	1 (3.7%)	27
	2	**20 (74.1%)**	5 (18.5%)	2 (7.4%)	27
	3	**19 (70.4%)**	7 (25.9%)	1 (3.7%)	27
Total		**57 (70.4%)**	20 (24.7%)	4 (4.9%)	81

Linear mixed models (LMM) was utilized to identify the overall fit (a 5-point Likert scale) for the three main effects (type, group, and judge) and three two-way interactions (type by group, type by judge, and group by judge). The F-values and means of the main effects are presented in Table 4-25. There was no significant interaction in this model. There were significant main effects of type, F (1, 124) = 24.09, $p<.05$, and judge, F (2, 124) = 3.26, $p<.05$ on overall fit scores. Judges had different levels of rating on overall fit, but there was no problem on interpreting the results of the type effect since there was no interaction between judges and the other two main effects. Type A (M = 3.61, SE =.11) had significantly higher overall fit scores than type B (M = 3.03, SE =.11).

Table 4-25. F-values and means of overall fit derived from LMM.

F-value						Mean							
Type	Group	Judge	Type × Group	Type × Judge	Group × Judge	Type		Group			Judge		
						A	B	1	2	3	1	2	3
24.085 * (*p* = .000)	.852	**3.260 (*p* = .041)**	.213	2.431	.471	**3.61**	**3.03**	3.44	3.15	3.35	**3.37**	**3.46**	**3.11**

Note. 1 (very bad), 2 (bad), 3 (neutral), 4 (good), and 5 (very good).
Since there were no significant interaction effects, LMM was re-performed with only three main effects, and the F-values of three main effects were described by this new LMM.

The questionnaire for judging the fit of the two types of pants at different body locations was constructed using a five-point scale. The middle value of the scale, 3, represented good fit. The end points of each scale varied depending on the fit location, for example very tight (1) – very loose (5), very short (1) – very long (5), very low (1) – very high (5), or very forward (1) – very backward (5). In order to compare which type of pants provided better fit in each body area, the value 3 was re-coded as ‘1’, and the rest of the values (1, 2, 4, and 5) were re-coded as ‘0’. A generalized estimating equation (GEE) was used to analyze 13 locations for the three main effects (pants type, body group, and judge) and three two-way interactions (pants type by body shape group, pants type by judge, body shape group by judge). Their *p*-values and means of the main effects are presented in Table 4-26. If certain significant interactions were found, GEE was re-performed with the main effects and the rest of the interactions. But if no significant interaction was found, only the three main effects were tested. In Table 4-26, *p*-values of the interaction effects with no significance were from the first GEE, and p-values of the main effects and interaction effect with significance were from the second GEE.

There was a significant main effect of type on front waist ease (A = .90, B = .59), back waist ease (A = .83, B = .37), front waist placement (A = .79, B = .60), back waist placement (A = .88, B = .69), crotch length (A = .85, B = .16) and side seam (A = .85, B = .16) (p<.05). In all six locations, type A ratings were significantly higher than type B. Especially in the areas of side seam placement, back waist ease, and front waist ease, type A was rated higher than B. There were no type by judge interactions in these locations except for the front waist placement. In Table 4-27, pairwise comparison of means on front waist ease, back waist ease, and side seam location depending on judges were significantly different on all three judges on the 0.05 level. At front waist placement, since there was a significant type by judge interaction, it was necessary to examine the means of type depending on judges. The A-B section on front waist placement in Table 4-27 shows that judge 2 (A-B = .27) and 3 (A-B =.18) rated type A higher than B, and the ratings of judge 3 were significant different (p<.05). In contrast to the other two judges, judge 1 rated type A lower than B (A-B = -.13). At back waist placement, judge 1 (A-B = .11), 2 (A-B = .20) and 3 (A-B =.26) rated type A higher than B, and ratings of judge 3 was significant different (p<.05). At crotch length, judge 1 (A-B = .15), 2 (A-B = .20) and 3 (A-B =.15) rated type A higher than B, and ratings of judge 2 was significant different (p<.05). In these cases the judge with different ratings rated type A over type

B with higher scores than the other judges.

Table 4-26. Expert judges' evaluation - P-values and means of fit scores at body locations derived from GEE.

Area	Test of Model Effect (Sig.)						Estimated Marginal Means							
	Type	Group	Judge	Type × Group	Type × Judge	Group × Judge	Type		Group			Judge		
							A	B	1	2	3	1	2	3
Front waist ease	.003	346	.166	.512	.119	.118	**.90**	**.59**	.74	.85	.90	.84	.76	.72
Back waist ease	.001	.435	.017	.750	.992	.625	**.83**	**.37**	.59	.56	.73	.75	.50	.62
Front waist placement	.036	.066	.001	.287	.032	.795	**.79**	**.60**	.83	.52	.71	.58	.46	.89
Back waist placement	.009	.403	.008	.070	.622	-	**.88**	**.69**	.85	.83	.70	.92	.66	.74
Abdomen ease	. 705	.575	.008	.666	.235	.278	**.40**	**.37**	.46	.37	.33	.44	.28	.44
Buttocks ease	.558	.530	.221	.922	.346	.762	**.52**	**.46**	.44	.46	.56	.50	.43	.54
Front crotch ease	.171	.556	.001	.462	.038	.753	**.54**	**.38**	.43	.53	.42	.67	.21	.54
Back crotch ease	.415	.091	.002	.543	.030	.979	.23	.31	.42	.20	.21	.48	.08	.38
Front thigh ease	.848	.070	.140	.505	.006	.354	**.63**	**.61**	.65	.49	.72	.74	.58	.54
Back thigh ease	.131	.418	.028	.914	.012	.363	.19	.34	.21	.18	.39	.18	.39	.21
Crotch length	.048	.446	.003	.199	.390	.644	**.37**	**.19**	.33	.21	.27	.29	.14	.44
Inseam length	.414	.636	.034	.961	.621	.316	.52	.58	.48	.58	.58	.56	.37	.71
Side seam placement	.000	.948	.016	.399	.147	.733	**.85**	**.16**	.50	.53	.49	.43	.33	.75

Note. 1 (good fit) and 0 (bad fit).
Cells of effects which had significance are shaded. Fonts are bold if type A had higher fit ratings than B.

The overall means of type A were higher than B for abdomen ease, buttocks ease, front crotch ease, and front thigh ease, even though they were not significant (Table 4-26). In Table 4-27, pairwise comparisons of means at abdomen ease depending on judges showed that judge 1 rated the two types equally (A-B = .00), judge 2 preferred type A (A-B = .19), and judge 3 judged type B to be better (A-B = -.08). Results from the judges were different, but the differences between A and B were small. Therefore, the two types can be considered to have relatively similar fit at the abdomen. For buttocks ease, judge 1 judged type B to be better (A-B = -.11), but judge 2 (A-B = .19) and 3 (A-B = .11) preferred type A. Even though the differences were not significantly different, type A can be considered to have a tendency toward better fit since two out of three judges considered type A better. For front crotch ease, a type

Table 4-27. Expert judges' evaluation - Pairwise comparison of means of fit scores of types according to judges derived from GEE.

	Judge	Type A	Type B	A-B	df	Sig.
Front waist ease	1	.91	.74	**.17**	1	.049
	2	.86	.60	**.26**	1	.020
	3	.93	.44	**.48**	1	.000
Back waist ease	1	.90	.52	**.38**	1	.001
	2	.74	.25	**.49**	1	.000
	3	.82	.37	**.45**	1	.001
Front waist placement (interaction)	1	.53	.66	-.13	1	.166
	2	.60	.33	**.27**	1	.055
	3	.97	.79	**.18**	1	.014
Back waist placement	1	.96	.85	**.11**	1	.083
	2	.76	.56	**.20**	1	.116
	3	.85	.59	**.26**	1	.009
Abdomen ease	1	.44	.44	**.00**	1	1.00
	2	.36	.17	**.19**	1	.151
	3	.40	.48	-.08	1	.636
Buttocks ease	1	.44	.56	-.11	1	.462
	2	.52	.33	**.19**	1	.151
	3	.59	.48	**.11**	1	.487
Front crotch ease (interaction)	1	.63	.71	-.07	1	.524
	2	.36	.10	**.26**	1	.039
	3	.63	.44	**.19**	1	.212
Back crotch ease (interaction)	1	.44	.52	-.08	1	.616
	2	.03	.18	-.14	1	.044
	3	.48	.29	**.20**	1	.152
Front thigh ease (interaction)	1	.56	.85	-.30	1	.019
	2	.71	.44	**.27**	1	.054
	3	.56	.52	**.04**	1	.781
Back thigh ease (interaction)	1	.07	.41	-.33	1	.005
	2	.36	.40	-.04	1	.705
	3	.18	.18	.00	1	1.000
Crotch length	1	.37	.22	**.15**	1	.193
	2	.22	.03	**.20**	1	.047
	3	.52	.37	**.15**	1	.308
Inseam length	1	.52	.59	-.07	1	.308
	2	.35	.35	.00	1	1.000
	3	.67	.74	-.07	1	.476
Side seam placement	1	.78	.14	**.63**	1	.000
	2	.78	.04	**.74**	1	.000
	3	.93	.37	**.56**	1	.000

Note. 1 (good fit) and 2 (bad fit).
Cells of effects which had significance are shaded. Fonts are bold if type A had higher fit ratings than B.

by judge interaction was found. Judge 1 judged type B to be better (A-B = -.07), but judge 2 (A-B = .29, $p<.05$) and 3 (A-B = .19) preferred type A. Since judge 2 and 3 considered type A better, and the difference between type A and B by judge 1 was small, type A can be considered to have a tendency toward better fit. For the front thigh ease, a type by judge interaction was found. Judge 1 judged type B to be better

(A-B = -.30, *p*<.05), but judge 2 (A-B = .27) and 3 (A-B = .04) preferred type A. Judge 1 strongly judged type B to be better fit with significance on the level of 0.05, but judges (particularly judge 2) had different opinions so results were mixed in this case.

For back crotch ease, back thigh ease, and inseam length, the overall means of type B were higher than A, though they were not significant (Table 4-26). For back crotch ease, a type by judge interaction was found. In Table 4-27, pairwise comparisons of means showed that judge 1 (A-B = -.08) and 2 (A-B = -.14, *p*<.05) judged type B to be better, but judge 3 considered type A better (A-B = .20). Judges had different opinions of the fit in this area, but type B can be considered to have a tendency towards better fit since two out of three judges agreed. Back thigh ease also had type by judge interaction. Judge 1 (A-B = -.33, *p*<.05) judged type B to be better, but 2 (A-B = -.04) judged type B to be only slightly better, and judge 3 considered type A and B equal (A-B = .00). Type B may be considered to have a tendency toward better fit by one out of three judges, but the other two judges assessed the fit somewhat equally for the two types. Regarding the inseam length, two judges considered type B to be slightly better than A (for both judges A-B = -.07), and one judge considered the fit of two types equal. Differences were minimal so the fit of the two types in inseam length can be considered to be essentially the same between the two types.

In order to analyze which type of pants provided better fit depending on body shape groups, paired t-test was conducted after splitting the data by shape groups (Table 4-28). When the fit of the two pants were compared within body shape groups only, the results showed that type A had better fit than B at eight (61.5%) out of thirteen locations (significantly better at four locations) in group 1, nine (69.2%) locations (significantly better at four locations) in group 2, and eight (61.5%) locations (significantly better at four locations) in group 3.

Table 4-28. Expert judges' evaluation - Pairwise comparison of means of fit scores of types according to groups derived by paired t-test.

	Group	Type A	Type B	A-B	t	df	Sig.
Front waist ease	1	.93	.48	**0.44**	4.000	26	.000
	2	.89	.52	**0.37**	3.407	26	.002
	3	.85	.74	**0.11**	1.000	26	.327
Back waist ease	1	.74	.37	**0.37**	3.058	26	.005
	2	.81	.30	**0.52**	4.647	26	.000
	3	.89	.48	**0.41**	3.328	26	.003
Front waist placement	1	.78	.74	**0.04**	.440	26	.663
	2	.52	.48	**0.04**	.328	26	.746
	3	.78	.52	**0.26**	2.054	26	.050
Back waist placement	1	.81	.81	**0.00**	.000	26	1.000
	2	.96	.63	**0.33**	3.122	26	.004
	3	.78	.56	**0.22**	2.280	26	.031
Abdomen ease (Front view)	1	.48	.44	**0.04**	.273	26	.787
	2	.44	.30	**0.15**	1.072	26	.294
	3	.30	.37	-0.07	-.527	26	.602
Buttocks ease (back view)	1	.44	.44	**0.00**	.000	26	1.000
	2	.52	.41	**0.11**	.769	26	.449
	3	.59	.52	**0.07**	.493	26	.626
Front crotch ease	1	.44	.48	-0.04	-.296	26	.769
	2	.67	.41	**0.26**	1.763	26	.090
	3	.52	.37	**0.15**	1.162	26	.256
Back crotch ease	1	.48	.44	**0.04**	.328	26	.746
	2	.19	.33	-0.15	-1.162	26	.256
	3	.30	.22	**0.07**	.570	26	.574
Front thigh ease	1	.63	.63	**0.00**	.000	26	1.000
	2	.56	.41	**0.15**	1.072	26	.294
	3	.63	.78	-0.15	-1.162	26	.256
Back thigh ease	1	.22	.30	-0.07	-.570	26	.574
	2	.11	.26	-0.15	-1.688	26	.103
	3	.33	.48	-0.15	-1.442	26	.161
Crotch length	1	.56	.15	**0.41**	3.051	26	.005
	2	.30	.19	**0.11**	1.140	26	.265
	3	.30	.30	**0.00**	.000	26	1.000
Inseam length	1	.44	.52	-0.07	-.700	26	.490
	2	.56	.59	-0.04	-.570	26	.574
	3	.56	.59	-0.04	-.570	26	.574
Side seam placement	1	.78	.22	**0.56**	4.507	26	.000
	2	.81	.22	**0.59**	4.841	26	.000
	3	.89	.11	**0.78**	9.539	26	.000

Note. 1 (good fit) and 0 (bad fit).
Cells of effects which had significance were shaded, and fonts were bolded if type A had higher fit ratings than B.

At front waist ease, pairwise comparisons of means in Table 4-28 showed that type A provided better fit in all three groups (A-B: group 1 = .44, group 2 = .37, and group 3 = .11). The results of group 1 and 2 were significantly different ($p<.05$). As shown in Figure 4-34, type A provided good fit for 92.6% of group 1, 88.9% of group 2, and 85.2% of group 3, and type B provided good fit for 74.1% of group 3 as well.

On the other hand, type B provided tight fit for 51.8% of group 1, and 44.4% of group 2.

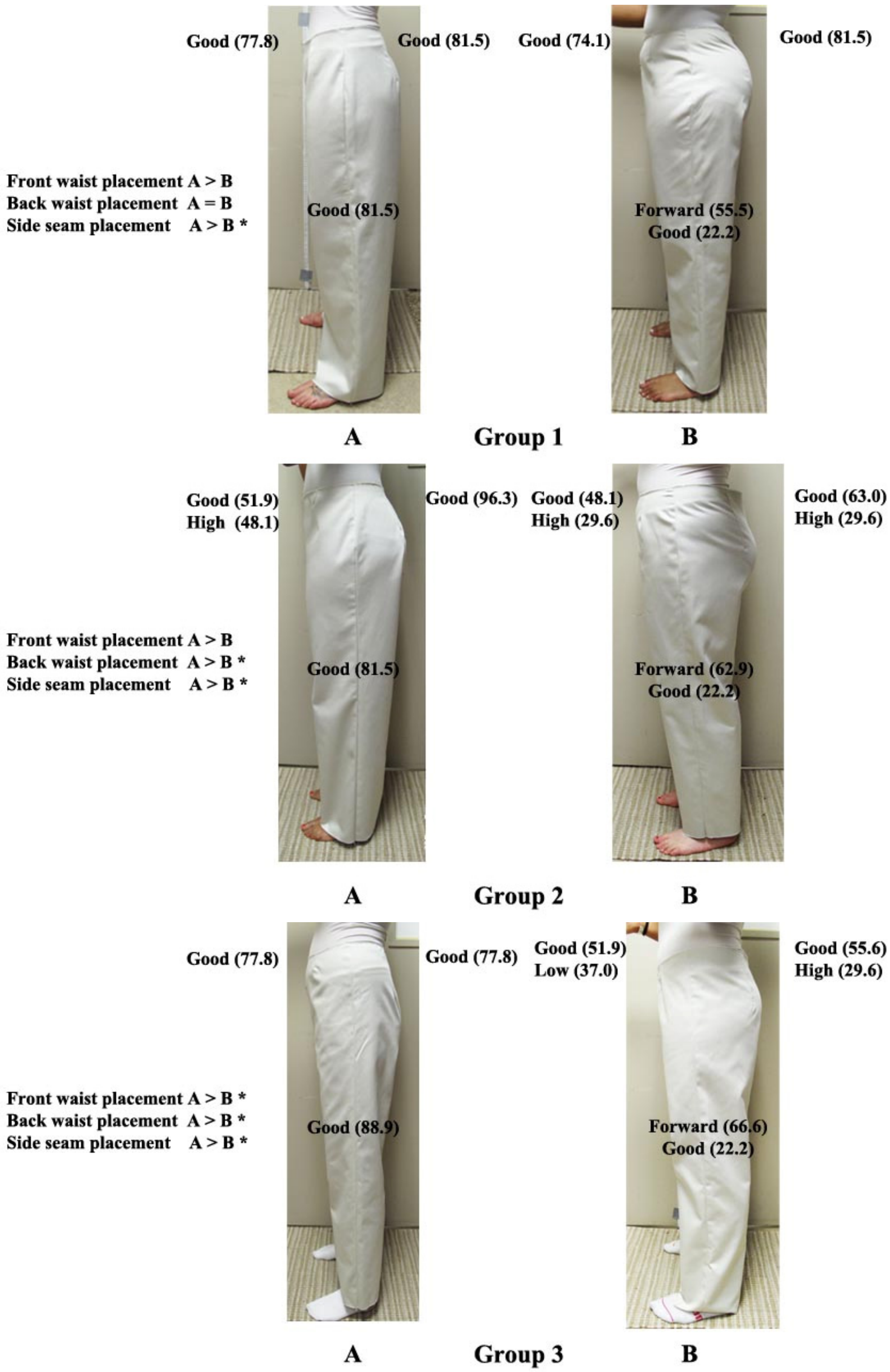
At back waist ease, pairwise comparisons of means in Table 4-28 showed that type A provided better fit in all three groups with significant differences (A-B: group 1 = .37, group 2 = .52, and group 3 = .41) (p<.05). As shown in Figure 4-36, type A provided good fit for 74.1% of group 1, 81.5% of group 2, and 88.9% of group 3. On the other hand, type B provided loose fit for 66.6% of group 2, and 37.2% of group 3.

At front waist placement, pairwise comparisons of means showed that type A provided somewhat slightly better fit in group 1 and 2 (A-B: group 1 = .04, and group 2 = .04). As shown in Table 4-28, both types provided good fit for most of group 1 (A: 77.8%, B: 74.1%), but provided good fit for about 50% of the group 2 (A: 52.0%, B: 48.1%). 48.1% of the group 2 had high placement in type A, while 29.6% had high placement and 22.2% had low placement in type B. In Group 3, type A provided significantly better fit than B (A-B = .26, p<.05). Type A provided good fit for 77.8% of group 3, while type B provided good fit for 51.9% and low placement for 37.0%.

At back waist placement, pairwise comparisons of means in Table 4-28 showed that type A provided somewhat equal fit for group 1 (A-B: group 1 = .00), but significantly better fit for group 2 (.33) and 3 and (.22) (p<.05). As shown in Figure 4-35, in group 1, both types provided good fit for most of group 1 (81.5%). However, in group 2, type A provided good fit for 96.3% while type B for 63.0%. In group 3, type B provided good fit for 55.6% while type A for 77.8%. In group 2 and 3, high back waist placement was found for 29.6%.

Note: Percentage of rating frequencies are presented in parentheses. Between picture A and B, the symbols >, <, or = indicate the results of pairwise comparison of means of fit scores of types from Table 4-28. The symbol * indicate results are significant.

Figure 4-34. Expert judges' evaluation of front ease values and crotch lengths of type A and B for each body shape group with selected front view pictures from the study as examples.



Note: Percentage of frequencies are presented in parentheses. The relationship between type A and B from Table 4-28 are shown to the left of each set of images. The symbol * indicates a significant result.

Figure 4-35. Expert judges' evaluation of waist placement and side seam placement of type A and B for each body shape group with selected side view pictures from the study as examples.

	A		B
Waist	Good (74.1)	> *	Good (37.0)
Hip	Good (44.4), Loose (29.6)	=	Tight (51.8), Good (44.4)
Crotch	Good (48.1), Loose (29.6)	>	Good (44.4), Tight (44.4)
Thigh	Loose (77.8), Good (22.2)	<	Loose (70.4), Good (29.6)

A Group 1 B

	A		B
Waist	Good (81.5)	> *	Loose (66.6)
Hip	Good (51.9), Loose (40.7)	>	Tight (55.5), Good (40.7)
Crotch	Loose (59.3), Tight (22.2)	<	Tight (63.0), Good (33.3)
Thigh	Loose (88.9), Good (11.1)	<	Loose (70.4), Good (25.9)

A Group 2 B

	A		B
Waist	Good (88.9)	> *	Good (48.1), Loose (37.0)
Hip	Good (59.3), Tight (22.2)	>	Good (51.9), Tight (48.1)
Crotch	Tight (51.8), Good (29.6)	>	Tight (56.6), Good (22.2)
Thigh	Loose (66.7), Good (33.3)	<	Loose (51.8), Good (48.1)

A Group 3 B

Note: Percentage of rating frequencies are presented in parentheses. Between picture A and B, the symbols >, <, or = indicate the results of pairwise comparison of fit scores of types from Table 4-28. The symbol * indicate results are significant, *.

Figure 4-36. Expert judges' evaluation of back ease values for each body shape group with selected back view pictures from the study as examples.

At crotch length, pairwise comparisons of means showed that type A provided significantly better fit for only group 1 (A-B: group 1 = .41, $p<.05$), slightly better fit for group 2 (.11) and equal fit for 3 (.00). As shown in Figure 4-34, only type A of group 1 had a high frequency of good fit (55.6%). Type B of group 1 (74.1%), and both types of group 2 (A: 70.3%, B: 70.3%) and 3 (A: 70.4%, B: 59.2%) had long crotch lengths.

At side seam location, type A provided significantly better fit for all groups with large differences (A-B: group 1 = .56, group 2 = .59, group 3 = .78, $p<.05$). Type A provided good fit for 77.8% of group 1, 81.5% of group 2, and 88.9% of group 3. On the other hand, type B provided forward side seam location for 55.5% of group 1, 62.9% of group 2, and 66.6% of group 3 (Figure 4-35).

For the rest of the fit locations there was not a significant difference between the two types. The differences were small, but positive or negative directions could show which type had a tendency toward slightly better fit. As shown in Table 4-28, at crotch length and inseam length, type B provided slightly better fit than type A in all body shape groups. At back thigh ease, both types showed loose fit problems in all groups (group 1: A-77.8%, B-70.4%, group 2: A-88.9%, B-70.4%, group 3: A-66.7%, B-51.8%) (Figure 4-36). Both types provided good fit for a low percentage of participants (22.2 to 33.3%). Type B had slightly higher percentage of good fit in this area (about 7 to 14.8%) in all groups. At inseam length, in all groups both types provided either good length or long fit problems for about 50% of the group. Type B had a very slightly higher percentage of good length (about 3.7 to 7.5%) in all groups (Figure 4-35).

At abdomen ease, type A provided slightly better fit in group 1 (A-B = .04) and 2 (.15), and type B was judged to be very slightly better fitted in group 3 (-.07). The percentage of good fit was low (29.6 to 37.0%) in both types across the three groups. Type B of group 1 (55.6%), type A of group 2 (59.3%), type A (55.6%) and B (59.3%) of group 3 had loose fit problems. Type A of group 1 and type B of group 2 had tight fit and loose fit relatively evenly (Figure 4-34).

At buttocks ease, both types provided good fit for about 50% of the group and type A provided slightly better fit than B in all groups. In all groups, type B had tight fit problems about 50% of the group (Figure 4-36). In group 2, type A had loose fit problems for 40.7% of the group, while type A in group 1 and 3 had tight fit and loose fit relatively evenly (about 20%).

At back crotch ease, the percentages of good fit in group 1 were 44.4 to 48.1%, and those of group 2 and 3 were relatively lower (18.5 to 33.3%) (Figure 4-36). In group 1 and 3, type A had slightly better fit while type B provided better fit for group 2. Type B of group 2 and both types of group 3 had tight fit problems (51.8 to 56.6%). Type A of group 1 was judged to have loose fit (59.3%).

At front thigh ease, group 1 showed the same proportion of good fit (63.0%). Type A had good fit for 55.6% of group 1 and 63.0% of group 2, and loose fit for 33.3% of group 1 and group 2. Type B had tight fit for 44.4% of group 2 and loose fit for 18.5% of group 3 (Figure 4-34).

Wearers' Fit Evaluation

Twenty seven wearers rated perceived fit at 12 areas, overall fit, and fit satisfaction using a five-point Likert scale. At the end of the questionnaire, they chose the pair that they felt was the best fitting overall. For all groups 59.3% (n = 16) of wearers selected type A, and 40.7% (n = 11) for type B. In group 1 and 3, 66.7% (n = 6) of wearers chose type A, and 33.3% (n = 3) selected type B. However, in group 2 results were more evenly divided, as 44.4% (n = 4) of wearers chose type A and 55.6% (n = 5) selected type B.

Table 4-29. Best fitting type judged by wearers.

		Type		
		A	B	Total
Body shape group	1	6 (66.7%)	3 (33.3%)	9
	2	4 (44.4%)	5 (55.6%)	9
	3	6 (66.7%)	3 (33.3%)	9
Total		16 (59.3%)	11 (40.7%)	27

The questionnaire for participant judgment of the fit of two types of pants was constructed using a five-point scale. The middle value of the scale, 3, represented perceived good fit. The end points of each scale varied depending on the fit location, for example very tight (1) – very loose (5), very short (1) – very long (5), very low (1) – very high (5), or very forward (1) – very backward (5). In order to compare which type of pants provided better perceived fit in each body area, the value 3 was re-coded as '1', and the rest of the values (1, 2, 4, and 5) as '0'. A generalized estimating equation (GEE) was used to analyze 12 locations for the two main effects (pants type and body shape group) and one two-way interaction (pants type by body shape group). If no significant interaction was found in a certain fit location, GEE was re-performed with the main effects. In Table 4-30, *p*-values of the interaction effects with no significance are from the first GEE, and p-values of the main effects and interaction effects with significance are from the second GEE. The results of pairwise comparison of perceived fit scores of types according to shape groups derived by GEE are shown in Table 4-31, and frequencies of perceived fit scores are shown in Table 4-32.

As shown in Table 4-30, there was no significant effect of group. Inseam length only had a type by group interaction. There were significant main effects of type on waist ease (A = .75, B = .44) and abdomen ease (A = .85, B = .56) ($p<.05$). In both waist and abdomen, type A provided significantly better perceived fit than type B.

In Table 4-31, pairwise comparisons of means at both locations depending on groups showed that type A was judged to be better than B across the three groups

Table 4-30. Wearers' perceived fit evaluation - P-values and means of fit scores at body locations derived from GEE.

Area	P-value			Mean				
	Type × Group	Group	Type	Type		Shape group		
				A	B	1	2	3
Waist ease	.965	.587	**.046 ***	**.75**	**.44**	.68	.62	.50
Abdomen ease	.515	.883	**.011 ***	**.85**	**.56**	.68	.74	.76
Hip ease	.163	.485	.763	.60	**.63**	.72	.61	.50
Crotch ease	.703	.655	.058	.37	**.59**	.56	.38	.50
Thigh ease	.934	.605	.564	.48	**.56**	.50	.44	.61
Knee ease	.517	.941	.739	.56	**.59**	.56	.56	.61
Ankle ease	.757	.778	.317	**.78**	.67	.73	.67	.78
Front waist placement	.287	.919	.257	**.71**	.59	.61	.67	.67
Back waist placement	.096	.855	.257	**.74**	.63	.72	.72	.62
Crotch placement	.204	.393	.564	.29	**.33**	.50	.24	.22
Side seam placement	-	-	-	**.98**	.85	1.00	.89	.89
Inseam length	**.031 ***	.947	.165	.60	.60	.80	.57	.39

* $p < .05$
Note. 1 (good fit) and 0 (bad fit).
Cells of effects which had significance are shaded, and fonts are bold for higher perceived fit ratings.

Table 4-31. Wearers' perceived fit evaluation - Pairwise comparison of means of fit scores of types according to shape groups derived by GEE.

Area	Group	Type A	Type B	A-B	t	df	Sig.
Waist ease	1	.78	.56	**0.22**	.800	8	.447
	2	.78	.44	**0.33**	1.155	8	.282
	3	.67	.33	**0.33**	2.000	8	.081
Abdomen ease	1	.89	.44	**0.44**	2.530	8	**.035 ***
	2	.89	.56	**0.33**	2.000	8	.081
	3	.78	.67	**0.11**	.555	8	.594
Hip ease	1	.56	.89	-0.33	-2.000	8	.081
	2	.67	.56	**0.11**	.426	8	.681
	3	.56	.44	**0.11**	.555	8	.594
Crotch ease	1	.44	.67	-.22	-1.000	8	.347
	2	.33	.44	-.11	-.555	8	.594
	3	.33	.67	-.33	-2.000	8	.081
Thigh ease	1	.44	.56	-0.11	-.555	8	.594
	2	.44	.44	**0.00**	.000	8	1.000
	3	.56	.67	-0.11	-.555	8	.594
Knee ease	1	.44	.67	-0.22	-1.000	8	.347
	2	.56	.56	**0.00**	.000	8	1.000
	3	.67	.56	**0.11**	.555	8	.594
Ankle ease	1	.78	.67	**0.11**	.555	8	.594
	2	.78	.56	**0.22**	1.000	8	.347
	3	.78	.78	**0.00**	.000	8	1.000
Front waist placement	1	.78	.44	**0.33**	2.000	8	.081
	2	.67	.67	**0.00**	.000	8	1.000
	3	.67	.67	**0.00**	.000	8	1.000
Back waist placement	1	.89	.56	**0.33**	2.000	8	.081

Table 4-31 (Continued)

	2	.78	.67	**0.11**	.555	8	.594
	3	.56	.67	-0.11	-1.000	8	.347
Crotch placement	1	.56	.44	**0.11**	1.000	8	.347
	2	.11	.33	-0.22	-1.512	8	.169
	3	.22[a]	.22[a]	-	-	-	-
Side seam placement	1	1.00[a]	1.00[a]	-	-	-	-
	2	.89	.89	**0.00**	.000	8	1.000
	3	1.00	.67	**0.33**	2.000	8	.081
Inseam length	1	.89	.67	**0.22**	1.512	8	.169
	2	.33	.78	**-0.44**	-2.530	8	**.035 ***
	3	.44	.33	**0.11**	1.000	8	.347

a. The correlation and t cannot be computed because the standard error of the difference is 0.
* *p* < .05
Note. 1 (good fit) and 0 (bad fit).
Cells of effects which are significant are shaded, and fonts are bold when A is rated higher than B.

Table 4-32. Wearers' perceived fit evaluation - Comparison of frequencies of fit scores according to body shape groups.

			Perceived fit score									
Areas	Group	Method	1		2		3		4		5	
Waist ease	Group 1	A					7	77.8%	2	22.2%		
		B	1	11.1%	3	33.3%	5	55.6%				
	Group 2	A					7	77.8%	1	11.1%	1	11.1%
		B	2	22.2%	1	11.1%	4	44.4%	2	22.2%		
	Group 3	A					6	66.7%	3	33.3%		
		B			1	11.1%	3	33.3%	2	22.2%	3	33.3%
Abdomen ease	Group 1	A					8	88.9%	1	11.1%		
		B	1	11.1%	3	33.3%	4	44.4%	1	11.1%		
	Group 2	A			1	11.1%	8	88.9%				
		B	1	11.1%	1	11.1%	5	55.6%	2	22.2%		
	Group 3	A					7	77.8%	2	22.2%		
		B			1	11.1%	6	66.7%	1	11.1%	1	11.1%
Hip ease	Group 1	A					5	55.6%	4	44.4%		
		B					8	88.9%	1	11.1%		
	Group 2	A					6	66.7%	3	33.3%		
		B					5	55.6%	4	44.4%		
	Group 3	A					5	55.6%	3	33.3%	1	11.1%
		B			1	11.1%	4	44.4%	3	33.3%	1	11.1%
Thigh ease	Group 1	A					4	44.4%	1	11.1%	4	44.4%
		B					5	55.6%	3	33.3%	1	11.1%
	Group 2	A					4	44.4%	4	44.4%	1	11.1%
		B			1	11.1%	4	44.4%	4	44.4%		
	Group 3	A					5	55.6%	3	33.3%	1	11.1%
		B			1	11.1%	6	66.7%	1	11.1%	1	11.1%
Knee ease	Group 1	A					4	44.4%	2	22.2%	3	33.3%
		B			1	11.1%	6	66.7%	2	22.2%		
	Group 2	A					5	55.6%	4	44.4%		
		B					5	55.6%	4	44.4%		
	Group 3	A					6	66.7%	1	11.1%	2	22.2%
		B			1	11.1%	5	55.6%	3	33.3%		
Ankle ease	Group 1	A					7	77.8%	1	11.1%	1	11.1%
		B			1	11.1%	6	66.7%	2	22.2%		
	Group 2	A					7	77.8%	2	22.2%		
		B					5	55.6%	3	33.3%	1	11.1%
	Group 3	A					7	77.8%			2	22.2%

Table 4-32 (Continued)

		B					7	77.8%	1	11.1%	1	11.1%
Crotch ease	Group 1	A					4	44.4%	3	33.3%	2	22.2%
		B					6	66.7%	2	22.2%	1	11.1%
	Group 2	A					3	33.3%	4	44.4%	2	22.2%
		B			1	11.1%	4	44.4%	1	11.1%	3	33.3%
	Group 3	A					3	33.3%	4	44.4%	2	22.2%
		B					6	66.7%	2	22.2%	1	11.1%
Front waist placement	Group 1	A					7	77.8%	1	11.1%	1	11.1%
		B					4	44.4%	4	44.4%	1	11.1%
	Group 2	A					6	66.7%	3	33.3%		
		B					6	66.7%	3	33.3%		
	Group 3	A	1	11.1%	1	11.1%	6	66.7%	1	11.1%		
		B	2	22.2%			6	66.7%	1	11.1%		
Back waist placement	Group 1	A					8	88.9%	1	11.1%		
		B			1	11.1%	5	55.6%	3	33.3%		
	Group 2	A			1	11.1%	7	77.8%	1	11.1%		
		B					6	66.7%	3	33.3%		
	Group 3	A	1	11.1%	3	33.3%	5	55.6%				
		B	2	22.2%			6	66.7%	1	11.1%		
Crotch placement	Group 1	A	4	44.4%			5	55.6%				
		B	3	33.3%	2	22.2%	4	44.4%				
	Group 2	A	2	22.2%	4	44.4%	1	11.1%	1	11.1%	1	11.1%
		B	1	11.1%	4	44.4%	3	33.3%	1	11.1%		
	Group 3	A	1	11.1%	5	55.6%	2	22.2%	1	11.1%		
		B			5	55.6%	2	22.2%	2	22.2%		
Hip placement	Group 1	A			1	11.1%	7	77.8%	1	11.1%		
		B			1	11.1%	8	88.9%				
	Group 2	A					8	88.9%	1	11.1%		
		B					9	100.0%				
	Group 3	A			1	11.1%	7	77.8%	1	11.1%		
		B	1	11.1%	1	11.1%	3	33.3%	3	33.3%	1	11.1%
Side seam placement	Group 1	A					9	100.0%				
		B					9	100.0%				
	Group 2	A					8	88.9%	1	11.1%		
		B					8	88.9%	1	11.1%		
	Group 3	A					9	100.0%				
		B			2	22.2%	6	66.7%	1	11.1%		
Inseam length	Group 1	A			1	11.1%	8	88.9%				
		B			3	33.3%	6	66.7%				
	Group 2	A			6	66.7%	3	33.3%				
		B			1	11.1%	7	77.8%	1	11.1%		
	Group 3	A			4	44.4%	4	44.4%	1	11.1%		
		B	1	11.1%	3	33.3%	3	33.3%	2	22.2%		

Note. Fit scores: The end points of each scale varied depending on the fit location, for example very tight (1) – very loose (5) or very short (1) – very long (5). The middle value of the scale, 3, represented good fit.

(waist ease A-B: group 1 = .22, group 2 = .33, group 3 = .33, abdomen ease A-B: group 1: .44, group 2 = .33, group 3 = .11). The difference of group 1 was significantly different at abdomen ease ($p<.05$). At waist, type A provided good perceived fit for 77.8% of group 1, 77.8% of group 2, and 66.7% of group 3. Type B had tight perceived fit problems for 44.4% of group 1, tight perceived fit for 33.3%

and loose perceived fit for 22.2% of group 2, and loose perceived fit for 55.5% of group 3. At abdomen, type A generally provided good perceived fit for 77.8 to 88.9% of the groups as well. Type B provided tight perceived fit for 44.4% of group 1, tight perceived fit for 22.2% and loose perceived fit for 22.2% of group 2, and loose perceived fit for 22.2% of group 3. These two locations were close each other, so these fit problems were generated in the same general area within the pattern.

For those locations with higher overall means of type A than B, four areas were identified: ankle ease, front waist placement, back waist placement, and side seam placement, even though none were significant (Table 4-30). In Table 4-31, pairwise comparisons of means of ankle ease depending on groups showed that type A had slightly better perceived fit than B in group 2 (.22), while both types were judged to be equal perceived fit in group 1 (.11) and 3 (.00). Wearers generally considered the ankle fit of both types good (77.8%), but in group 2 loose fit problems were identified for 44.4%.

At front waist placement, type A provided better perceived fit than B in group 1 (A-B = .33) while the two types were judged to be equal in group 2 and 3. Type A generally provided good front waist location (66.7 to 77.8%), but type B had high front waist locations for 55.5%.

At the back waist placement, type A had slightly better perceived fit than B in group 1 (A-B = .33), while the perceived fit of the two types were considered equal for group 2 and 3. Type A in group 1 and 2 had good perceived fit (88.9% and 77.8%) while type B provided good perceived fit for 55.7% of group 1 and 66.7% of group 2. Type B in both groups had high back waist location for 33.3%. In group 3, type A had good perceived fit for 55.6%, but low back waist placement for 44.4%.

At the side seam location, wearers indicated good perceived fit overall. In group 1 and 2, almost all wearers indicated good fit, so both types had similar fit. In group 3, type A was judged to have better side seam locations than B (A: 100% good, B: 66.7% good, and 22.2% forward).

For those locations where the overall means of type B were higher than A, five areas were identified: hip ease, crotch ease, thigh ease, knee ease, and crotch placement, even though they were not significant (Table 4-30). In Table 4-31, pairwise comparisons of means of hip ease depending on groups showed that type B had slightly better perceived fit than A in group 1 (A-B = -.33), while both types had similar perceived fit in group 2 and 3. Type B of group 1 provided good perceived fit for 88.9%, but type A of group 1 and both types of group 2 and 3 provided good perceived fit for approximately 50% and loose fit for about 50%.

For the crotch ease, type B provided better perceived fit than A in group 1 (A-B = -.22) and 3 (-.33), and slightly better in group 2 (-.11). Type A provided good fit for 33.3 to 44.4% across the groups. All the areas with perceived fit problems were loose. Type B had problems with loose fit as well, but the percentage of good fit was a little higher than B.

At the thigh location, the perceived fit of both types were judged to be similar: good fit was reported for approximately 50% and loose fit for about 50%, but type B of group 3 provided higher ratings of good fit (66.7%) than other groups. The perceived fit problems for the rest of the wearers were judged to be too loose.

At the knee location, type B (good fit: 66.7%) provided better perceived fit than A (good fit: 44.4%) in group 1. In groups 2 and 3, the perceived fit of both types were judged to be similar: good fit was perceived by approximately 50% and loose fit by about 50%.

For the crotch placement, type B had slightly better perceived fit than A in group 2 (A-B = -.22). In group 1, good fit was perceived for 55.6% for type A and 44.4% for type B. But in group 2 and 3 good fit was perceived for fewer wearers (11.1

to 33.3%). Fit problems identifying low placement (long crotch length) were perceived across the groups.

At the inseam length, the overall mean of type A was the same as type B (Table 4-30). But a type by group interaction was found in this area with significance. In group 2, wearers judged type B to be significantly better fitted than type A (A-B = .-.44, $p<.05$). Type B provided good inseam length for 77.8% while type A had good length for 33.3% and short length for 66.7%. In group 1, type A provided good length for 88.9% of wearers and type B for 66.7%. In group 3, type A provided good length for only 44.4% of wearers and type B for 33.3%. A short inseam length was generally the fit problem identified.

To sum up, wearers' evaluation of fit found that type A had better fit than B at seven (58.3%) out of twelve locations (significantly better at one location) in group 1, five (41.7%) locations in group 2 (none significant), and six (50%) locations in group 3 (none significant). Wearers considered the fit of the two pants equal at one (8.3%) location in group 1, four (33.3%) locations in group 2, and three (25%) locations in group 3.

Linear mixed models (LMM) was utilized to identify fit satisfaction at 12 locations and overall fit satisfaction assessed by a 5-point Likert scale (1 = very dissatisfied, 2 = dissatisfied, 3 = neutral, 4 = satisfied, 5 = very satisfied) for the two main effects (type and group) and a two-way interaction (type by group). Their F-values and means of main effects were presented in Table 4-33. There was no significant main effect of group, and a type by group interaction was found only at inseam length.

There were significant main effects of type on waist ease satisfaction (A = 3.91, B = 3.37) and abdomen ease satisfaction (A = 4.00, B = 3.63) ($p<.05$). In both locations, type A provided significantly higher fit satisfaction than type B. In Table 4-

34, pairwise comparisons of means at both locations depending on groups showed that in all groups type A provided higher fit satisfaction than B (waist ease A-B: group 1 = .61, group 2 = .44, group 3 = .56, abdomen ease A-B: group 1= .67, group 2 = .33, group 3 = .11). The difference of group 1 was significantly different for waist ease satisfaction (p = .051).

For those locations where type A tended to provide higher satisfaction than B, five locations were identified: hip ease, front waist placement, back waist placement, side seam placement and inseam length, even though they were not significant (Table 4-33). In Table 4-34, pairwise comparisons of means of hip ease satisfaction depending on groups showed that type B was rated as providing higher fit satisfaction than A in group 1 (-.22), while type A was rated higher than B in group 2 (.22) and 3 (.55, p<.05). Regarding front waist placement, type A provided higher fit satisfaction than B in group 1 (.44) and 2 (.22), while fit satisfaction of both types were rated equally in group 3. For back waist placement, type A provided higher fit satisfaction than B in group 1 (.22) and 2 (.78), while fit satisfaction of both types was rated equally in group 3. With respect to side seam placement satisfaction, all groups indicated that type A provided higher fit satisfaction (.11, .11, .38). For inseam length satisfaction, type A provided higher fit satisfaction than B in group 1 (.28) and 3 (.67, p<.05), while fit satisfaction with type B was higher than A in group 2.

For those locations where type B had higher overall means of fit satisfaction than A, five locations were identified: crotch ease, thigh ease, knee ease, ankle ease and crotch placement, even though none were significant (Table 4-33). At crotch ease, type B provided higher satisfaction than A in all groups. At thigh ease, type B provided higher satisfaction than A for group 1 (-.44) and 2 (-.33), and a similar level of satisfaction for group 3. At knee ease, type B provided higher satisfaction than A for group 1 (-.39), both types gave similar level of satisfaction for group 2, and type B

Table 4-33. Wearers' fit evaluation - P-values and means of fit satisfaction scores derived from LMM.

Area	P-value			Mean				
	Type × Group	Group	Type	Type		Shape group		
				A	B	1	2	3
Waist ease	.057	.206	7.372 * (*p*=.012)	**3.91**	3.37	3.75	3.67	3.50
Abdomen ease	.457	.188	4.319 * (*p*=.048)	**4.00**	3.63	3.78	3.72	3.94
Hip ease	1.542	1.598	1.000	**3.67**	3.48	3.89	3.78	3.06
Thigh ease	.270	. 106	1.080	3.22	**3.48**	3.44	3.39	3.22
Knee ease	1.185	.113	1.663	3.52	**3.57**	3.53	4.00	3.11
Ankle ease	.565	1.011	.720	3.67	**3.81**	3.72	4.06	3.44
Crotch ease	.059	.246	1.925	2.93	**3.33**	3.28	2.94	3.17
Front waist placement	.449	.111	1.405	**3.89**	3.67	3.89	3.78	3.67
Back waist placement	1.642	.763	3.250	**3.93**	3.59	4.11	3.61	3.56
Crotch placement	.171	.387	.026	3.07	**3.11**	3.33	2.89	3.06
Side seam placement	.364	.137	2.390	**4.15**	3.96	4.17	3.94	4.06
Inseam length	5.200 * (*p*=.013)	1.660	2.547	**3.70**	3.50	4.08	3.28	3.44
Overall	.138	.215	.011	**3.44**	3.43	3.50	3.53	3.28

* $p < .05$
Note. 1 (very dissatisfied), 2 (dissatisfied), 3 (neutral), 4 (satisfied), and 5 (very satisfied).
Since there were no significant interaction effects, LMM was re-performed with only three main effects, and the F-values of three main effects were described by this new LMM.

Table 4-34. Wearers' fit evaluation - Pairwise comparison of means of fit satisfaction of types according to groups derived by paired t-test (after splitting shape groups).

		Type					
		A	B	A-B	t	df	Sig.
Waist ease	**1**	4.06	3.44	**.61**	1.444	8	.187
	2	3.89	3.44	**.44**	1.180	8	.272
	3	3.78	3.22	**.56**	2.294	8	.051
Abdomen ease	**1**	4.11	3.44	**.67**	2.000	8	.081
	2	3.89	3.56	**.33**	.894	8	.397
	3	4.00	3.89	**.11**	.555	8	.594
Hip ease	1	3.78	4.00	-.22	-.800	8	.447
	2	3.89	3.67	**.22**	.512	8	.622
	3	3.33	2.78	**.56**	3.162	8	.013*
Crotch ease	1	3	3.56	-.56	-1.170	8	.276
	2	2.78	3.11	-.33	-.555	8	.594
	3	3	3.33	-.33	-.667	8	.524
Thigh ease	1	3.22	3.667	-.44	-1.057	8	.321
	2	3.22	3.556	-.33	-.632	8	.545
	3	3.22	3.222	**.00**	.000	8	1.000
Knee ease	1	3.33	3.722	-.39	-1.049	8	.325
	2	4.00	4.00	**.00**	.000	8	1.000
	3	3.22	3.00	**.22**	.800	8	.447
Ankle ease	1	3.56	3.89	-.33	-1.414	8	.195
	2	4.11	4.00	**.11**	.555	8	.594
	3	3.33	3.56	-.22	-.512	8	.622
Front waist placement	1	4.11	3.67	**.44**	1.180	8	.272

Table 4-34 (Continued)

	2	3.89	3.67	**.22**	.555	8	.594
	3	3.67	3.67	**.00**	.000	8	1.000
Back waist placement	1	4.22	4	**.22**	1.000	8	.347
	2	4.00	3.22	**.78**	1.673	8	.133
	3	3.56	3.56	**.00**	.000	8	1.000
Crotch placement	1	3.33	3.33	**.00**	.000	8	1.000
	2	2.78	3.00	-.22	-.389	8	.708
	3	3.11	3.00	**.11**	.359	8	.729
Side seam placement	1	4.22	4.11	**.11**	1.000	8	.347
	2	4.00	3.89	**.11**	.426	8	.681
	3	4.22	3.89	**.33**	1.414	8	.195
Inseam length	1	4.22	3.94	**.28**	1.474	8	.179
	2	3.11	3.44	-.33	-1.155	8	.282
	3	3.78	3.11	**.67**	4.000	8	.004*
Overall	1	3.44	3.56	**.11**	-.426	8	.681
	2	3.56	3.5	**.06**	.141	8	.892
	3	3.33	3.22	**.11**	.426	8	.681

* $p < .05$

Cells of effects which are significant are shaded, and fonts are bold when A is rated higher than B.

provided higher satisfaction than A for group 1 (.22). Regarding ankle ease, type B provided higher satisfaction than A for group 1 (-.33) and group 3 (-.22), and type B provided higher satisfaction than A for group 2 (.11). In the area of crotch placement, both types gave similar level of satisfaction for group 1, type B provided higher satisfaction than A for group 2 (-.22), and type A provided higher satisfaction than B for group 3 (.11).

Overall fit satisfaction was similar between the two types (A: .3.44, B: 3.43), and the results of pairwise comparisons of means of type according to groups showed that type A tended to be rated with a slightly higher fit satisfaction than B.

CHAPTER 5. DISCUSSION AND CONCLUSIONS

Body Shape Analysis

With 3D body scan technology, new types of measurements such as width, front depth, back depth, front and back arc measurements, and their drops are relatively easily available. This new capability makes it possible to think about body shape in a new way. In this study the variety of body measurements that could be derived and used in analysis allowed me to think about body shape in a new way, incorporating measurements that can quantify both the silhouette view and the profile view of the body. Using these new measurements in PCA I could prevent the problems demonstrated in past PC studies of body shape using PCA and cluster analysis, in which sets of horizontal measurements and vertical measurements tended to collect into PC1 and PC2, thus obscuring the differences in body shapes (M. E. Green, 1981; C.J. Salusso-Deonier et al., 2006; C. J. Salusso-Deonier et al., 1985). In this study I identified three principal components, and z-scores of two variables (corresponding PC4 and PC5 values identified from a pre-PCA analysis) that clearly represented distinctive shapes from the silhouette and profile views of the lower body. A representative system identifying three lower body shape groups was developed using cluster analysis, and the three groups were shown to be significantly different from one another on all components.

Three clusters may not be sufficient to fully represent complex body shapes. It is difficult to categorize the specific number of clusters needed since the data are continuous, resulting in the difficulty of dividing groups into distinct clusters, an issue with any shape analysis system. However, three clusters were the most efficient cluster number for this study when compared to two, four, or five clusters. Here I present a new methodology for body shape analysis. In future studies these methods can be used to develop other body shape groups using different body measurements or different numbers of clusters. For example, I rejected the 5 cluster model because cluster number 3 in this model represented a very small percentage of the population. It would have been difficult to locate a sufficient number of study participants in this shape group (that would not be well represented in the population) for the work conducted on automated pattern systems for 'each' shape group for this study,. However for some purposes it may be desirable to identify such a small group of individuals with a unique shape. Perhaps this shape group would be a good target market niche for an apparel company.

My body shape analysis method has improved features which may be more effective at describing unique and useful body categories when compared to the methods which have been previously published.

For example, while the method described by Connell et. al (2006) described body shape in all dimensions, it relies on a visual analysis method using nine scales for body shape assessment from front and side views. However, subjective visual analysis may not provide reliable results. My method is more objective and reliable since determination of body shapes is done using statistical methods of categorizing from body measurements. Other popular categorization methods such as that developed by Simmons, Istook, and Devarajan (2004) based on ratios of body circumferences have value; body shapes can be easily determined by the public if they know their girth measurements at key body locations. However, this method can only represent general proportions and is unable to differentiate shapes in all dimensions (front and side views) completely. My method uses a variety of measurements and more complex calculations which can describe front and side silhouettes more distinctively and completely.

While my method has strengths, my method also has some weaknesses. If a person has their 3D scan and her measurements are generated using $[TC]^2$ automated measuring software, her body shape can be easily determined by calculating her discriminant scores. However if a person does not have access to body scan technology or the $[TC]^2$ software, then manual measurements are not a good substitute. It would be not be easy to obtain measurements without somebody's help, especially arc, front depth, and back depth measurements. Although the measuring procedures and measurement locations are described completely, tools and skills for taking the measurements are not easily available. Another issue is side seam locations. Side seam locations for arc measurements are different at waist, top hip and hip. In addition, side seam locations for front and back depths are different from those for arc measurements. My method was based on SizeUSA data, so arc measurements were defined automatically and constrained to the definition used in SizeUSA. If $[TC]^2$ measuring software is developed to enable to define an 'optimal' single definition of side seam placements, this may improve the reliability of this method.

Previous studies which used PCA and cluster analysis did not progress past the initial stage of identifying different groups. However, in order to use these results, it is necessary to be able to easily identify the body shape group of new individuals compared to the database used for analysis. Therefore, I went one stage further to develop an application for determining a new person's body shape group; a discriminant analysis process.

Other methods can be used to define the body shape of a new individual. For example, it is possible to define cluster models which could be used to score new subject's measurements as having the highest likelihood of belonging to an individual cluster. Specifically, from new measurements, the individual's corresponding PC scores could be derived through transposing the measurements with the eigenvectors calculated from our training sample. These scores could then be classified as belonging to one of the PC clusters where each individual PC cluster would have a mean PC score with a known variability. The mean and variation would allow the calculation of a probability score for the new person from the new PC scores for each cluster. The highest probability would define the cluster the new subject belonged to.

Another possibility would simply to run the cluster analysis again, with the new individual added to the database. It is then possible to see which cluster the individual is assigned to.

However, I believe that the advantages of the discriminant analysis method are that it is more direct and intuitive. Since the functions just consist of two simple equations, the scores can be calculated simply without access to the full database used to identify PC clusters. Identifying an individual's place in the cluster is easier because it is a simple process to compare the two scores with a bivariate scatterplot that shows the composition of each group plotted by their discriminant analysis scores. The method that I developed can also show if a person is centered in the cluster, or is close to a border between clusters.

This body shape analysis was a starting stage of the whole study whose goal is to develop an improved automated custom patternmaking system. I developed a block pants pattern for each body shape group identified by this study in stage 2, and tested a shape-driven customization system whose alterations start from the appropriate block patterns for each of the three body shape groups in stage 3. Then, I tested whether the new system provided custom pants with better fit.

In existing automated made-to-measure computer-aided design programs, girths (e.g., waist girth and hip girth) and lengths (e.g., inseam and waist to crotch height) can be easily altered, however, pattern alterations such as the center back seam angle (affected by buttocks angle), the center front seam angle (affected by abdomen prominence), the proportion of front to back panels and side seam location (front and back depth proportions) are difficult areas to adjust in the automated system. Different block patterns based on body shape can be used to establish appropriate angles and pattern proportions and may be a means to solve these problems. Therefore, for this shape analysis, I decided that, though important, I would not include size-related variables such as girths and lengths because these measures are linked to relatively simple alterations. Instead, I focused on sorting into groups based on shape-related variables such as drops of girths that define proportional measures. However, for further studies pursuing other purposes (e.g., creation of ready-to-wear sizing systems), different sets of vertical and horizontal descriptors may be useful for analysis.

In this study I focused on analysis of body shape from waist to hip levels. This study did not include measurements related to thigh areas, so analysis of hip to thigh shape was not conducted. (In the initial stage of the PCA, I added drop of hip girth to max-thigh girth, but it was not separated as one of the PCAs, so I removed it from the analysis). Hip to thigh shape is critical to lower body shape analysis and pants fit. But this shape is complicated and difficult to analyze, so there have been few research studies addressing this body area.

To analyze hip to thigh shape, I suggest three strategies for further studies: The first strategy is to include more measurements related to from hip to thigh areas beyond the SizeUSA data (The current SizeUSA dataset has only max-thigh girths and mid-thigh girths). The ability to generate new measurements from the 3D body scans is one of the key advantages of an anthropometric study conducted using 3D scan technology. For example, as new measurements, girth measurement taken from a half (a third or two thirds) level between hip and max-thigh levels can be considered. I expect that if drops between these measurements are added in PCA, separate PCs related to one of the distinctive shapes between hip to thigh levels could be extracted. The second strategy is to analyze only a half side (left or right) of the body from the hip to thigh levels. For example, for the PCA, drop of half hip girth (from a center front point to a center back point) to thigh girth would be more appropriate than drop of full hip girth to thigh girth when analyzing the hip to thigh shape. Using these strategies, if hip to thigh shapes are extracted as one of the PCs, my body shape analysis would have more strength. A third strategy would be to use the drop of half hip width to thigh width (both measured from centerline of body) which would define side profiles in this area more effectively.

This study analyzed lower body shapes of a population of U.S. women of age 18 to 35 within the 90th percentile of BMI (34.14). Further research can be conducted using these methods to develop body shape categories for the upper body, for larger women, for older women, and for women of different ethnicities. Similar studies can also be conducted for men. It has long been recognized that successful sizing systems and mass customization systems must be based on complex variations in body shape and posture as well as size. With the use of 3D body scan data and the methods presented here for categorizing complex body shape measures reliably, these important variations in the population can be addressed and accommodated.

Development of Block Patterns for Each Body Shape Group

I developed a block pattern for each body shape group identified by the body shape analysis for this study. Based on comparisons of patterns within the group and among the groups, variance in pattern shape was found in five areas of the pattern: center back seam slope, center front seam slope, front dart amount, silhouette of side seam, and proportion of front and back pattern pieces. The most obvious differences among the patterns were the center back seam slopes. As the buttocks angles increased, the slopes became more tilted. The buttocks of group 2 were the most prominent (25.8°), while group 1 and 3 had less prominent buttocks (21.3° and 20.6°). Therefore the center back seam slope of group 2 was the most tilted. Since the relationship between the buttocks prominence and the back seam slope was obvious, I could make a decision about the most effective pattern alterations easily. In stage 3, the results showed that the fit of pants type A made using shape-driven customization method provided better fit than type B at back waist and hip areas. The results showed that appropriate center back seam slopes were developed in this stage, so the back seam slope changes can be considered as an effective strategy for automated custom fit.

The center front seam slopes were also varied according to body shape groups. The degree of slope was influenced by drop of front abdomen depth to front hip depth. As the drops were larger, the center front seam slopes became more tilted. Since group 2 had the largest drop, the center front seam slope was the most tilted. It was found that the drop of front hip girth to front waist girth was also related to the center front seam slope when patterns were compared within groups 1 and 2, even though the differences were not found in comparisons among the final three block patterns. As the drop increased, the center front seam slope became more tilted since increasing or decreasing the front waist girth was conducted in both center front seam and side seam. Analysis of the relationship between center front seam angle and body areas was more difficult than center back seam slope. Buttocks prominence had larger variations, so it was easy to find a relationship between the body and the back seam slope. However the two drops used for the analysis of the center front seam slope had small variations (less than 0.5 in) across the fit models, so it was difficult to analyze. The center front seam slope of group 2 was different from the other three patterns (group 1, 3 and industry pattern), which were similar each other.

The third difference in patterns was the front dart amount. The drop of front top hip girth to front waist girth and drop of front abdomen depth to front waist depth affected the front dart amount. As the drop increased, the dart amount became larger.

The dart length was relatively related to the dart amount. For example, as the dart amount was larger, the dart length became longer. Based on the results of fit evaluation in stage 3, the center front seam slope and the front dart amount influenced the fit of pants less than the center back seam slope.

The fourth difference in patterns was the silhouette of the side seams. Depending on abdomen and buttocks prominence, silhouettes of the side seams were changed. Group 1 had curvier side seams from waist to top hip level, while group 3 had straighter side seams from waist to hip level than the other groups.

The last difference was in the proportion of the front and back pattern pieces. At waist level, the front pattern piece of group 1 had a larger proportion than the back pattern piece (1:0.97), while the other group's patterns were smaller in front compared to the back (group 2: 1:1.08, group 3: 1:1.02). One important finding of this study was that silhouette and location of the side seam were differentiated by lower body shape groups. Previous studies of pattern development techniques related to body shape variables generally adjusted only center back seam slope and crotch extension depending on buttocks shape (full or flat), and researchers did not address possible changes to the side seam. However, in this study I discovered that side seam placement overall affected the pants fit more than previously expected. As shown by the results of fit evaluations in stage 3, this factor influenced waist, hip, and crotch fit as a whole. 50 to 60% of type B had problems with forward placement of the side seam, while type A had good fit for 81.5 to 88.9% of the group. Therefore the side seam locations developed in stage 2 can be considered as a well-determined area, and an effective pattern alteration strategy to improve the fit of custom-made pants.

For the analysis of relationships among body shapes and patterns, the fit at the waist, hip, and side seams in patterns were relatively easy to analyze and accommodate, but it was difficult to analyze crotch extension. In order to analyze the differences of front crotch extension and back crotch extension depending on shape groups, it was necessary to mark the crotch point location of the front and back patterns during the fit session. However, it was very difficult to identify and mark the crotch point during the fit session. Since front and back crotch extensions in patterns could not be accurately obtained from the fitting, it was not easy to analyze this pattern variable in relation to body shape and size. Another reason for the difficulty of analysis of the crotch shape in patterns is that thigh girth, hip depth and abdomen depth were inter-related and simultaneously influenced the crotch curve shape and crotch extension amount. It was found that crotch extension was related to thigh girth and buttocks depth, but the proportion of front to back crotch extension in relation to body shape differences and other pattern modifications was hard to identify. Thigh measurements were not included in the body shape analysis to determine body groups, so there would be variability within each group on the thigh shapes, which would also impact the crotch extension.

This dissertation studied methods of improving the overall fit of pants, so I could not concentrate on pattern development at crotch area specifically. If fit models have more available time for fittings and patternmakers with a high level of experiences in crotch fit conduct fittings, the crotch area in patterns would be more accurately developed, and the analysis of the relationship between the crotch shape in patterns and body shape and size would be more reliable.

During the fittings I encountered some difficulties. Fitting pants is a complicated process requiring high level skills, labor and time. To create pants patterns with good fit, each fit model needed three to five fittings, and sometimes more than five fittings were necessary. However, participants could not be convinced to come more than five times, so the last correction of the pattern was not confirmed by an actual fitting for some of the models. However this was not considered to be a big issue since the patterns just needed minor corrections at this stage and the final block pattern for each group was made based on comparisons of three fit models' patterns.

I think if I had tested the pilot pant pattern shape on more than two people (beyond myself) and had perfected this pattern more carefully before developing patterns and conducting fittings with participants, the number of fittings could have been decreased by at least one or two. In setting up the pilot made-to-measure system, I created pants using my size and tested the system. At that time the hip ease amount of the base prototype patterns had been decreased by 2.5 cm (1 in). Though this ease amount was appropriate for my size (flat buttocks shape and small hip size), the ease amount was probably decreased too much at that time for average women. Since the participants' custom pants were altered and generated from these base patterns (with an incorrect hip ease amount), most of the participants' pants had tight fit at the hip area at the first fitting.

Another difficulty was communication with the fit models. These participants were not professional fit models, so they had no knowledge of good fit. In the apparel industry, designers or technical designers generally rely on not only garment appearance, but also professional fit models' responses to their fit. Sometimes, even if the appearance of the clothing on a dress form is good with no stress folds, the fit can be too tight since extra ease amounts are necessary for movement. Therefore live fit models are commonly used for evaluating clothing fit because human bodies are involved and their comments on fit are valuable (Bye & LaBat, 2005). The professional fit models know what fit criteria designers and patternmakers consider important at each location, and they can express them in detail using appropriate precise apparel terms. Also, they can judge the fit regardless of their individual fit preferences and represent a general customer's perspective. However, when I asked my fit models about the fit of their custom pants, most of the fit models generally only indicated when their pants felt very tight or very loose to them. Some fit models preferred a very tight fit, like the fit of a skinny jeans style currently popular in the young women's market. Therefore the fit of pants was mainly determined by expert analysis of the five fit standards (ease, line, grain, balance and set defined by Erwin, Kinchen, & Peters (1979), rather than each fit model's different responses based on their own fit perceptions and preferences.

During the fit sessions, the fit of pants was determined by one judge (myself). The silhouette and ease amounts of the final pants were slightly different across the pants. During the fit sessions, I mainly focused on fit analysis to provide comfort ease and remove wrinkles. Therefore I think that I developed the pants with generally looser fit, though the style of the pants was also originally loose. If I had enough resources to conduct the study with a second fitting expert, the alterations made to the pants to develop the block patterns for each group would be more validated, and may have removed a possible bias toward looser fit that could have been introduced by myself as the lone expert.

Another issue in this study was that slightly different ease amounts were used across the three block patterns. I had first considered that the same ease amounts would be needed across the three block patterns, but as I fitted each of the nine fit models, I decided not to standardize ease values as there was a possibility that each body shape needs different ease amounts at each body location, as determined by Adriana Petrova in her study (Petrova & Ashdown, 2008). If ease amounts are arbitrarily changed, the pattern proportions could be distorted, or fit problems which were not identified for those fit models who did not have a final fitting could occur. This is an important factor as ease values for the automated patternmaking process are established in the system by the relationships between the body chart and garment chart, which were established based on the development of the block patterns. It was unclear whether this determination of ease was a good strategy. Further study is needed for this variable.

Even though there were some unresolved issues at this stage, this study has several strengths, so it is expected to contribute to future studies of this kind for discovering new ways of establishing shape groups, selecting fit models, and developing pattern blocks. One strength of this study is that the block patterns were developed by fitting pants on multiple fit models. Development of accurately shaped block patterns is critical to apparel companies. They produce only several sizes (e.g., xs, s, m, l, xl) to accommodate their target market customers, so their block patterns should be developed to represent body shapes of their target market as much as possible. However, in the apparel industry, prototype garments are generally fitted on a single fit model, and base patterns and grade rules are developed matching the proportions of their fit model. However it is difficult and sometimes impossible to find a fit model who has perfect body measurements and proportions at all body locations. Also, it is likely that she cannot represent all body shapes of a target market of the company. As this study showed, even if women had the same body size, pattern shapes were different as their shapes were different (both within and among the three shape groups). If garments in a base size are fitted on a single fit model that cannot represent the chosen target market completely, fit problems can occur across the full range of sizes. In this study it was possible to see variations in pattern shapes and to find an optimal pattern shape by fitting pants on multiple fit models in each body shape group. I could create block patterns with more reliability and validity than those that are developed by fitting to a single model.

While apparel companies fit their garments on a single fit model, they can revise and update their block patterns by analyzing feedback (e.g., return rates and store managers' comments about fit) regarding fit from their customers. My study has an advantage because the fitting was done on multiple fit models, but I missed the stage of validating whether the developed block patterns can represent a range of women in each body shape group, before proceeding to stage 3. If time and labor resources are available, testing fit of the developed block patterns on several random women in each body shape group would increase the validity of the developed block patterns.

The process of selecting fit models is also one of the strengths of this study. Generally, when fit models are selected, their body sizes (e.g., bust girth, waist girth, and hip girth) are the only variables considered. In this study, fit models were selected with consideration of body shape as well. The first criterion for selection of fit models was the hip girth measurement (body size), and the second set of criteria related to body shape; all participants' five variable (distinctive body shape) scores were compared with the median size model's scores of their body shape group using pentagonal graphs. Each individual's placement of five variables was compared within the group and among the groups, and the most representative three fit models were selected.

In this study the fit testing was conducted with four postures (standing, sitting on a chair, walking, and stepping) to analyze the fit in both the standard position and in active positions, because comfort ease amounts can be more effectively identified when a wearer is moving. When wearers judged the fit at inseam length, they did not identify length problems in the pants when they were standing, but they felt the inseam was short when sitting or walking. In stage 3, expert judges were provided with only pictures in standing posture when judging the fit, so they could not identify short length problems related to sitting and walking. Therefore I highly recommend fit testing in different active postures to identify fit problems.

Another advantage of this study is that development of block patterns was based on an objective body shape analysis and classification. There have been a few studies that analyzed the relationships between lower body shape and patterns. Earlier studies for pattern development based on body shape were limited to classification of the degree of buttocks prominence into two or three groups by visual judgment, or calculation of waist to hip proportion. However in this study, body shapes were classified by cluster analysis using five component scores derived from PCA, so the development of patterns were based on a much more objective, data-driven, and detailed method. This process helped to identify relationships between body shape and patterns more broadly and interactively since the method of this body shape analysis could represent shape variations across a wide range of locations.

Comparison of Fit of Two Pairs of Pants Made by Standard Customization System and Body Shape Driven Customization System

The fit of pants developed from an automated custom-made system using three block patterns driven by body shape *(type A: body shape driven customization method)* was statistically compared with the fit of pants created from an automated custom-made system using a single block pattern (*type B: standard customization method)*. Evaluation of fit was conducted by both experts and wearers. Overall, pants from body shape driven customization method (type A) were judged to have better fit than pants created from standard customization method (type B) at most body locations, especially by the experts. The results of experts' evaluation of fit showed that type A provided significantly better fit at waist ease, waist placement, crotch length, and side seam placement ($p < .05$). At abdomen ease, buttocks ease, front crotch ease, front thigh ease, and side seam location, type A was also judged to have tendencies toward better fit even though the differences of the two types were not significantly different. At back crotch ease, thigh ease, and inseam length, type B had a tendency to exhibit equal or better fit, but the fit variables were not significantly different and the fit differences were not large. Wearers' fit analysis showed some similar results to those of the expert analysis process. Type A was judged to have better fit at waist and abdomen with significant differences ($p < .05$). At crotch ease and thigh ease, type B were judged to have better fit, but not at a significant level.

At the waist and abdomen, type A provided good fit for most of the wearers, and definitely had better fit than type B. At the hip, type A had good or loose fit. However, type B had tight fit problems at the front waist, loose fit problems at the back waist, and tight fit problems at the back hip overall. These fit problems caused tight fit problems at the back crotch. The fit problems of type B were caused by the center back seam slope and side seam placement which were not balanced for each participant's body shape. While the alteration process of type B started from a single block pattern, type A was made on the basis of block patterns of their selected group that are balanced and corrected for each participant's figure type and posture. The made-to-measure system could effectively alter the girth measurements, but it could not automatically adjust the center back seam slope and the proportion of the front and back pattern pieces from the block patterns. Therefore in type B, even though the waist girth and hip girth were adjusted to meet each participant's size, the front waist was tight and back waist was loose since the center back seam angle in their block patterns was too vertical for their back waist to buttocks shapes, and the side seam location was too forward for their front to back proportions.

When the fit of hip and crotch areas were analyzed, the different perspectives between wearers' and experts' fit evaluations were found. For example, experts judged type B to have tight fit (55.5%) or good fit (40.7%) at the hip, but wearers judged the fit as loose (44.4%) or good (55.6%) in group 2. Wearers tended to feel loose in the areas of the pants judged to have good fit by experts, and good fit in the areas of the pants judged to have tight fit by experts. These kinds of differences were found in all groups. At the back crotch area, experts found tight fit problems (44.4 to 63.0%) in type B for all groups, and in front crotch area for type B (33.3%) in group 2 and in group 3 (25.9%). However, wearers perceived good fit for 33.3 to 66.7% across these groups in this area, and all the areas with perceived fit problems were judged to be loose, except for one case. Many times stress folds due to tightness were visible in the type B pants, but wearers still preferred type B to type A.

At the crotch and thigh areas, about 50% of the wearers perceived loose, and type A had loose fit problems about 10% more than B. The reason that loose fit problems were slightly less detected in type B was that type B had interactions with the tight fit problems at front waist and back hip areas, resulting in the fabric at the back thigh being pulled toward the front. Regarding crotch length, both A and B types were judged to have long fit problems for over 50% of the participants.

One possible reason that about 50% of the wearers perceived loose fit at the crotch and thigh areas is that the style of the test pants was a 'trouser' style which hung straight from the abdomen and buttocks to the hem as shown in Figure 5-1. I used this style because of its ubiquity and potential for use as base pattern for other styles. The style was designed to have much looser fit and longer crotch length than the jeans currently popular in women aged 18 to 35 in the market, so wearers judged the fit of the pants (from the thigh to hem) to have loose fit problems. Before I started this study, I intended to test a more fitted style. However after the pilot test, I realized that the property of the test fabric did not allow me to test the tight style since the fabric was not as flexible as denim or fabrics with a Lycra ® content, resulting in exaggerating on stress folds. Therefore I changed the style to a trouser style for the study. For the further study, if it is possible to obtain more appropriate fabric, the style can be designed to be more fitted (between ‘slack’ and ‘jeans’ in Figure 5-1), and better responses to fit in the thigh area can be obtained from wearers.

Another possible reason that I realized is that most of the participants of this study were in younger age group (aged 18 to 25) that generally prefers tight fit to loose fit. During the fitting, particularly young participants (undergraduates) told me that they did not like the style and fit of the pants, because the pants were too loose overall and the silhouette was too straight and baggy, compared to their preferences. However, I felt that if the age of the participants was higher, participants liked the pants more. If a similar style and fit were tested on an older age group, I expect that the results of fit evaluation would be different since they may prefer a more comfortable and less body-revealing fit. I tested for a relationship between fit judgments and age statistically, but the sample of women 25 to 35 was too small to see an effect. I expect that this would be a good research topic for further study.

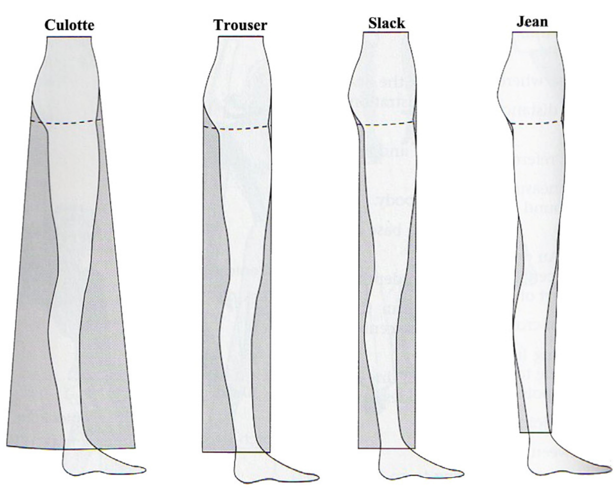


Figure 5-1. Pants styles defined by Armstrong (2006).

For the inseam length, the fit of the two pants were slightly different. Experts evaluated that both types provided either good length or long fit problems for about

50% of the group in all groups. Type B had a very slightly higher percentage of good length (about 3.7 to 7.5%) in all groups. It was found that wearers had different perspectives than the experts on inseam length. Wearers judged the fit ‘good’ which experts judged as ‘short, and ‘long’ which experts judged as s ‘good’. Even though the pictures of the standard posture showed that the pants had the right length or somewhat long, wearers actually reported that the length was short when they were sitting or walking. Expert fit judges were provided with front, side and back views of the standard posture, but I did not provide pictures of sitting and walking postures since each judge had to analyze front, side, and back view pictures of 2 sets of 27 participants in the single standing posture ($3 \times 2 \times 27 = 162$ images). I determined that pictures of standard posture would be sufficient for judges to analyze the fit. There was no problem in judging the fit at the majority of the body areas, but when judging the inseam length, the judges would have had more complete information with additional pictures of active postures. Actually the fit at the previous locations discussed and analyzed are closely related to body shapes, but inseam length is related to body size (leg length). Therefore, it is relatively less meaningful to compare the inseam length issues between the two types based on body shape groups.

This study was designed to test a shape-driven customization system whose alterations start from appropriate block patterns. This study can be considered as the first trial to test the automated system utilizing different block patterns shaped for different body shapes, as no previous published study was found to test this issue even though both Nancy Staples and Cynthia Istook have addressed the significance of body shape information for custom-pattern generations. The results of this study showed that the new made-to-measure system incorporating body shape information into block patterns can generate custom patterns with better fit. This study can work as a pioneer in these kinds of studies and provide new and valuable information for both the academic field of apparel design and the apparel industry.

This study found that appropriate block patterns can improve fit of custom pants generated by automated made-to-measure CAD software. However, a well-shaped block pattern is just one of the critical elements in setting up the system. Further studies need to study methods of creating a body size chart that reflects the target market, developing correctly graded patterns that are used for alteration, determining appropriate alteration rules, accommodating an individual's fit preference to the system, and taking accurate measurements that are matched to those in a body chart.

Among these elements, a study to determine appropriate alteration rules can be the next stage of this study. For this study I set alteration rules as simply as possible to reduce the influence of alteration rules to the system, since the purpose was to judge influences of block patterns to the system. Therefore this study set up alteration rules only at primary locations such as waist girth, hip girth, thigh girth, waist to crotch length, and inseam length. However if multi dimensional and specified alterations are set up in the system, they can help with improving fit of custom clothing generated by the system.

Methods for setting up multi dimensional alterations can be developed on the basis of an analysis of the nine well-shaped patterns made for development of the three block patterns in this study. The process of refining the patterns and comparisons of patterns enable to show where size and shape in patterns are changed depending on body size and shape. Beyond altering at only primary girth or length measurements, if additional locations such as abdomen prominence (depth from front waist point to abdomen point), slope of front abdomen to front hip point (related to center front slope), buttocks prominence (related to center back slope), waist to abdomen length, waist to hip length are added in alteration process, the fit of custom clothing would be improved.

This study addressed the commercial systems that use body measurements to generate custom fit patterns by applying automated alterations to a graded pattern. But various elements such as body charts, block patterns, grading, and garment charts need to be correctly set up in the system, so the preparatory activities are laborious. Limited alterations are conducted because the system selects a pattern from a previously graded nest of patterns and alters it. If new software which can create automated custom-made patterns directly from an individual's body measurements is developed, the laborious process for matching all these elements is not necessary. Valuable data obtained from this study are the nine patterns made for fit models of different shapes and the 27 custom patterns developed from these base patterns. These patterns, and patterns developed using similar methods can be used to develop a new concept in custom patternmaking software. After the participants in each shape group within the most well-fitted patterns are selected, their patterns and their body measurements which were used for development of the patterns can be linked. When Bye, LaBat, McKinney, & Kim (2008) developed fit-to-shape grading method, they found that increasing/decreasing amounts, and locations where changes occur were different depending on sizes. Therefore in order to develop a formula used to change the block pattern according to an individual's body measurements, it is necessary to analyze the relationships between size/shape in patterns and body size/shape in detail. I have 27 fit models' numerous detailed body measurements such as depth, width, front and back arcs taken from the 3D scans, and their well-fitted custom patterns. Therefore it would be easy to see the variations between the pattern and body, and this information would help with developing the new software to generate custom fit pants. Eventually it should be possible to create a system that morphs the two dimensional pattern directly, based on body measurements that define the three dimensional body shape.

APPENDICES

APPENDIX 1: Frequencies of judges’ fit scores of type and shape group (five-point scale).

Areas	Group	Type	Fit score 1		2		3		4		5	
Front waist ease	1	A			2	7.4%	25	92.6%				
		B	2	7.4%	12	44.4%	13	48.1%				
	2	A			3	11.1%	24	88.9%				
		B	3	11.1%	9	33.3%	14	51.9%	1	3.7%		
	3	A			2	7.4%	23	85.2%	2	7.4%		
		B			7	25.9%	20	74.1%				
Back waist ease	1	A			3	11.1%	20	74.1%	4	14.8%		
		B	3	11.1%	5	18.5%	10	37.0%	8	29.6%	1	3.7%
	2	A	1	3.7%	4	14.8%	22	81.5%				
		B	1	3.7%			8	29.6%	11	40.7%	7	25.9%
	3	A			3	11.1%	24	88.9%				
		B	1	3.7%	3	11.1%	13	48.1%	6	22.2%	4	14.8%
Abdomen ease	1	A	1	3.7%	8	29.6%	8	29.6%	9	33.3%	1	3.7%
		B			4	14.8%	8	29.6%	15	55.6%		
	2	A			1	3.7%	10	37.0%	15	55.6%	1	3.7%
		B	1	3.7%	8	29.6%	8	29.6%	9	33.3%	1	3.7%
	3	A			4	14.8%	8	29.6%	15	55.6%		
		B			1	3.7%	10	37.0%	15	55.6%	1	3.7%
Buttocks ease	1	A			7	25.9%	12	44.4%	7	25.9%	1	3.7%
		B	3	11.1%	11	40.7%	12	44.4%	1	3.7%		
	2	A			2	7.4%	14	51.9%	9	33.3%	2	7.4%
		B	2	7.4%	13	48.1%	11	40.7%	1	3.7%		
	3	A	1	3.7%	5	18.5%	16	59.3%	5	18.5%		
		B	4	14.8%	9	33.3%	14	51.9%				
Front crotch ease	1	A			6	22.2%	12	44.4%	8	29.6%	1	3.7%
		B			3	11.1%	13	48.1%	8	29.6%	3	11.1%
	2	A			3	11.1%	18	66.7%	4	14.8%	2	7.4%
		B	1	3.7%	8	29.6%	11	40.7%	5	18.5%	2	7.4%
	3	A			7	25.9%	14	51.9%	5	18.5%	1	3.7%
		B			5	18.5%	10	37.0%	5	18.5%	7	25.9%
Back crotch ease	1	A	5	18.5%	1	3.7%	13	48.1%	8	29.6%		
		B	3	11.1%	9	33.3%	12	44.4%	3	11.1%		
	2	A	2	7.4%	4	14.8%	5	18.5%	15	55.6%	1	3.7%
		B	3	11.1%	14	51.9%	9	33.3%	1	3.7%		
	3	A	7	25.9%	7	25.9%	8	29.6%	5	18.5%		
		B	5	18.5%	13	48.1%	6	22.2%	3	11.1%		
Front thigh ease	1	A			3	11.1%	17	63.0%	6	22.2%	1	3.7%
		B			6	22.2%	17	63.0%	4	14.8%		
	2	A			3	11.1%	15	55.6%	6	22.2%	3	11.1%
		B	1	3.7%	11	40.7%	11	40.7%	4	14.8%		
	3	A			1	3.7%	17	63.0%	9	33.3%		
		B			1	3.7%	21	77.8%	5	18.5%		
Back thigh ease	1	A					6	22.2%	17	63.0%	4	14.8%
		B					8	29.6%	16	59.3%	3	11.1%
	2	A					3	11.1%	17	63.0%	7	25.9%
		B			1	3.7%	7	25.9%	17	63.0%	2	7.4%
	3	A					9	33.3%	14	51.9%	4	14.8%
		B					13	48.1%	13	48.1%	1	3.7%

Crotch length	1	A			1	3.7%	15	55.6%	9	33.3%	2	7.4%
		B			3	11.1%	4	14.8%	15	55.6%	5	18.5%
	2	A					8	29.6%	13	48.1%	6	22.2%
		B			3	11.1%	5	18.5%	13	48.1%	6	22.2%
	3	A					8	29.6%	14	51.9%	5	18.5%
		B			3	11.1%	8	29.6%	8	29.6%	8	29.6%
Inseam length	1	A					12	44.4%	12	44.4%	3	11.1%
		B					14	51.9%	11	40.7%	2	7.4%
	2	A			1	3.7%	15	55.6%	6	22.2%	5	18.5%
		B			2	7.4%	16	59.3%	5	18.5%	4	14.8%
	3	A			1	3.7%	15	55.6%	10	37.0%	1	3.7%
		B			2	7.4%	16	59.3%	8	29.6%	1	3.7%
Front waist placement	1	A			4	14.8%	21	77.8%	2	7.4%		
		B			4	14.8%	20	74.1%	3	11.1%		
	2	A					14	51.9%	12	44.4%	1	3.7%
		B	1	3.7%	5	18.5%	13	48.1%	8	29.6%		
	3	A			2	7.4%	21	77.8%	4	14.8%		
		B	1	3.7%	9	33.3%	14	51.9%	3	11.1%		
Back waist placement	1	A			1	3.7%	22	81.5%	3	11.1%	1	3.7%
		B			1	3.7%	22	81.5%	4	14.8%		
	2	A			1	3.7%	26	96.3%				
		B			2	7.4%	17	63.0%	8	29.6%		
	3	A			1	3.7%	21	77.8%	5	18.5%		
		B			4	14.8%	15	55.6%	8	29.6%		
Side seam placement	1	A			5	18.5%	21	77.8%	1	3.7%		
		B	5	18.5%	10	37.0%	6	22.2%	5	18.5%	1	3.7%
	2	A					22	81.5%	5	18.5%		
		B	5	18.5%	12	44.4%	6	22.2%	3	11.1%	1	3.7%
	3	A			2	7.4%	24	88.9%	1	3.7%		
		B	8	29.6%	10	37.0%	3	11.1%	5	18.5%	1	3.7%

Note. Fit scores: The end points of each scale varied depending on the fit location, for example very tight (1) – very loose (5) or very short (1) – very long (5). The middle value of the scale, 3, represented good fit.

APPENDIX 2: Expert judges' test - Frequencies (%) of fit scores of type and shape group (sum of three judges).

	Body shape driven method (type A)			Standard method (type B)		
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
Front waist ease	Good (92.6) Tight (7.4)	Good (88.9) Tight (11.1)	Good (85.2) Tight, Loose (7.4)	Good (48.1) Tight (51.8)	Good (51.9) Tight (44.4) Loose (3.7)	Good (74.1) Tight (25.9)
Back waist ease	Good (74.1) Loose (14.8) Tight (7.2)	Good (81.5) Tight (18.5)	Good (88.9) Tight (11.1)	Good (37.0) Loose (33.3) Tight (29.6)	Loose (66.6) Good (29.6) Tight (3.7)	Good (48.1) Loose (37.0) Tight (14.8)
Abdomen ease	Loose (37.0) Tight (33.3) Good (29.6)	Loose (59.3) Good (37.0) Tight (3.7)	Loose (55.6) Good (29.6) Tight (14.8)	Loose (55.6) Good (29.6) Tight (14.8)	Loose (37.0) Good (29.6) Tight (33.3)	Loose (59.3) Good (37.0) Tight (3.7)
Buttocks ease	Good (44.4) Loose (29.6) Tight (25.9)	Good (51.9) Loose (40.7) Tight (7.4)	Good (59.3) Tight (22.2) Loose (18.5)	Tight (51.8) Good (44.4) Loose (3.7)	Tight (55.5) Good (40.7) Loose (3.7)	Good (51.9) Tight (48.1)
Front crotch ease	Good (44.4) Loose (33.3) Tight (22.2)	Good (66.7) Loose (22.2) Tight (11.1)	Good (51.9) Tight (25.9) Loose (22.2)	Good (48.1) Loose (40.7) Tight (11.1)	Good (40.7) Tight (33.3) Loose (25.9)	Loose (44.4) Good (37.0) Tight (18.5)
Back crotch ease	Good (48.1) Loose (29.6) Tight (22.2)	Loose (59.3) Tight (22.2) Good (18.5)	Tight (51.8) Good (29.6) Loose (18.5)	Good (44.4) Tight (44.4) Loose (11.1)	Tight (63.0) Good (33.3) Loose (3.7)	Tight (56.6) Good (22.2) Loose (11.1)
Front thigh ease	Good (63.0) Loose (25.9) Tight (11.1)	Good (55.6) Loose (33.3) Tight (11.1)	Good (63.0) Loose (33.3) Tight (3.7)	Good (63.0) Tight (22.2) Loose (14.8)	Tight (44.4) Good (40.7) Loose (14.8)	Good (77.8) Loose (18.5) Tight (3.7)
Back thigh ease	Loose (77.8) Good (22.2)	Loose (88.9) Good (11.1)	Loose (66.7) Good (33.3)	Loose (70.4) Good (29.6)	Loose (70.4) Good (25.9) Tight (3.7)	Loose (51.8) Good (48.1)
Crotch length	Good (55.6) Long (40.7) Short (3.7)	Long (70.3) Good (29.6)	Long (70.4) Good (29.6)	Long (74.1) Good (14.8) Short (11.1)	Long (70.3) Good (18.5) Short (11.1)	Long (59.2) Good (29.6) Short (11.1)
Inseam length	Long (55.5) Good (44.4)	Good (55.6) Long (40.7) Short (3.7)	Good (55.6) Long (40.7) Short (3.7)	Long (48.1) Good (51.9)	Good (59.3) Long (33.3) Short (7.4)	Good (59.6) Long (33.3) Short (7.4)
Front waist placement	Good (77.8) Low (14.8) High (7.4)	Good (51.9) High (48.1)	Good (77.8) High (14.8) Short (7.4)	Good (74.1) Low (14.8) High (11.1)	Good (48.1) High (29.6) Short (22.2)	Good (51.9) Low (37.0) High (11.1)
Back waist placement	Good (81.5) High (14.8) Low (3.7)	Good (96.3) Low (3.7)	Good (77.8) High (18.5) Low (3.7)	Good (81.5) High (14.8) Low (3.7)	Good (63.0) High (29.6) Low (7.4)	Good (55.6) High (29.6) Low (14.8)
Side seam placement	Good (77.8) Forward (18.5) Backward (3.7)	Good (81.5) Backward (18.5)	Good (88.9) Forward (7.4) Backward (3.7)	Forward (55.5) Good (22.2) Backward (22.2)	Forward (62.9) Good (22.2) Backward (14.8)	Forward (66.6) Backward (22.2) Good (11.1)

APPENDIX 3: Questionnaire for wearers' fit test.

<Questionnaire: Development of Custom-Made Pants Driven by Body Shape>

Participant #______, Body shape group #______

1. Please judge the fit of each body location. And indicate **how satisfied you are with the fit of the custom pants** on a scale of 1 to 5. Circle only one.

<Style A>

Areas	Judge the fit of each location							NOT Satisfied at all (1) ←		(3)	→ Very Satisfied	(5)
Waist ease	**Too Tight**	1	2	3	4	5	**Too Loose**	1	2	3	4	5
Abdomen ease	**Too Tight**	1	2	3	4	5	**Too Loose**	1	2	3	4	5
Hip ease	**Too Tight**	1	2	3	4	5	**Too Loose**	1	2	3	4	5
Thigh ease	**Too Tight**	1	2	3	4	5	**Too Loose**	1	2	3	4	5
Knee ease	**Too Tight**	1	2	3	4	5	**Too Loose**	1	2	3	4	5
Calf ease	**Too Tight**	1	2	3	4	5	**Too Loose**	1	2	3	4	5
Ankle ease	**Too Tight**	1	2	3	4	5	**Too Loose**	1	2	3	4	5
Crotch ease	**Too Tight**	1	2	3	4	5	**Too Loose**	1	2	3	4	5
Front Waist Placement	**Too Low**	1	2	3	4	5	**Too High**	1	2	3	4	5
Back Waist Placement	**Too Low**	1	2	3	4	5	**Too High**	1	2	3	4	5
Crotch Placement	**Too Low**	1	2	3	4	5	**Too High**	1	2	3	4	5
Hip Placement	**Too Low**	1	2	3	4	5	**Too High**	1	2	3	4	5
Side Seam Placement	**Too Forward**	1	2	3	4	5	**Too Backward**	1	2	3	4	5
Inseam Length (Pant Length)	**Too Short**	1	2	3	4	5	**Too Long**	1	2	3	4	5
Overall Fit				→				1	2	3	4	5

<Style B>

Areas	Judge the fit of each location							**NOT** Satisfied at all (1) ←		(3)	→	**Very** Satisfied (5)
Waist ease	**Too Tight**	1	2	3	4	5	**Too Loose**	1	2	3	4	5
Abdomen ease	**Too Tight**	1	2	3	4	5	**Too Loose**	1	2	3	4	5
Hip ease	**Too Tight**	1	2	3	4	5	**Too Loose**	1	2	3	4	5
Thigh ease	**Too Tight**	1	2	3	4	5	**Too Loose**	1	2	3	4	5
Knee ease	**Too Tight**	1	2	3	4	5	**Too Loose**	1	2	3	4	5
Calf ease	**Too Tight**	1	2	3	4	5	**Too Loose**	1	2	3	4	5
Ankle ease	**Too Tight**	1	2	3	4	5	**Too Loose**	1	2	3	4	5
Crotch ease	**Too Tight**	1	2	3	4	5	**Too Loose**	1	2	3	4	5
Front Waist Placement	**Too Low**	1	2	3	4	5	**Too High**	1	2	3	4	5
Back Waist Placement	**Too Low**	1	2	3	4	5	**Too High**	1	2	3	4	5
Crotch Placement	**Too Low**	1	2	3	4	5	**Too High**	1	2	3	4	5
Hip Placement	**Too Low**	1	2	3	4	5	**Too High**	1	2	3	4	5
Side Seam Placement	**Too Forward**	1	2	3	4	5	**Too Backward**	1	2	3	4	5
Inseam Length (Pant Length)	**Too Short**	1	2	3	4	5	**Too Long**	1	2	3	4	5
Overall Fit				→				1	2	3	4	5

2. Of the two pants, A and B, **which do you prefer the fit?** **A** style [ ] **B** style [ ]

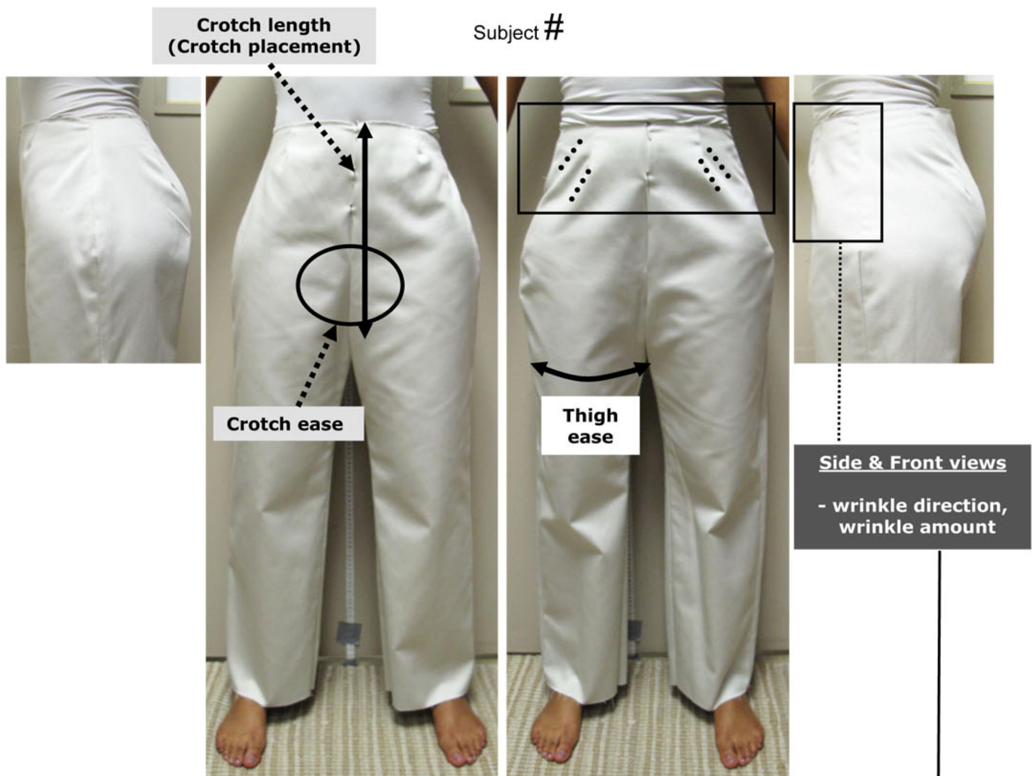
3. **Why** did you prefer this pant? ______________________________

____

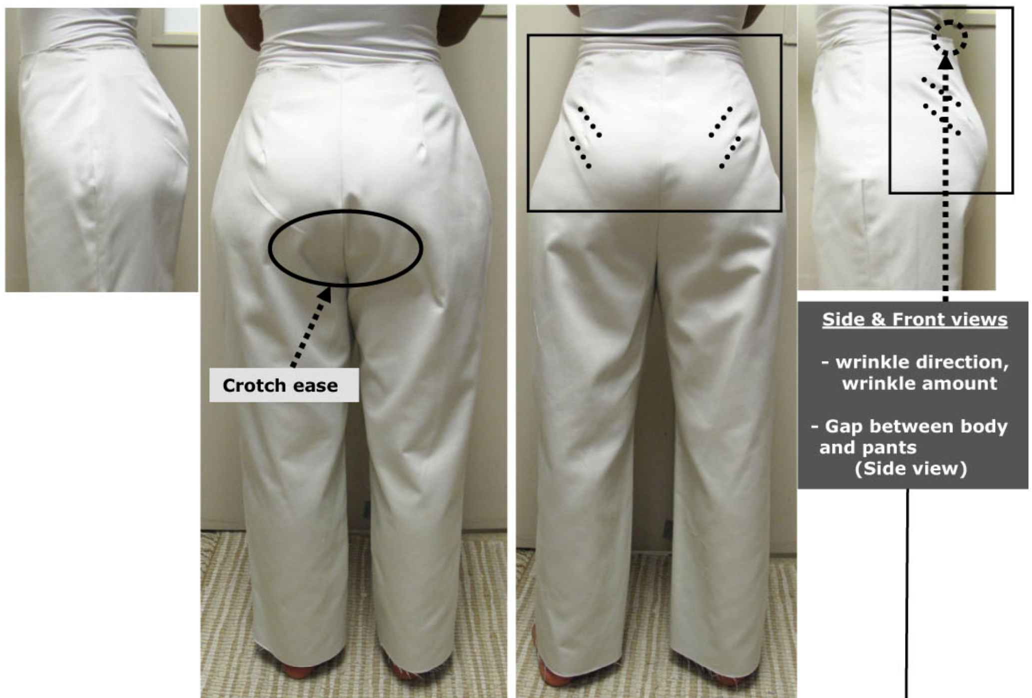
____

Thank you for your participation!

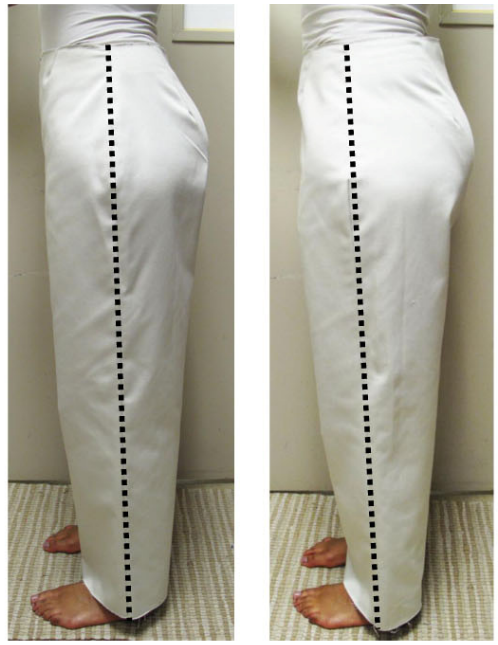
APPENDIX 4: Instruction for training expert judges.



Front View	Style A							Style B						
Waist ease	Too Tight	1	2	3	4	5	Too Loose	Too Tight	1	2	3	4	5	Too Loose
Abdomen ease	Too Tight	1	2	3	4	5	Too Loose	Too Tight	1	2	3	4	5	Too Loose
Thigh ease	Too Tight	1	2	3	4	5	Too Loose	Too Tight	1	2	3	4	5	Too Loose
Crotch ease	Too Tight	1	2	3	4	5	Too Loose	Too Tight	1	2	3	4	5	Too Loose
Crotch Length	Too Short	1	2	3	4	5	Too Long	Too Short	1	2	3	4	5	Too Long
Inseam Length	Too Short	1	2	3	4	5	Too Long	Too Short	1	2	3	4	5	Too Long



Back View	Style A							Style B						
Waist ease	Too Tight	1	2	3	4	5	Too Loose	Too Tight	1	2	3	4	5	Too Loose
Hip ease	Too Tight	1	2	3	4	5	Too Loose	Too Tight	1	2	3	4	5	Too Loose
Thigh ease	Too Tight	1	2	3	4	5	Too Loose	Too Tight	1	2	3	4	5	Too Loose
Crotch ease	Too Tight	1	2	3	4	5	Too Loose	Too Tight	1	2	3	4	5	Too Loose



Side seam should be <u>perpendicular</u> to the floor & placed in the <u>mid-point between abdomen and buttocks points.</u>

Side View	Style **A**	Style **B**
<u>Front</u> Waist Placement	Too Low 1 2 3 4 5 Too High	Too Low 1 2 3 4 5 Too High
<u>Back</u> Waist Placement	Too Low 1 2 3 4 5 Too High	Too Low 1 2 3 4 5 Too High
Side Seam Placement	1 Too Forward 2 3 4 5 Too Backward	1 Too Forward 2 3 4 5 Too Backward

★ **Please judge the overall fit [Front + Back + Side views] for 2 pairs [A + B] of pants.**

Overall Fit	Style **A**	Style **B**
	1 Very Bad 2 3 4 5 Very Good	1 Very Bad Good 2 3 4 5 Very

★ **Of the two pants, which one has better fit**? Style **A** [ ] Style **B** [ ]

★ **Please write some comments regarding the fit of two pairs of pants.**

Examples – Good fit

Examples – Poor fit (Waist & Hip)

Front Waist Ease	Very **Tight**
Back Hip Ease	**Tight**

Front Waist Ease	**Good** or **a little tight**
Back Hip Ease	**Tight**
Back Waist Ease	**Loose**

Examples – Poor fit (Side seam placement)

Good location

Poor location (Forward)

Poor location (Forward)

APPENDIX 5: Questionnaire for expert judges' fit test.

Subject # 2

Front View	Style **A**	Style **B**
Waist ease	Too Tight 1 2 3 4 5 Too Loose	Too Tight 1 2 3 4 5 Too Loose
Abdomen ease	Too Tight 1 2 3 4 5 Too Loose	Too Tight 1 2 3 4 5 Too Loose
Thigh ease	Too Tight 1 2 3 4 5 Too Loose	Too Tight 1 2 3 4 5 Too Loose
Crotch ease	Too Tight 1 2 3 4 5 Too Loose	Too Tight 1 2 3 4 5 Too Loose
Crotch Length	Too Short 1 2 3 4 5 Too Long	Too Short 1 2 3 4 5 Too Long
Inseam Length	Too Short 1 2 3 4 5 Too Long	Too Short 1 2 3 4 5 Too Long

Back View	Style **A**							Style **B**						
Waist ease	**Too Tight**	1	2	3	4	5	**Too Loose**	**Too Tight**	1	2	3	4	5	**Too Loose**
Hip ease	**Too Tight**	1	2	3	4	5	**Too Loose**	**Too Tight**	1	2	3	4	5	**Too Loose**
Thigh ease	**Too Tight**	1	2	3	4	5	**Too Loose**	**Too Tight**	1	2	3	4	5	**Too Loose**
Crotch ease	**Too Tight**	1	2	3	4	5	**Too Loose**	**Too Tight**	1	2	3	4	5	**Too Loose**


Side View	Style **A**	Style **B**
Front Waist Placement	Too Low 1 2 3 4 5 Too High	Too Low 1 2 3 4 5 Too High
Back Waist Placement	Too Low 1 2 3 4 5 Too High	Too Low 1 2 3 4 5 Too High
Side Seam Placement	1 2 3 4 5 Too Forward Too Backward	1 2 3 4 5 Too Forward Too Backward

★ **Please judge the overall fit [Front + Back + Side views] for 2 pairs [A + B] of pants.**

Overall Fit	Style **A**	Style **B**
	1 2 3 4 5 Very Bad Very Good	1 2 3 4 5 Very Bad Very Good

★ **Of the two pant, which one has better fit**? Style **A** [ ] Style **B** [ ]

★ **Please write some comments regarding the fit of two pairs of pants.**

REFERENCES

[TC]². (2004). *USA, The National Sizing Survey Final Report (2003-2004)*.

[TC]². (2006). The second annual SizeUSA users group meeting. *[TC]² By-Weekly Technology Communicator*. Retrieved January 2, 2009, from http://www.tc2.com/newsletter/arc/071206.html#two

[TC]². (2009). Custom clothing. Retrieved April 4, 2010, from http://www.tc2.com/news/3dbody.html

AFNOR. (1995). Textiles hosiery articles: Determination of the dimensions of stretched stockings, tights and other hosiery articles (Vol. NF G, pp. 32-104).

Aldrich, W. (2003). The impact of fashion on the cutting practices for the woman's tailored jacket 1800-1927. *Textile History, 34*(2), 144.

Aldrich, W. (2007). History of sizing systems and ready-to-wear garments. In *Sizing in clothing: Developing effective sizing systems for ready-to-wear clothing*. Cambridge, England: Woodhead Publishing Limited.

Alexander, M., Connell, L. J., & Presley, A. B. (2005). Communications: Clothing fit preferences of young female adult consumers. *International Journal of Clothing Science and Technology, 17*(1), 52-64.

Apeagyei, P. R., & Otieno, R. (2007). Usability of pattern customizing technology in the achievement and testing of fit for mass customization. *Journal of Fashion Marketing and Management, 11*(3), 349-365.

Archetype Solutions. (n.d.). *Refining apparel*. Retrieved August 26, 2009, from http://www.archetype-solutions.com

Armstrong, H. J. (1987). *Patternmaking for Fashion Design*. New York: Harper and Row.

Armstrong, H. J. (2006). *Patternmaking for Fashion Design*. New Jersey: Pearson

Prentice Hall.

Ashdown, S. P., Devine, C., & Erickson, P. (2010). *Research in body/garment relationships.* Proceeding of the International Conference on 3D Body Scanning Technologies, Lugno, Switzerland.

Ashdown, S. P., & Dunne, L. (2006). A study of automated custom fit: readiness of the technology for the apparel industry. *Clothing and Textiles Research Journal, 24*(2), 121-136.

Ashdown, S. P., Loker, S., & Adelson, C. (2005). Improved apparel sizing: Fit and anthropometic 3-D scan data Retrieved June 3, 2009, from National Textile Center: http://www.ntcresearch.org/pdf-rpts/Bref0607/S04-CR01-07.pdf

Ashdown, S. P., Loker, S., Schoenfelder, K., & Lyman-Clarke, L. (2004). Using 3D scans for fit analysis. *Journal of Textile and Apparel, Technology and Management, 4*(1), 1-12.

Ashdown, S. P., & O'Connell, E. K. (2006). Comparison of test protocols for judging the fit of mature women's apparel. *Clothing and Textiles Research Journal, 24*(2), 137-148.

August, B. (1981). *The Complet Bonnie August's Dress Thin System: 642 + Ways to Correct Figure Faults with Clothes*. New York: Rawson, Wade Publishers.

Benander, K. (2010). Levi's revolutionary new fit system focuses on shape, not size. Retrieved October 16, 2010, from http://www.highbeam.com/doc/1G1-233958261.html

Brackelsberg, P., Ferrell-Beck, J. A., & Winakor, G. (1986). Comparing fit of basic bodices and skirts altered by traditional and experimental techniques. *Clothing and Textiles Research Journal, 5*(1), 34-41.

Brackelsberg, P., & Marshall, R. (1990). *Unit Method of Clothing Construction* (7th ed.). Prospect Heights, IL: Waveland Press.

Bray, N. (1978). *Dress Fitting: Principle and Practice*. London: Lockwood.

Bray, N. (1994). *Dress Pattern Designing - the Basic Principle of Cut and Fit* (5th ed.). Oxford: Blackwell Scientific.

Brinson, E. G. (1977). *Pattern alterations predicted and quantified using angle measurements.* Auburn University, Auburn, AL.

Buckner, K., Ashdown, S. P., & Lyman-Clarke, K. (2007). *Nike lifestyle jacket style #251314: Sizing, fit and design features for a younger demographic*. Ithaca: Department of fiber science and apparel design, Cornell University.

Bye, E., & LaBat, K. (2005). An analysis of apparel industry fit session. *Journal of Textile and Apparel, Technology and Management, 4*(3), 1-5.

Bye, E., LaBat, K., McKinney, E., & Kim, D. (2008). Optimized pattern grading. *International Journal of Clothing Science and Technology, 20*(2), 79-92.

Carrere, C., Istook, C. L., Little, T., Hong, H., & Plumlee, T. (2002). Automated garment development from body scan data Retrieved October 12, 2010, from National Textile Center: http://www.ntcresearch.org/pdf-rpts/Bref0601/I00-S15.pdf

Carter, L., & Heath, B. H. (1990). *Somatotyping - Development and Application*: Cambridge University Press.

Charoensiriwath, S., & Spichaikul, P. (2009, Oct 6-8). *Constructing Thailand's national anthropometrics database using 3D body scanning technology.* Proceeding of the Pacific Neighborhood Consortium Conference, Taipei, Taiwan.

Cho, J. S. (1993). *A study on development of an optimal crotch line in pants pattern for CAD application.* Unpublished master's dissertation, Seoul National University, Seoul.

Churchill, E., Churchill, T., McConville, J. T., & White, R. M. (1977). *Anthropometry* *of women of the U.S. army-1977* (No. 2). Natick: U.S. Army Research and Development Command.

Connell, L. J., Ulrich, P. V., Brannon, E. L., Alexander, M., & Presley, A. B. (2006). Body shape assessment scale: Instrument development for analyzing female figures. *Clothing and Textiles Research Journal, 24*(2), 80-95.

Cotton Incorporated. (2002). *Women uncover the key to looking great*. Retrieved June 26, 2010, from http://www.cottoninc.com/lsmarticles/?articleID=97

Croney, J. (1977). An anthropometric study of young women fashion students including a factor analysis of body measurements. *Man, 12,* 484-496.

Davis, K., & Munro, K. (2008). [TC]² activity-AAFA fit symposium. *[TC]² By-Weekly Technology Communicator*. Retrieved January 2, 2009, from http://www.tc2.com/newsletter/2008/020608.html#tc2

DOB-Verband. (1983). *Women's outer garment size chart*. Cologne: DOB-Verband.

Douty, H. I. (1968). "Visual somatometry" in health related research. *Journal of the Alabama Academy of Science*, 21-34.

Duray, R., Ward, P., Milligan, G., & Berry, W. (2000). Approaches to mass customization; configurations and empirical validation. *Journal of Operations Management, 18*(6), 605-625.

Erwin, M., Kinchen, L., & Peters, K. (1979). *Clothing for Moderns* (6th ed.). Englewood Cliffs, New Jersey: Prentice Hall.

Ferrell-Beck, J. A., & Pouliot, C. J. (1983). Pants alteration by graphic somatometry techniques. *Home Economics Research Journal, 12*(1), 95-105.

Gazzuolo, E. B., Delong, M. R., Lohrs, S., LaBat, K. L., & Bye, E. K. (1992). Predicting garment pattern dimensions from photographic and anthropometric data. *Applied Ergonomics, 23*(3), 161-171.

Goldsberry, E., Shim, S., & Reich, N. (1996). Women 55 years and older: Part II.

Overall satisfaction and dissatisfaction with the fit of ready-to-wear. *Clothing and Textiles Research Journal, 14*(2), 121-132.

Green, M. E. (1981). An application of U.S. army women's anthropometric data to the derivation of hypothetical sizing/tarrifing systems. *Clothing Research Journal, 9*, 16-32.

Green, N. L. (1997). *Ready-to-Wear Ready-to-Work*. Durham, North Carolina: Duke University Press.

Haisley, T. (2002, February). Brooks brothers digital tailors measure up. *Bobbin,* 26-30.

Huck, J., Maganga, O., & Kim, Y. (1997). Protective overalls: Evaluation of clothing design and fit. *International Journal of Clothing Science and Technology, 9*(1), 45-61.

InnovMetric Software Inc. (2002). Polyworks v. 7.2® Quebec, Canada: InnovMetric Software, Inc.

International Organization for Standardization. (1991). ISO/TR 10652, Standard sizing systems for clothes.

Istook, C. L. (2002). Enabling mass customization: Computer-driven alteration methods. *International Journal of Clothing Science and Technology, 14*(1), 61-76.

Japanese Standards Association. (2001). JIS L 4005:2001, Sizing systems for women's garments.

Kidwell, C. B., & Christman, M. C. (1974). *Suiting everyone: The democratization of clothing in America* (Vol. Publication No. 5176). Washington, DC: Smithsonian Institution Press.

Kim, H., Suh, C., Suk, E., Park, S., & Lim, J. (2001). A study of the comparative evaluation of wearing fitness of women's ready-made jackets using 3D scanner.

Journal of the Korean Society of Clothing and Textiles, 25(10), 1707-1718.

Kohn, I. L., & Ashdown, S. P. (1998). Using video capture and image analysis to quantify apparel fit. *Textile Research Journal, 68*(1), 17-26.

Korean Standard Association. (2009). KS K 0051:2009 Sizing systems for female adult's garments.

Kurt Salmon Associates. (2000, February). *Which way to the emerald city? Consumers search for the ideal shopping experience.* Proceeding of the American Apparel and Footwear Association Apparel Research Committee, Orlando, FL, USA.

LaBat, K. L., & Delong, M. R. (1990). Body cathexis and satisfaction with fit of apparel. *Clothing and Textiles Research Journal, 8*(2), 43-48.

Lane Bryant. (2010a). Lane Bryant relaunches right fit premium denim and kicks off two exciting sweepstakes on Facebook and in stores. Retrieved October 16, 2010, from http://www.highbeam.com/doc/1G1-234166066.html#

Lane Bryant. (2010b). The return of right fit. Retrieved October 16, 2010, from http://www.lanebryant.com/content.jsp?pageName=RightFit&

Levi's. (2010). Levi's Curve ID. Retrieved October 16, 2010, from http://us.levi.com/shop/index.jsp?categoryId=4370093&cp=3146849.3146879.3146880

Li, P., Corner, B. D., Paquette, S., Lee, C., & Kim, I. Y. (2000). *Analysis of air gap size and distribution in single and multilayer clothing systems using 3-D whole body digitizing.* Proceeding of the XIVth Triennial Congress of the International Ergonomics Association and the 44th Annual Meeting of the Human Factors and Ergonomics Society, San Diego, CA.

Liechty, E. G., Pottberg, D. N., & Rasband, J. A. (1992). *Fitting and Pattern Alteration: A Multi-Method Approach*. New York: Fairchild Fashion and

Merchandising Group.

Likert, R. (1932). *A Technique for the Measurement of Attitude*. New York: New York University.

Loker, S., Ashdown, S. P., & Schoenfelder, K. (2005). Size-specific analysis of body scan data to improve apparel fit. *Journal of Textile and Apparel, Technology and Management, 4*(3), 1-15.

McConville, J. T. (1978). Anthropometry in sizing and design. In *Anthropometric Source Book, NASA Reference Publication 1024, Volume 1: Anthropometry for Designers.* (Vol. 1, pp. VIII-1 to VIII-15). Washington, DC: National Aeronautics and Space Administration.

McConville, J. T. (1986). Anthropometric fit testing and evaluation. In R. L. Barker & G. C. Coletta (Eds.), *Performance of Protective Clothing: ASTM STP 900* (pp. 556-568). Philadelphia, PA: American Society for Testing and Materials.

Minott, J. (1978). *Fitting Commercial Patterns: The Minott Method*. Minneapolis, MN: Burgess Publishing Company.

National Heart Lung and Blood Institute. (2009). BMI Categories. Retrieved August 6, 2009, from http://www.nhlbisupport.com/bmi/bmicalc.htm

Newcomb, B., & Istook, C. (2004). A case for the revision of U.S. sizing standards. *Journal of Textile and Apparel, Technology and Management, 4*(1), 1-6.

Ng, R., Chan, C. K., Pong, T. Y., & Au, W.-M. (1997). *Objective measurement of the 'fit' of apparel.* Proceeding of the World Conference of the Textile Institute, Manchester, England.

O'Brien, R., & Shelton, W. C. (1941). *Women's measurements for garment and pattern construction* (No. Miscellaneous Publication 454). Washington, DC: U.S. Department of Agriculture.

Oblander, R., & Anderson, J. (1996). *The Sew/Fit Manual: Making Patterns Fit: A*

Guide to Pivoting and Sliding. Bedford Park, IL: Sew/Fit Co.

Perry, P. (Ed.). (1972). *The Vogue Sewing Book of Fitting, Adjustments, and Alterations*. New York, NY: Butterick Fashion Marketing Company.

Petrova, A., & Ashdown, S. P. (2008). Three-dimensional body scan data analysis: Body size and shape dependence of ease values for pants' fit. *Clothing and Textiles Research Journal, 26*(3), 227-252.

Piller, F. T. (2004). Analysis: Why Levi Strauss finally closed it's [sic] "Original Spin" MC operations [Electronic Version]. *Mass Customization News*, *7*, 1-3, from www.mass-customization.de

Pine, J., II. (1993). *Mass Customization: The New Frontier in Business Competition*. Boston, MA: Harvard School of Business School Press.

Rasband, J. A. (1994). *Fabulous Fit*. New York: Fairchild Publications.

Robinette, K. M. (1993). *Fit testing as a helmet development tool.* Proceeding of the Human Factors and Ergonomics Society 37th Annual Meeting, Santa Monica, CA.

Salusso-Deonier, C. J., Borkowski, J. J., Reich, N., & Goldsberry, E. (2006). An alternative approach to sizing apparel for women 55 and older. *Clothing and Textiles Research Journal, 24*(2), 96-111.

Salusso-Deonier, C. J., Delong, M. R., Martin, F. B., & Krohn, K. R. (1985). A multivariate method of classifying body form variation for sizing women's apparel. *Clothing and Textiles Research Journal, 4*(1), 38-45.

Schlosser, U. (2004, December 13). Cashing in on the new world of me a handful of companies are finally perfecting made-to-order for the masses. Here's how. *Fortune Magazine*.

Schofield, N. A., Ashdown, S. P., Hethorn, J., LaBat, K., & Salusso, C. J. (2006). Improving pant fit for women 55 and older through an exploration of two pant shapes. *Clothing and Textiles Research Journal, 24*(2), 147-160.

Secord, P. F., & Jourard, S. M. (1953). The appraisal of body-cathexis: Body-cathexis and the self. *Journal of Consulting Psychology, 17*(5), 343-347.

Sewing Pants That Fit. (1989). Minnetonka, MN: C. DeCosse.

Sheldon, W. H., Stevens, S. S., & Tucker, W. B. (1940). *The Varieties of Human Physique: An Introduction to Constitutional Psychology*. New York: Harper & Brothers.

Shen, L., & Huck, J. (1993). Bodice pattern development using somatographic and physical data. *International Journal of Clothing Science and Technology, 5*(1), 6-16.

Simmons, K. P., Istook, C. L., & Devarajan, P. (2004). Female figure identification technique (FFIT) for apparel, Part II: Development of shape sorting software. *Journal of Textile and Apparel, Technology and Management, 4*(1), 1-15.

Song, G. (2007). Clothing air gaps layers and thermal protective performance in single layer garment. *Journal of Industrial Textiles, 36*(3), 193-205.

Speer, J. K. (2008). Victoria's Secret: Framing the fit problem Retrieved August 2009, from Apparel Magazine: http://www.apparelmag.com

Taya, Y., Shibuya, A., & Nakajima, T. (1995). Evaluation method of clothing fitness with body, Part 2: Application of symmetrized dot patterns to the visual characterization of clothing wave forms. *Journal of the Textile Machinery Society of Japan, 48*(6), 51-60.

Warner, R. M. (2008). *Applied Statistics: From Bivariate Through Multivariate Techniques*. Los Angeles: SAGE Publications.

Watkins, S. M. (1995). *Clothing: The Portable Environment* (2nd ed.). Ames, Iowa: Iowa State University Press.

Whife, A. A. (1965). Designing and cutting ladies' garments. *The Taylor and Cutter*, 1-16.

Yu, W., Fan, J. T., Qian, X. M., & Tao, X. M. (2001). *Development of a mannequin for garment pressure evaluation.* Proceeding of the Textile Education and Research: Strategies for the New Millennium, 1st AUTEX Conference, Portugal.

Yu, W. M., Harlock, S. C., Leaf, G. A. V., & Yeung, K. W. (1997). Instrumental design for capturing three-dimensional moire images. *International Journal of Clothing Science and Technology, 9*(4), 301-310.

Yu, W. M., Yeung, K. W., & Lam, Y. L. (1998, April). *Assessment of garment fit.* Proceeding of the HKITA and CTES Conference on Hand-in-Hand Marching into 21 Century, Shanghai, China.

Zafu. (2009). *We match jeans to you*. Retrieved February 11, 2010, from http://www.zafu.com/