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Review of a Research Program in Apparel Sizing and Fit

Susan P. Ashdown
Dept. of Textiles & Apparel, Cornell University

The story of the research program on sizing and fit of apparel that has been created at Cornell University is the story of the many people who have contributed to the program in different ways. The graduate students, under-graduates, colleagues, visiting professors, staff, and alumni who have worked with me on the research addressing this complex topic all contributed their part to build the current dynamic and effective research program.

My own fascination with the fit of clothing began with my previous career in theatrical costuming. A stage costume has one purpose only; to communicate the qualities of the characters, and through them, the themes of the play. Although the style, color, line, texture, and other design features of the costumes contribute to this purpose, the fit of clothing also has a part to play. An ill fitting garment can convey poverty, negligence, or a distraught character, while the perfect fit of the stylish and elegant character can communicate style, confidence, flair and/or wealth. Changes in the fit of costumes can convey a character's changing circumstances. Creating costumes from every imaginable period and silhouette for a wide range of body types and utilizing the appropriate fit for each costume was an ideal preparation for my current research program. The study of period shapes and the correct body stance for each period gave me an understanding of the relationship between the body and clothing. Creating fast change costumes and costumes in which actors could dance and fight taught me the importance of fit in relationship to function. Creating padding to mimic pregnancy and layers of body fat gave me an understanding of a variety of body types. Lessons learned in the theater contribute to the way I approach research in sizing and fit today.

The fit of clothing and the structure and function of sizing systems is a fascinating and complex topic. Under-standing the relationships and interactions between and among population measures and sizing, fit preferences of the designer and wearer, design ease and functional ease, material properties and fit, and body movement and fit all require careful and well defined research projects. There is a need for rigorous, tightly focused studies that investigate relationships on a micro level, and also a need for broader studies that establish trends and investigate complex relationships in a valid manner.

This is an exciting time to be an apparel researcher. The tools that we have available are powerful, effective, and are rapidly becoming more affordable and easy to use. The full body three-dimensional (3-D) body scanner is one new technology that contributes to our research, but sophisticated computer-aided patternmaking and automated custom patternmaking systems, automated single ply cutting, dress forms created from 3-D scans of fit models, virtual fit models and 3-D virtual draping systems, data from recent anthropometric studies, and use of the Internet to collect survey data all contribute to sophisticated new possibilities for research.

My research in sizing and fit began when I was a master's student at Cornell University with Susan Watkins in 1988. I used a method of creating honeycomb slashes in the non-woven fabric of protective coveralls and visual analysis of the images of the opening areas to look at the relationship between design features and fit for workers in active positions. My next project was my dissertation project with Marilyn Delong at the University of Minnesota in 1990, an investigation of the perception of ease using a blind constant difference stimulus test. Three years later, in the Fall of 1991, I began my present tenure at Cornell University and an exciting period of research. I and my graduate students first conducted studies of expert fit analysis using panels of judges, and also image analysis of honeycomb slashed fabrics as created for the coverall study. We also looked at the relationships between sizes and proportions of period patterns for children's wear and modern children's clothing.

Another pivotal study from this period undertaken for US Army Natick Soldier Labs was an investigation of the development of sizing systems from anthropometric data. For this study we made use of the 1988 anthro-

pometric survey of U.S. Army men and women (ANSUR) to sort the population into size groups. We created and compared different sizing systems by controlling variables including the numbers of sizes in the system, the complexity of the proportional variation allowed, and a mathematical fit score. An increase in the complexity of proportional variation and numbers of sizes led to better fit scores, but also resulted in unrealistically high number of stock keeping units and a system in which size selection could only be accomplished with a computer. With the mathematical analysis procedure it was possible to choose the optimal numbers of sizes based on the number of stock keeping units desired and to measure the affect on the level of fit for a specific style. Although the use of many body measurements improved fit scores this also had the effect of increasing the complexity of the grade and of the size selection process as each size group is optimized based on their individual proportions.

During this time my graduate students and I undertook many other studies including focus group discussions of fit issues with older women, the development of a tool for measuring shoulder slope and forward roll in older women, development and fit testing of a jacket style designed for women over 55 years of age, a test of the ability of men to identify fit preference from visual images, fit satisfaction and ease values in men's shorts, the effect of training on the reliability of fit judge's assessments of fit, the use of 3-D data to create a skirt pattern, and the development of a theoretical framework of the study of sizing and fit. Though often subject numbers of these studies were low, this period in my research career helped me form an overall understanding of both the research questions that are in need of answers and of the methods that will result in the most reliable and valid data for answering these questions.

The next period of my research began in 2000, and has been enriched and shaped by the donation from alumna Rebecca Quinn Morgan of funding to acquire a 3-D body scanner. This generous donation has changed the scope of the research on sizing and fit at Cornell, as it has worldwide. The introduction of the 3-D body scanner has the potential to revolutionize the way we create and distribute apparel. I believe that it will have an impact as great as the development of the power loom and sewing machine had during the industrial age. The 3-D scanner has already made affordable anthropometric studies possible. Multiple studies have been conducted or are underway worldwide, giving the industry access to a wealth of population data that can be analyzed based on demographic variables. Other uses of body scan data are rapidly being developed and will impact our field and the lives of our students greatly in the future.

The scanner is primarily being used today as a rapid, cost effective and reliable tool for extracting the measurements that our industry has traditionally taken with a tape measure, but this is only a very small part of its potential. At Cornell we have embarked on multiple studies to look for new ways of using this rich and novel source of data. These studies fall into three main categories: studies related to ready-to-wear fit and sizing, anthropometric studies, and visual analyses of the fit and function of clothing from 3D scans. We have also conducted studies of the level of acceptance of the body scanner and of potential virtual fit methods.

The main focus of our work with the scanner is based on a concept developed by Kathleen Robinette of the U.S. Air Force Computerized Anthropometric Research and Design Laboratory. Robinette conceptualized the merging of a body scan of a subject with a scan of the same subject in clothing to measure the difference between the surface of the body and the surface of the clothing. At Cornell we have used this concept to study the sizing and fit both fashionable and functional of clothing. Our primary study is designed to develop a method for scanning subjects who belong to a ready-to-wear firm's target market to capture both body scans and the same subject in the clothing of the firm. Analysis of the fit of the garments and the measurements from the scans can then be used to quantify fit. We collect linear data from the scans, but we are also investigating the use of slice area, surface area, and volume measurements that can provide additional informa-tion about fit. From this data we are developing a mathematical model that will generate recommendations to adjust the sizing system of the firm based on their own target market and garment style.

We have also completed several anthropometric studies, including comparisons of measures from subjects in the anthropometric position and in active positions (various arm and shoulder positions, and seated to standing positions), the analysis of body angles and measurements of women 55 years and older, automatic placement of side seams on 3-D body scans, and an analysis of scan data to investigate the relationship between body mass index measures and body shape variation.

I also derive a great deal of pleasure from the contacts and collaborative projects I have engaged in with other researchers in body scan research. Some of the collaborative projects that we have completed or that are underway are the quantification of the fit of cooling vests with the University of Oklahoma, the design of protective

sun hats with the University of Michigan, interactions among the factors of design, sizing, and fit of protective coveralls with a consortium of several universities, and the sizing of spacesuits for astronauts with the National Aeronautics and Space Agency (NASA). Each of these projects brings its own insights on the power and effectiveness of scan data.

Another research area where we see great promise is in the visual analysis of scans of clothed subjects as a fit analysis tool. A scan image that is captured in less than a minute can be analyzed in three dimensions for stress folds and for problems with the balance of the garment, providing much more fit information than can be seen in a photograph or a video. We have completed a study of the use of scans for fit analysis. We believe this could be an effective tool for apparel firms to effectively capture information on the fit of their garments on a range of sizes and body types in their target market for analysis.

The scanner is a powerful research tool, but it also has the potential to be a powerful tool for the apparel industry. It is already being widely used to create dress forms based on scans of company's fit models. Scanning also has great potential for the consumer, to create affordable custom fitted clothing, for automatic size selection, for virtual try-on of clothing, and for co-design and mass customization of clothing. We have engaged in research projects in these areas as well, including a study of the willingness of people to be scanned and a study of consumer's reactions to the concept of virtual try-on. I have also used the scanner as a teaching tool. For one class project we have repeated several times we locate an industry collaborator who will donate a set of ready-to-wear garments and the pattern for these garments. We then scan subjects from their target market, and use their scan measurements and off-the-shelf software to create customfitted patterns for each subject. We send these patterns to the collaborator's sample shop to be constructed, and then fit each subject in the ready-to-wear garment that fits them the best and in their custom fitted garment to compare the two garments. Students learn the process and potential of mass customization, and how it compares to standard sizing in fit satisfaction.

I have always appreciated the research model of a research group, in which faculty, graduate students, undergraduate students, colleagues from other universities, and industry collaborators work together on a variety of projects. Each project adds to the knowledge of the whole, and each person contributes their own understanding and focus to the work. The research in this model does not 'belong' to any one person. Articles from the work have a string of names, each of whom contributed in their own way, and research meetings are lively discussions in which each person contributes their point of view. Decisions are made collaboratively, and the work is much stronger than any one person can produce on their own. I am very grateful for the opportunity to work at Cornell University in the Department of Textiles and Apparel, where this model is supported and accepted. I am also grateful to be engaged in research in the field of apparel, where problems are complex and fascinat-ing, and where answers are elusive but obtainable with the technologies available today.

Susan P. Ashdown

1975-1988: Worked in theatrical costuming before discovering her true passion, teaching and research in the areas of functional apparel design, technology, and the apparel industry.

1991-Now: Department of Textiles and Apparel, Professor for 15 years where she teaches technical apparel design and does research in sizing and fit of apparel, functional apparel design, and the use of three-dimensional body scanning as a research tool for the apparel industry.

현재 : Dept. of Textiles & Apparel Cornell University
Tel: +1-607-255-1929
Fax: +1-607-255-1093
E-mail: spa4@cornell.edu