Posture Modification Effects Using Soft Materials Structures

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ABSTRACT

The purpose of this study was to develop a textile component system mimicking anatomical structures that when added to a typical shapewear product will straighten and balance a person's posture. The experimental system is referred to as the "Posture Modification System using Soft materials structures" or PMSS. Current posture modification garments fall into two categories: 1) health and rehabilitation garments focused on physical changes using rigid materials and 2) lingerie-type garments typically called shapewear that focus on achieving an ideal body using compression qualities of knit fabrics. This study explored the middle ground of designing a comfortable, wearable product that aligns posture using textile correction forces strategically placed in the garment.

A biomimicry approach was used in designing the prototype using the inspiration of anatomical features of a woman's torso to determine size and placement of textile components (PMSS) in a garment. A prototype was developed by incorporating the PMSS into a commercially available shapewear product. After a pilot test, the prototype was refined and a more comprehensive test was conducted. Twelve women participated in the study to determine effectiveness of the prototype including: 1) posture changes, 2) posture correction force, and 3) wearer acceptability. Participants were scanned three times; while wearing the prototype, wearing a typical shapewear product, and in their own underwear. Posture differences in wear conditions were analyzed. Posture correction forces of the textile materials were measured using standard fabric tests. Participants completed questionnaires on wearer acceptability.

Results included: 1) body angle assessment indicated that wearing the prototype affected posture including more balanced shoulders, aligned lateral center of gravity, and straighter spine, 2) textile characteristics of the PMSS incorporated into a shapewear compression garment contribute to a more erect and balanced posture, and 3) participants were more satisfied with posture and body shape when wearing the prototype then when wearing the shapewear garment.

This study indicates that the inherent properties of textiles (compression and tensile force from stretch) can be manipulated in a garment in various ways to modify posture.

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CHAPTER ONE: INTRODUCTION

Statement of Problem

Posture is an important factor contributing to overall health and influencing body image. “Good posture” is described related to physical and social/psychological contexts; although the definition of “good” in these contexts is not always clearly defined. Kendall, McCreary, Provance, Rodgers, and Romani (2005) define posture as “the relative arrangement of the parts of the body” (p. 51). They go on to define good posture, in physical terms, as “that state of muscular and skeletal balance which protects the supporting structures of the body against injury or progressive deformity, irrespective of the attitude (erect, lying, squatting, or stooping) in which these structures are working or resting.” (p. 51). While poor posture assumes a faulty relationship of the various parts of the body leading to concurrent pain in the head, neck, and jaw as well as structural adaptations such as ligamentous and muscle shortening or lengthening with continued faulty posture on a daily basis (Norkin & Levangie, 1992). Gilman (2014) stated that faulty posture reflects a characteristic of health as well as beauty as faulty posture is aesthetically unattractive. Several studies describe the ideal body in the western social/psychological context as posture that is symmetrical with balanced proportions (DeLong, 1990; Delong, 1998; Douty, 1968a; Horn & Gurel, 1981; LaBat, 1987; LaBat & Rasband, 2006; Tate & Shafer, 1982).

Over the years garments have been designed to modify posture and/or body shape to achieve what is determined to be either good physical posture or an ideal posture based on social and cultural norms. Garment designs focused on physical posture tend to emphasize possible positive health effects. Types of girdles, trusses, back supporters, and posture correctors are marketed as posture modification garments that may correct poor posture. These garments, often made of rigid materials, are typically uncomfortable because of skin stress and mobility limitations, so everyday use is difficult (McRoberts, 2008).

Garments designed to modify the body, in both shape and posture, to meet social appearance ideals have also been available for years with most of these garments marketed to women. The corset may be the most well-known and controversial garment in the history of fashion (Steele, 2001). Variations of the waist-cinching corset are still marketed today. Other body modification undergarments include bras, girdles and other foundation garments. “Foundation” presumably refers to the garment providing the basis for other garments worn over the undergarment, and possibly providing a solid postural foundation to the wearer’s body (Steele, 2001). Modern shape modifying products are different and are commercially successful because they are made of soft stretchable textiles developed to provide relative comfort and enhanced body shape (Apsan & Stark, 2006; Entwistle, 2000). Jones and Guilbault (2014) reported the success of the 2013 foundation garment market with U.S. sales of foundation garments, today known as shapewear, at $697.6 million.

Some shapewear companies claim body shape effects as well as posture modification effects based solely on compression of the textiles on the torso, and possibly the legs, of the body. Although the garments may be relatively comfortable and body smoothing, effects on posture are not as evident. This study focused on the possibility that textile elements added to currently available shapewear products may have noticeable visual effects on body posture. Experimenting with the inherent stretch and compression characteristics of textiles to modify body posture could provide a middle-ground between rigid posture "correctors" and fashion shapewear that uses compression distributed equally around the torso.

Statement of Purpose

The purpose of this study was to develop a textile component system added to a shapewear product and to evaluate the posture effects of the modified shapewear. The system added to the shapewear is referred to as the "Posture Modification System using Soft materials structures" or PMSS. The principle of this system is to combine the general compression of the shapewear with a system of extensible textile bands applied to the back portion of the shapewear that simulate the postural muscles of the back of the human body. The PMSS structured with specified elastic material bands may be added to commercially available shapewear garments and other compressive sewn-products originally designed to provide overall definition of the mid-torso. The goal of the PMSS is to achieve modified posture and smooth body shape with relative comfort using non-rigid materials and structures. In addition the study goes beyond assessment of posture changes in the standard standing anatomical position to postural effects on the body in various load carrying positions.

Objectives

Objective 1: To develop a PMSS to be inserted into a compressive soft-structural garment, specifically a typical shapewear garment.

Objective 2: To develop a prototype by modifying a commercially available shapewear product with addition of the PMSS.

Objective 3: To assess effectiveness of the prototype in modifying posture as compared to wearing a commercial shapewear product and no shapewear (person wearing their own underwear).

Objective 4: To assess posture correction force of the prototype upon the body as compared to wearing a commercial shapewear product.

Objective 5: To assess wearer acceptability of the prototype as compared to wearing a commercial shapewear product.

Research Questions

Question 1: Can the PMSS added to a commercially available shapewear product be effective in modifying posture?

Question 2: Do the PMSS materials combined with the shapewear product fabrics provide greater posture correction force than the shapewear product fabrics alone?

Question 3: Will the PMSS added to the shapewear product be acceptable to wear?

Significance of Study

Some shapewear companies achieved commercial success by providing shaping effects with comfort and various forms of the garments; for example, Spanx® and Madenform® generate around $250 million (Ireland, Hoskisson, & Hitt, 2010) and $210 million (Chaudhuri, 2013) in annual sales respectively. However, there appear to be opportunities to further improvement the shapewear products. A soft structural design element mimicking the back muscles and spinal column combined with a shapewear garment may reduce reliance on compression alone to achieve ideal posture by using the unique directional forces of textiles to strategically direct posture change. This study investigates the possibility of using materials of differing extensibility and pounds of force to develop a more comfortable garment while maintaining desired posture and shaping effects. This study can lead to investigation of other types of directional force materials to strategically align and shape the human body.

Limitations

The limitations of this study include: a small sample size, application of the textile support band system to an existing commercial product, and the prototype is not intended as a therapeutic posture device.

Twelve participants tested the prototype. However, the sample number is not sufficient for statistical analyses so that the study will not represent the range of the population of US women. However, observation of coherent and consistent posture changes through diverse scan positions for each participant should provide sufficient information on effects of the PMSS on posture changes. Future studies should include a larger sample representing a broader range of sizes.

For efficiency and to test just one component of a wearable posture support system, the prototype focused on supplementing a commercially available shapewear product with additional elements to the back of the garment. The additional bands (PMSS) cannot function independently but must be anchored to a shapewear garment or a compression garment. Thus, wearing a garment that provides compression is necessary. Understanding the total scope of human posture related to a complete garment design is necessary in the next steps of development. So consideration of the relationship of garment compression along with strategically placed directional forces designed into the garment will be necessary for future design exploration.

The PMSS added to a commercial shapewear product is not intended as a therapeutic device to correct posture abnormalities and not intended for long-term use. Rather the exploration of the potential of textile structures to modify posture is intended as a starting point for further development of wearable products that change and shape the body.

Definitions of Terms

Postural Alignment: Postural alignment is determined by the vertical positioning of the vertebrae (Rhodes, 1996; Saladin & McFarland, 2008; Western, Rhodes, & Stevenson, 2002). Vertical positioning of the vertebrae is established by the relationship between the five regions of the spinal column and their relationships to one another (Rhodes, 1996). The spinal column comprises five regions: the cervical area (neck), thoracic area (upper back), lumbar area (lower back), the sacral area (pelvis), and the coccygeal (tailbone).

Posture Modification Garment: As one of the effective traditional posture correction methods, a garment (or device/orthosis) has been applied to the user in order to train body muscles for proper posture via a passive force (Bazzarelli, Durdle, Lou, & Raso, 2001; Dworkin et al., 1985; Wong & Wong, 2008). In this study, apparel products for posture modification (or improvement/change) purpose are called posture modification garments (definition of the term original to this study). Some products which claim posture modification are currently on the commercial market called: back supporter, posture corrector, shapewear, girdle, lingerie, brace, bra, corset, etc.

Posture Modification System using Soft materials structures (PMSS): Experimental device or textile band structure incorporated into a typical shapewear garment made of soft stretchable fabrics providing posture support to align the spine and shoulders and enhancing the body shape (definition of the term and system original to this study).

Posture Correction Force: The degree of spinal correction using orthosis/device/garment is related to many interconnected factors (Aubin at al., 1999). One of these is the forces acting through the pads/device of the orthosis upon the body (Van den Hout, Van Rhijn, Van den Munckhof, & Van Ooy, 2002).

Load-elongation Behavior of Stretch Fabrics: "True elastic fabrics containing substantial percentages of elastomeric fibers such as spandex may be used in foundation garments, brassieres, swim suits, and some active sportwear. Low-power form-fitting fabrics may also be used in swimwear and activewear. Comfort stretch fabrics are used in looser-fitting garments that will stretch under light loads." (Merkel, 1991).

Shapewear: Shapewear is a foundation garment functionally designed to help wearers achieve a desired body shape for aesthetic purposes, post-surgical support or posture support by providing clothing pressure (Pithers, 2010).

Shapewear Firmness Level: Shapewear garments may be categorized according to level or shape control offered for instance, light, medium or firm. Some shapewear companies define the firmness levels: 1) light, moderate, firm, and ultra-firm defined by Maidenform® (Retrieved December 2, 2014, from http://www.hanes.com/onehanesplace/womens-shapewear), 2) medium, super, and super-duper by Spanx® (Retrieved December 2, 2014, from http://www.spanx.com/shop/spanx/shapewear/cat-38-catid-tn_spx_sw).

Comfort: Comfort is a subjective perception and judgment of a wearer on the basis of integration of physiological, psychological and physical variables and their interactions with the environment (Li, 2001; Slater, 1985; Tarafder, 1994).

Wearer Acceptability: Wearer acceptability scales determine how subjects feel and also how they perceive the fit and comfort of clothing. (Huck, Maganga, & Kim, 1997).

CHAPTER TWO: REVIEW OF LITERATURE

A review of literature was conducted as background for this study. The review is organized under four themes: product development, posture, posture correction force, and wearer acceptability. The posture theme includes three topics: human posture in context, posture modification methods, and posture assessment methods. The posture correction force theme includes clothing pressure, measuring posture correction force using pressure sensors, and measuring posture correction force of stretchable fabrics.

Product Development

Product development for apparel involves processes the designers use to develop a garment and to understand how acceptable the proposed design is to the wearers. To systematically organize the design ideas for task performance, use of an effective design process is necessary. Various sources were reviewed to determine effective functional clothing design processes for the PMSS development.

Functional clothing development can be commonly characterized by a user-oriented process and the design processes heavily emphasize the initial research phase when the users and use-situation are investigated (DeJonge, 1984). Some design process frameworks for functional clothing design have been developed to lead designers to conduct more research at the initial phase for effective problem solving and optimal user performance.

DeJonge (1984) proposed a design process for functional clothing design. She emphasized the importance of the first step in design; at this early stage, the designer should explore as many directions as possible and the criteria for the prototype evaluation when the initial request is made for a design solution. After a prototype is developed, evaluation of the prototype is made possible by using the criteria developed in an earlier stage.

Later, Watkins (1988) proposed seven steps for teaching functional clothing design adapted from Koberg and Bagnall (1981) including the following steps; 1) acceptance, 2) analysis, 3) definition, 4) ideation, 5) idea selection, 6) implementation, and 7) evaluation. This process has some common stages compared to the framework developed by DeJonge (1984).

Design processes developed by other disciplines also can be applied to functional clothing design. For instance, Lewis and Samuel (1989) proposed an engineering design process including the following stages: 1) problem recognition, 2) problem definition, 3) exploration of the problems and solutions, 4) search for alternative, 5) evaluations and decisions, 6) specification of solution, and 7) communication of solutions. This process heavily focuses on the initial phase for problem definition and has some common stages compared to design processes for functional clothing design.

LaBat and Sokolowski (1999) stated that many fields such as education, psychology, and philosophy have used some design processes evolved from these fields contributing to the use of similar processes in all applied design fields to aid creative thinking. They reviewed design processes from architecture, environmental and industrial design fields. The common stages of the design processes were divided into (a) problem definition and research, (b) creative exploration, and (c) implementation. This design process was used for this study since it has been established as a systematic framework including design stages playing a key role in the process for functional product development.

Posture

Human Posture in Context

Posture is defined as the alignment or orientation of body segments while maintaining an upright position (Kendall et al., 2005). Good posture helps a person to participate in an active and healthy life and achieve good body image (Danielsson, Romberg, & Nachemson, 2006). Since posture reflects a characteristic of health as well as beauty, posture can be assessed from a purely physical perspective and from a psychological/social perspective.

Posture: Physical Perspective

From a physical therapy or physical medicine perspective good posture is defined as "that state of muscular and skeletal balance which protects the supporting structures of the body against injury or progressive deformity, irrespective of the attitude (erect, lying, squatting, or stooping) in which these structures are working or resting." (Kendall et al., 2005). In a physical perspective balance is an important factor in describing good posture. Posture asymmetries are associated with the risk of progression in posture deformities (Kouwenhoven & Castelein, 2008), and can affect functional activities (Chow et al., 2006; Mahaudens, Thonnard, & Detrembleur, 2005) because maintaining improper posture for prolonged time exerts significant stress on the spine (Lewis &Valentine, 2010). Poor posture that assumes a faulty relationship of the various parts of the body can lead to concurrent pain in the head, neck, and jaw as well as structural adaptations such as ligamentous and muscle shortening or lengthening with continued faulty posture on a daily basis (Norkin & Levangie, 1992). Furthermore, poor posture is related to the physical abnormalities such as scoliosis, kyphosis, or lordosis (Birbaumer, Flor, Cevey, Dworkin, & Miller, 1994).

Scoliosis is a medical condition in which a person's spine is curved laterally (from side to side). The signs of thoracic scoliosis include a rib prominence or a prominent shoulder blade, caused by rotation of the ribcage, uneven hips, arms or leg lengths. It is important to prevent or treat extreme scoliosis because it causes uneven musculature on one side of the spine, putting pressure on the heart, and restricting physical activities, and low nerve action in some cases (Saladin, & McFarland, 2008). Eighty percent of people with scoliosis are women and a goal for treatment of scoliosis is to modify body imbalance caused by excessive spinal curvature (Dworkin, et al., 1985). Achievement of aligned spine is important to treat or prevent not only scoliosis but also kyphosis defined as an exaggerated thoracic curvature and lordosis defined as an exaggerated lumbar curvature affected by aging or weight gain as it can affect functional activities and limit participation in active life (Danielsson et al., 2006; Mahaudens et al., 2005).

Medical posture modification interventions are used with the goal of preventing further progression of a posture deformity and further achieving the balanced alignment of the body.

Posture: Social/Psychological Perspective

What is beautiful or aesthetically pleasing about the human body is determined within a social setting (LaBat & Delong, 1990). Defining or prescribing an ideal body is controversial, but ideal body definitions are undeniably a part of society and culture. As an important aesthetic component of the human body, ideal posture can be defined within a social context. However, there are few studies that provide a clear definition of “good/ideal” posture in these contexts. Various sources were reviewed to determine what is deemed to be ideal posture in a social context.

Douty (1968a) proposed body shape and posture assessment tools relative to the fit of apparel using a research technique called somatography. This method is based on the theory of recommended alignment of segmental body units for the purpose of body image assessment. The alignment of the body segments on a somatograph, a silhouette of the body photographed against a screen marked with a grid, is compared to a balance line and thereby any misalignment of any unit could be identified. Douty (1968a) proposed posture scales for assessing the lateral silhouette alone. However, assessment of anterior and posterior views is important in determining a person’s shape and posture (Hutton, Bayley, Broadhead, & Knox, 2002). Douty (1968a) rated posture on a 5-point Scale: faulty (1 point), poor (2 points), average (3 points), good (4 points), and excellent (5 points). She described excellent/ideal posture (Figure 1a) as: head up, shoulders up, abdomen flat, back curve within normal limits, knees flexed, body balanced over arches, alignment perfect, shoulders even, legs straight. The description of posture assumes that the ideal posture exhibits a balanced alignment of the body.

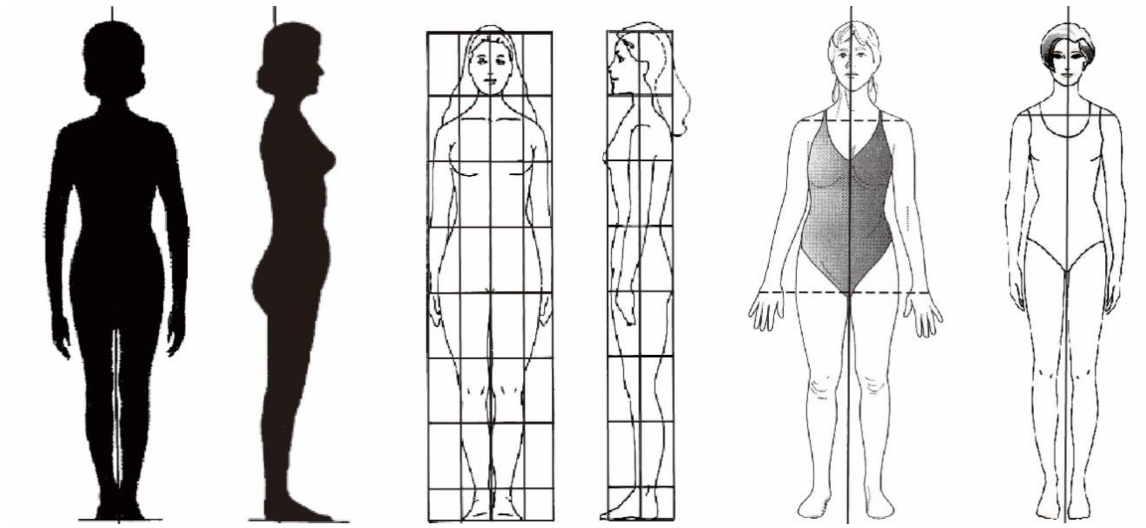
Several researchers studied the ideal figure in regards to balanced body structure and proportion. Proportion or the relationship of one segment of the body to another is often used in describing the ideal figure (LaBat, 1987). Horn and Gurel (1981) described the average figure as a realistic ideal figure in terms of proportion (Figure 1b). They included body alignment as an important factor indicating perfection in proportion. Their description of body alignment is:

> “Body alignment is indicated by a perpendicular line falling from the ear lobe to the inside of the heel, passing through the center of the shoulder and hipline and slightly

> to the front of the leg at knee level. The body weight at chest, waist, and hip levels is thus balanced on either side of the plumb line in profile view. Looking at the figure from the front, straight legs meet at upper thigh, knee, calf, and foot (Horn & Gurel, 1981, p. 369)."

This description of body alignment indicates that balanced structure is a critical part of the ideal figure and proportion. Tate and Shafer (1982) stated that idealized figures shown in fashion illustration, photography, and runway models conform to the ideal in proportion and balance. O'Brien and Shelton (1941) emphasized that proportion and balance are important factors in describing ideal figures although manufacturers' standards for apparel sizing systems vary. In describing an ideal figure, Delong (1998) assumed the anterior view of the body is bilaterally symmetrical; that is, the left and right halves appear similar with the widths of the silhouettes and body configurations varying (Figure 1c). The previous studies indicate that although the segments of the silhouettes and body configurations differ, balanced skeletal structure is assumed in describing an ideal figure.

Rasband (2006) determined six body characteristics affecting the ideal figure. The characteristics include: height, bone size or structure, weight, proportional body areas, contour and figure type, and posture. She emphasized the importance of posture in describing an ideal figure. She defined poor posture as a slumped, slouched, rounded and swayed body alignment causing apparel fitting problems at the shoulders, breasts, stomach and buttocks. She stated that although a woman has an ideal proportion and body weight, poor posture makes her body less perfect. Conversely, a less than ideal body can appear more nearly ideal with an ideal posture. She assumed that ideal posture is evident when the head and neck are centered over the shoulders (Figure 1d). The balanced shoulder and slightly lifted chest with the hip being level are also necessary. She stated that fitting problems can often be eliminated or improved by achieving an ideal posture providing balanced structures.



a. Douty (1968a) b. Horn & Gurel (1981) c. Delong (1998) d. Rasband (2006)

Figure 1. Ideal postures assumed in social contexts

The term "ideal posture" is not often used in research literature, however by viewing visual documentation and reading descriptions, it is fairly evident that ideal posture assumes the balanced alignment and proportion of the body.

Posture Modification Methods

To achieve balanced alignment of the body in physical and social/psychological contexts, a variety of posture modification methods have been developed for clinical or non-clinical purposes. Methods and techniques to modify posture are described in medical literature related to health improvement and apparel literature related to achieving an ideal body.

Surgical methods are used to correct posture deformities and to relieve pain; however, the focus of this study is on non-surgical methods, especially external wearables used to modify posture. Non-surgical treatment methods that have received much attention in research include exercise therapy, biofeedback and orthoses (bracing) (Lou, Lam, Hill, & Wong, 2012).

Physical Therapy and Biofeedback

Although problematic spinal regions are different for scoliosis, kyphosis, and lordosis, treatments have been developed to strengthen overall back muscles using different methods (e.g. by exercising or training using electronic device or a garment). Some studies indicated that the primary aim of exercise therapy is to strengthen back muscles and increase spinal flexibility of the patient and sometimes, to improve kyphotic deformity but typically insufficient in improving posture compared to other posture alignment methods such as biofeedback or orthoses (Frontera, Silver, & Rizzo, 2008; Wong & Wong, 2008).

Recently, biofeedback which involves a device placed on the body to detect body signals that tell the person about his/her postural changes has been used (Wong & Wong, 2008). Many studies found this method effective but there are some limitations associated with biofeedback devices or data. For instance, SEMG record, surface electromyographic activity, is only a close approximation of the level of electrical activity of the muscle, and it may not directly represent the numbers of firing frequency of the motor units in the muscle of interest so that it is possible to use the SEMG records of large superficial muscles for the purpose of biofeedback (Türker, 1993).

Orthoses

Orthoses (bracing/corset/vest) have been used to decrease pain, to protect against further injury, to assist weak muscles, and to prevent or help correct a deformity by supporting trunk alignment via a passive force (Bazzarelli et al., 2001; Dworkin et al., 1985; Fisher, 1990; Wong & Wong, 2008). Lusskin and Berger (1975) stated that these objectives are gained through the biomechanical effects of 1) trunk support, 2) motion control, and 3) spinal realignment.

Fisher (1990) categorizes orthoses into two categories related to the area of the bodies that is covered; cervical orthoses and thoracolumbosacral orthoses. Some types of orthoses currently on the market are: thoracolumbar orthoses, prefabricated orthoses such as the *Boston orthosis*, and custom-made orthoses such as the *Chenau corset* common in Europe (Dolan & Weinstein, 2007). Appendix A shows a range of orthoses currently on the market purporting to provide posture modification. A search of the market indicates that various orthoses have been developed; however, there is lack of academic research on orthoses design and effectiveness of designs. Two studies focusing on evaluating effectiveness of orthoses were found and reviewed. Million, Nilsen, Jayson, and Baker (1981) compared a corset without support to one manufactured by Johnson and Johnson Ltd consists of a wide wrap-over body belt in various sizes. They concluded that the spinal support in a lumbosacral corset provided significant relief effects on symptoms and the corset with support was subjectively preferred by the wearers. Loguidice, Mahoney, Haldeman, and Andersson (2005) evaluated the acceptability and effectiveness of a brace-like vest which applies a traction force to the spine and the researchers concluded that the braces benefit patients with back pain.

Although generally orthoses are effective in modifying posture or easing back pain as a treatment for clinical purposes, they can cause health problems. Bazzarelli et al. (2001) emphasized that prolonged brace usage has been related to reduced spinal flexibility, permanent deformation of the rib cage or soft tissues of the body at pressure points, skin breakdown or allergies and altered gastrointestinal motility (Frontera et al., 2008) as well as reducing the amount of muscular activity needed to maintain truck support (Fisher, 1990). Beyond those problems, poor product quality and/or bulky seams may cause discomfort and products may lack durability (Macintyre & Baird, 2006; Ng-Yip, 1993). Thus, some researchers emphasized that the problems such as bulkiness, device discomfort, limiting activities, and attracting unwanted attention may lead to lower wearer acceptability (Bazzarelli et al., 2001; Frontera et al., 2008).

Clothing pressure can be a health risk factor. Sometimes higher clothing pressure is necessary to treat abnormal bone structures by forcing the abnormal spinal curvature into a modified posture. Recent experimental studies on tight fitting clothing have indicated that the pressure exerted by clothing adversely affects certain aspects of the normal physiological balance of the wearer's body (Harumi, Miyuki, Hideo, & Kiyokazu, 2001; Lee, Hyun, & Tokura, 2000; Sone, Kato, Kojima, Takasu, & Tokura, 2000). Functions that were affected included dietary carbohydrate absorption (Sone et al., 2000), a rectal temperature increase (Lee et al., 2000) and blood pressure (Harumi et al., 2001). Miyatsuji et al. (2002) demonstrated that bras exerting pressures as high as 75 mmHg have a significant negative impact on the autonomic nervous system.

To avoid possible health risks and low wearer acceptability of orthoses made of rigid/non-stretchable materials or higher clothing pressure, there have been some academic studies with different approaches to develop posture modification garments using soft structural materials. The academic search resulted in only two proposed designs, one developed by an undergraduate and one by a doctoral student (see Appendix B). Both studies conducted to develop and assess the products focused on the upper body (thoracic region) only (above the waist). Results of the studies were documented in the published theses. Few studies for development of posture modification garments indicate a possibility of modifying posture using soft structural materials for non-clinical purposes, not for treatment. However, to improve overall spinal regions, more research on the development of soft structural devices or garments is needed.

This study aims to develop an effective and comfortable posture modification system using soft structural materials.

Fashion Shapewear as a Posture Modification Garment

Garments intended to achieve an ideal balanced body shape have been worn by people throughout history. Posture modification garments continue to be developed and worn today with acceptance and popularity apparently tied to social/cultural expectations.

For women in Western cultures today, body shape is an important factor in self and social evaluations to attain positive attention in a social group (Gatward, 2007; Gilbert, Price, & Allan, 1995). Sypeck et al. (2006) stated that a thin and hourglass figure is substantially related to feminine attractiveness. However, the ideal is unnatural and difficult to achieve for most women (Chrisler, 2013). To achieve an ideal body shape, people have worn body shaping products that control bulges and constrict the body throughout history: corsets, foundation garments, girdles, etc. Steele (2001) stated that the corset, a type of foundation garment, may be the most controversial garment in the entire history of fashion and has been an essential element of fashionable dress for about 400 years. However, the corset became less popular and gradually faded after the turn of the 20th century because of discomfort from rigid materials causing negative effects on the body such as gastric reflux, compressed stomach or intestines. Recently, constricting garments have come back into fashion with a new and growing consumer culture embracing the trend toward thinness due to fashion illustration and ads featuring slim and ideal models (Fraser, 2009). Unlikely older corsets and girdles, modern styles, today often called shapewear, made of soft structural materials are more breathable and flexible (Apsan & Stark, 2006). Shapewear is available in a variety of types: control briefs, control thongs, control shorts, control camisole, bandeau-style full slip, long-leg panties or pants liners, half-slip, body briefer, strapless, waist-cincher/waspie/french cinch (Apsan & Stark, 2006). By providing comfortable garments in a variety of forms, shapewear companies have achieved commercial success; for instance, Spanx® generates around $250 million in annual sales (Ireland, Hoskisson, & Hitt, 2010) and the estimated 2013 annual sales of Maidenform® in the shapewear category was $210 million (Chaudhuri, 2013). Chaudhuri (2013) reported that Maidenform® has annual sales of about $600 million with 57% of Maidenform's revenue generated by bra sales and 35% by shapewear sales in 2013. Shapewear companies claim that these garments can help to achieve ideal body shape by transforming the silhouette of a woman’s body to an ideal slim form creating the illusion of an hourglass figure. Some shapewear companies claim posture modification effects by relying on overall clothing pressure on the body in many products. For example, Braologie® (retrieved from http://braologie.com/posturebra/#05) and Amia® (retrieved from http://www.amiashapewear.com/blog) claim shoulder and spine improvement when wearing their shapewear garments. However, the potential of shapewear, beyond compressing and smoothing the body, to effectively align posture has not been explored.

Posture Assessment Methods

When a posture modification product or therapy is developed, a method of assessing posture, before, during and after use, is necessary. Several methods have been tried to measure posture with qualitative methods such as posture rating scales or quantitative methods such as body angle/distance calculation methods.

Qualitative Methods

Some researchers have developed posture rating scales, for example Douty's posture scales (1954, 1968a, 1968b, 1968c) as previously discussed and the New York Posture Rating Chart developed by the New York State Education Department in 1958. The New York Posture Rating Chart has been used in several studies mostly for the purpose of health assessment. The chart consists of drawings illustrating the alignment of human body segments and three types of scales including: good (10 points), fair (5 points) or poor (0 point). Briedenhann (2004) used the scale to assess posture in athletes and McRoberts, Cloud, and Black (2013) used a 3D scanner to gather static 3D body shape data and also used photographic images to assess posture and then both body scans and photographs were subjectively evaluated by medical experts referring to the New York Posture Rating Chart. However, qualitative evaluations require subjective judgments by the evaluators. It may result in intra- and inter-observer errors in measurement depending on each evaluator's standards. To provide more reliable posture assessment results, quantitative posture assessment methods using numerical body unit data have been developed.

Quantitative Methods

Perry, Smith, Straker, Coleman, and O'sullivan (2008) divided quantitative posture assessment methods into five categories: roentenography, three-dimensional motion analysis, rasterstereography, manual analysis, and photographic analysis.

Roentenography is a posture assessment tool for the calculation of angles and distances using radiographic images. However, radiation hazards preclude its widespread use in research studies (Jackson, Kanemura, Kawakami, & Hales, 2000). Thus, this method typically has been used for clinical purposes only. As a spinal curvature assessment method using roentenography, the Cobb angle developed by John Robert Cobb (1948), has subsequently been adopted to measure coronal plane deformity on antero-posterior plane radiographs in the classification of scoliosis for clinical purposes (Cobb, 1948). Akel et al. (2008) analyzed shoulder imbalance in scoliotic patients using radiological images because shoulder imbalance is one of the criteria used to evaluate the outcomes of spinal deformity surgery. The evaluated parameters included coracoid height difference (CHD), clavicular angle (CA), the clavicle–rib cage intersection difference (CRID), clavicular tilt angle difference (CTAD), and T1-tilt. The researchers demonstrated that the radiological parameters used to evaluate the shoulder imbalance correlate with the clinical appearance in scoliosis.

Three-dimensional motion analysis using electromagnetic sensors has been evaluated as an optical method in measuring body movement because this type of system offers a detailed record of body movement without being invasive (Dunne, Walsh, Hermann, Smyth, & Caulfield, 2008; Straker et al., 2008). This technique has been used for posture assessment and reported to be valid (Sprigle, Wootten, Bresler, & Flinn, 2002) and reliable (Lissoni, Caimmi, Rossini, & Terenghi, 2001) in adults. However, Lissoni et al. (2001) pointed out that this method requires expensive equipment.

A few studies have specifically examined posture in various positions and movement using sensing technologies for apparel application such as elongation sensors (De Rossi et al., 2003; Mattmann, Amft, Harms, Troster, & Clemens, 2007; Tognetti et al., 2005), bend sensors (Edmison, Jones, Nakad, & Martin, 2002), and inertial sensors (Farringdon, Moore, Tilbury, Church, & Biemond, 1999; Knight et al., 2007; Lee & Mase, 2002; Mathie, Coster, Lovell, & Celler, 2004). These techniques provide real-time biofeedback by allowing for long-term monitoring of the user in the work environment. However, these methods have some limitations associated with the social and physical comfort which is a significant factor for wearable devices (Dunne et al., 2008). To minimize wearable device discomfort, Dunne et al. (2008) developed a wearable plastic optical fiber (POF) sensor for monitoring seated spinal posture and demonstrated that it is more accurate in measuring seated positions than an expert's visual analysis. This wearable device has potential in monitoring seated positions in an office environment for long-term use.

Rasterstereography (Asher, Lai, Burton, & Manna, 2004) involves the multidirectional illumination of the back surface of the body during stereo video imaging to produce a high-resolution three-dimensional computer reconstruction of the back surface of the body (Perry et al., 2008). Although this method was found to be reliable

(Goh, Price, Leedman, & Singer, 1999), Asher et al. (2004) stated that it has not been shown to be valid compared to roentenography.

Manual measurement techniques include types of devices such as the pelvic goniometer (Sprigle, Flinn, Wootten, & McCorry, 2003) and flexicurve (Hart & Rose, 1986). Hutchinson and Munden (1978) used a body caliper for measuring shoulder-slope angles of British females who were divided into three age groups for body shape classification. Perry et al. (2008) stated that manual measurement methods have been shown to be valid and reliable when assessing adults. However, these methods may be time-consuming, introducing intra-inter observer errors in measuring posture and are useful for single angular measures only (Engh, Fall, Henning, & Soderlund, 2003; Hickey, Rondeau, Corrente, Abysalh, & Seymour, 2000).

The traditional photographic method for assessing posture applies a set of standards by calculating body angles and distances on the photographs of a person placed in front of a grid (Douty, 1968b; Perry et al, 2008). Many researchers stated that a promising technique to assess posture may be this type of method because it is fast, easy and accessible for most evaluators (Belli, Chaves, Oliveira, & Grossi, 2009; Fortin, Feldman, Cheriet, & Labelle, 2010; Lafond, Descarreaux, Normand, & Harrison, 2007; McEvoy & Grimmer, 2005; Normand et al., 2007; Pownall, Moran, & Stewart, 2008; Smith, O'Sullivan, & Straker, 2008). Perry et al. (2008) emphasized that the photographic image based method is more accurate and suitable for multiple angles in measuring posture than other methods. However, the method has some drawbacks; two-dimensional reference points are not entirely successful in interpreting three-dimensional data and traditional photographic images have some issues of distortion in the real camera setting and posture changes between back/front and side views. Thus, many researchers are now using 3D scanning technology to assess posture.

As a static posture capturing system, 3D scanning technology has proved reliable and valid (Bye, LaBat, McKinney, & Kim, 2008; Choi & Ashdown, 2011; Petrova & Ashdown, 2008). Three-dimensional scanning technology provides new measurements for quantifying the body and it makes it possible to digitize the complete surface of a large number of human bodies, providing much richer and more precise information about body shape (Li & Weiyuan, 2007). Several studies have used a 3D scanner to extract various body angles for apparel application. Sook Cho et al. (2006) extracted back and hip angles for 20 subjects to define posture for body shape classification. Ashdown and Na (2008) demonstrated that 3D scan data provides sufficient body measurement/angle data by taking nineteen upper-body angles, sixteen linear measurements, and one proportional measurement in older women. Chen, LaBat, and Bye (2010) employed a 3D body scanner to extract upper body angles from college women in order to categorize physical characteristics into shoulder slope, bust prominence, back curvature and acromion placement for apparel applications. These studies demonstrated that a variety of angles and shapes as well as linear measurements including length, width and circumference can be extracted from 3D scan data.

After reviewing historical and current methods of assessing posture, 3D scanning technology was selected as the assessment method for this study since 3D scanning technology is promising in assessing posture by measuring a variety of numerical body segments on the 3D scanned body for non-clinical purposes. In this study numerical body angles were calculated using coordinates of the reference points on the 3D scanned body to achieve reliability and validity of the posture assessment.

Posture Correction Force

Since pressure, in regards to posture correction force exerted from devices and garments, are associated with the effectiveness of modifying posture, many researchers have tried to directly measure posture correction force using pressure sensors placed under devices or garments. Some researchers explored indirect methods that estimate correction forces from stretchable material properties. Both direct and indirect methods were reviewed to determine an effective method measuring posture correction force of soft structural materials.

Clothing Pressure

Clothing pressure is often caused by the size differential between the smaller garment and the larger body (Chen, 2011; Gwosdow, Stevens, Berglund, & Stolwijk, 1986; Kenins, 1994). Morooka, Fukuda, Nakahashi, Morooka, and Sasaki (2005) stated that clothing pressure is affected by body movement, posture, breathing and BMI with a greater clothing pressure applied to a person's body having a higher BMI. Garments with low compression (e.g., low spandex content) are typically marketed and worn for fashion while high compression garments (e.g., power lifting bench shirt) are intended for mechanical support (Silver, Fortenbaugh, & Williams, 2009).

Although the level of compression varies depending on its purpose, off-range compression causes possible health risks or low efficiency of its effects on the body. Kraemer et al. (2010) emphasized that exceeding the level of optimal pressure causes skin oppression and restriction. To overcome this resistance, more power increasing the amount of energy consumption is needed and causing discomfort as well as further health risks including chronic constipation/diarrhea, headache, and visceral displacement. On the other hand, lack of clothing pressure leads to low efficiency in movement and protecting the body as well as no positive effects on appearance enhancement. Thus, Kraemer et al. (2010) highlighted the importance of investigating the optimal pressure range of compression garments. Several studies (Kraemer et al., 1998; Kraemer et al., 2001a; Kraemer et al., 2001b) demonstrated that the optimal compression allows the body structures (e.g. limbs) to be held in place in the standard anatomical position.

Measuring Correction Force Using Pressure Sensors

Since the pressure of a garment/device is a significant factor in function and comfort, studies have been conducted using direct pressure sensors to measure optimal pressure for compression garments and posture correction devices. As another approach some researchers studied pressure effects using elongation properties of the garment fabrics.

Methods using pressure sensors exerting direct forces on the body have been used for clinical purposes and non-clinical purposes. Correction levels of pressure applied to the body are significant for medical treatments like compression on burn-damaged tissues for scar prevention and non-clinical purposes like movement efficiency, comfort, and appearance enhancement.

For medical purposes, elastic pressure garments used to minimize scarring and uneven skin texture due to burn damage have been tested with pressure sensors by applying consistent pressure to the skin surface (Salleh, Acar, & Burns, 2011). This method is also used for assessment of posture correction forces for medical purposes. In the medical product category, the degree of spinal correction is related to many interconnected factors (Aubin et al., 1999). One of these is the force acting through brace pads made of plastics or boning or non-stretchable materials of a spinal orthosis upon the body. One of the working mechanisms is direct compressive force working through the brace upon the body and thereby correcting the spinal deformity, achieving optimal fit of the individual orthosis (Van den Hout et al., 2002). Since the magnitude of corrective forces is an important factor for optimal curve correction, some researchers tried to determine direct corrective forces or distribution of the pressure acting upon the body during brace treatment using different types of force measurement systems. Van den Hout et al. (2002) measured the exerted forces using the electronic PEDAR measuring device manufactured by Novel (Munich, Germany). Pham et al. (2008) measured pressures using the Tekscan ClinSeat Type 5315 Sensor. Loukos, Zachariou, Nicolopoulos, Korres, and Efstathopoulos (2011) analyzed the direct posture correction force exerted by a dynamic derotation brace (DDB)'s main pad using the F-Socket 9801 pressure sensor.

Several non-clinical studies were conducted to find compression garment optimal clothing pressure using direct pressure sensors. Chan and Fan (2002) conducted a study of optimum clothing pressure distributions of a girdle for ten body dimensions using the pressure device SD500 digital skin evaluator and demonstrated the accuracy and reproducibility of the device. The range of optimum pressure (mmHg) included: front tummy (7.03), left front tummy (9.2), right front tummy (9.15), left side (11.98), right side (11.57), left front lower (7.34), right front lower (7.5), left hips (4.34), right hips (4.37), waist level (6.47). Liu, Chen, Wei, and Pan (2013) investigated the bust girth range of a sports vest compression garment using the pressure measuring device AMI3037 S-5, a pneumatic pressure testing device. They found that the comfortable pressure range on the breast was 0.96–1.355 kPa by analyzing the relationship between objective clothing pressure and subjective compressive feeling.

Since measurement of pounds of force of materials using pressure sensors may help obtain accurate results for a device or garment made of rigid or soft structural materials, most researchers used direct measurement of correction forces for posture that involves the use of a sensor to measure the pressure exerted by medical devices/compression garments (Giele, Liddiard, Currie, & Wood, 1997; Harries & Pegg, 1989; Mann, Yeong, Moore, & Engrav, 1997). Although this type of method has been widely used, a drawback of the direct measure of the corrective force is associated with a limited number of sensors, time-consuming nature of the studies, and uneconomical processes (Aubin et al., 1999; Fan & Chan, 2005; Yu, Fan, & Qian, 2004; Zhang, Yeung, & Li, 2002).

To overcome those problems, Salleh, Acar, and Burns (2011) proposed a non-contact pressure simulation method to predict pressure distribution exerted by a garment. They developed a 3D pressure garment model based on the size of a mannequin. Then the 3D model was flattened into a 2D pattern and the pressure that the garment exerts on the body part was calculated by using the pressure model. However, this system includes only two types of pressure patterns (2.666 kPa and 5 kPa) on a specific fabric (modulus of elasticity of 504 N/m) so that it is difficult to apply to all types of fabrics.

In measuring posture correction forces of the garment tested in this study, direct pressure measure alone may be insufficient. The study garment relies on forces of stretchable materials to modify posture, so exploring methods of measuring stretch properties of fabrics is necessary. The measures for materials (bands) used in this study provide a starting point for testing other types of materials in future studies.

Measuring Correction Force of Stretchable Fabrics

Fabric stretch is distinguished from the usual meaning of elongation. Elongation is the amount of increase in specimen length at any given moment during a tensile strength test. This type of test method has been used to examine fabric stretch under a particular load or the load at a particular amount of stretch (Merkel, 1991). Measuring tensile forces of fabrics involves many variables of the textile, its fiber, yarn, and structure and its incorporation into the garment structure. A few studies that explored the relationship between fabric elongation and clothing pressure regarding tensile forces were located and reviewed.

A study conducted by Kraemer et al. (2000) found optimal clothing pressure for compression garments using fabric elongation properties. They examined the compression levels created by spandex content and construction design using fabric elongation properties. They found that compression which is 24–27% of the fabric elongation and construction provides optimal skin contact in regards to the garments performance effects.

Some researchers studied the relationships between the fabric corrective force/pressure distribution and fabric elongation. Leung, Yuen, Ng, and Shi (2010) developed a pressure prediction model incorporated into different design factors to estimate the pressure that might be exerted by compression garments before fabrication. The researchers tested fabric elongation properties for three different types of elastic fabrics in single-layered and double-layered conditions using a tensile tester to predict pressure levels to be exerted on the body. They demonstrated that the double-layered construction provides a larger range of target pressure at a particular strain according to the exerted pounds of force by elongation rate compared to the single-layered fabrics. The study indicated that compression garments or systems can be methodically analyzed based on the fabric types and the amount of layers according to the fabric elongation properties using a tensile strength tester.

Another study focused on the relationships between clothing pressure and fabric elongation in developing comfortable compression garments. Chen, Liu, Zhang, and Wang (2013) investigated the effects of elastic modulus and elongation and relaxation properties of fabrics on clothing pressure using a universal testing machine (LRXPLUS) and a pressure measuring device (AMI3037 S-5). They found that clothing pressure linearly increases with the increase of fabric elongation until 60% of the fabric elongation and higher clothing pressure is exerted from the fabric which has greater elastic modulus than the fabric with lower elastic modulus at the same level of elongation. This study showed that the elastic modulus and elongation are the indicators affecting clothing pressure in calculating the force of the materials.

One of the goals of this study is to systematically analyze fabric tensile forces in regard to correction effects of the PMSS using soft structural materials in changing posture. Material elongation properties were calculated from tensile test results and reaction of various types of layered materials when incorporated into the garment both off the body (flat measured) and on the body to determine force effects in modifying posture.

Wearer Acceptability

Wearer acceptability is an especially important factor in assessing individuals' perceptions of functional apparel since a garment must be acceptable to the wearer to prevent possible health risks and provide physical comfort (Huck et al., 1997). To assess broader acceptability of the functions of a garment, a few researchers have developed and used wearer acceptability assessment methods. In addition, several researchers have adopted and modified wearer acceptability scales according to the functional garments intended purpose and use.

Huck et al. (1997) developed wearer acceptability scales incorporating 12 bi-polar word pairings to verify that the design process yielded an improved garment design. Each subject was asked to complete a wearer acceptability scale after completing a series of motion movements based on the procedure outlined in ASTM F1154-88 for evaluating comfort, fit and function of chemical protective suits (Wang, Mok, Li, & Kwok, 2010). Several researchers have adopted and modified the wearer acceptability scales developed by Huck et al. (1997). Researchers focused on the main functions of the test garments in assessing wearer acceptability. Nam and Branson (2012) evaluated armor treatment and shoulder and arm movement using a five-point response scale by modifying Huck et al. (1997) scales, the questions were modified to reflect wearing conditions of protective armor. They assessed: 1) comfort, 2) acceptability, 3) flexibility, 4) freedom of movement, 5) ease of movement, 6) fit satisfaction, 7) preference, and 8) tightness. McRoberts, Black, and Cloud (2015) evaluated comfort, ease of movement, and fit of a posture modification garment made of softs structural materials by modifying Huck et al.

(1997) scales. The categories of two global assessments, seven assessments of comfort, four assessments related to movement, and two assessments of fit were included.

Rutherford-Black and Khan (1995) developed wearer acceptability scales including 18 word pairs to evaluate police bicycle officers' satisfaction with the physical aspects of their patrol uniforms. Black and Cloud (2008) adopted and modified the wearer acceptability scales developed by Rutherford-Black and Khan (1995) to investigate selected comfort aspects of police officers' standard issue ballistic vests. The wearer acceptability scales using five-point bipolar scales include the officers' perceptions of their current uniform for overall satisfaction, eighteen instrumental performance properties, four expressive performance properties, and three properties that have both instrumental and expressive aspects. The main evaluation categories included: 1) comfort, 2) durability, 3) protection, and 4) changes in garment dimensions in regard to the shape of the garment, "loses shape" or "retains shape".

Lee (2012) developed wearer acceptability scales focusing on a fit assessment for women's "skinny jeans". Lee (2012) went beyond having participants assess the jeans while standing in the typical static anatomical position assessing the jeans while the participant stood in various positions. For fit analysis, various movement functionality and appearance sensory tests were conducted. The participants were asked to evaluate fit and comfort of each jean using a five-point Likert scale. The evaluation dimensions included: 1) six areas on the front including waist, hip, crotch, thigh, knee, and hemlines, 2) two areas on the side including side seam and waist, and 3) five areas on the back including waist, yoke, hip, crotch, and thigh.

The literature review indicates that fit evaluation is necessary in assessing wearer acceptability of a prototype garment. Further, the purpose of the prototype garment should be considered when developing the wearer acceptability assessment.

Summary

To prepare for conducting this study of the potential of soft fabric structures in modifying posture, a review of literature was conducted organized in these content areas: product development, posture, posture correction force, and wearer acceptability.

The product development review assisted in providing a procedural structure for the study. The three stage design process developed by LaBat and Sokolowski (1999) was reviewed and adopted with some modifications as the organizing framework to explore the potential of textile structures used to apply strategic directional forces in modifying posture.

Review of physical, psychological and social aspects of posture and posture modification garments provided context for developing a prototype and evaluating posture effects of the prototype. The review indicated that good posture assumes the balanced alignment of the body in physical and social/psychological contexts. To achieve the balanced body alignment, posture modification garments have been designed for health/medical benefits (e.g. bracing/corset/vest made of rigid materials, called orthoses) and aesthetical benefits (e.g. foundation garment/lingerie made of soft structural materials, often called shapewear). Orthoses are effective in modifying posture; however, there can be possible health risks such as restricting spinal flexibility, permanent deformation of the rib cage or soft tissue at pressure points, skin breakdown or allergies possibly leading to lower wearer acceptability (Frontera et al., 2008). On the other hand, shapewear lingerie type body modifying garments are commercially successful because the garments are relatively comfortable and aesthetically pleasing. Shapewear body modification is achieved primarily through overall body compression. Understanding purposes, positive and negative aspects of the two garment categories can lead to new methods of modifying posture. The search revealed two academic studies conducted to develop body modifying garments.

A search for posture assessment methods found several that have been used, some more reliable and valid than others. This study focused on a combination of 3D body scanning technology and a photographic method to assess prototype effects on the human posture.

Posture correction force and methods of measuring were reviewed to assist in developing methods for measuring posture correction forces of the study prototype. The review indicated that the pressure of a garment/device is a significant factor in function and comfort so that many researchers have tried to directly measure posture correction force using pressure sensors placed under devices or indirectly by estimating correction forces from stretchable material properties. Since this study was initiated using stretch materials for the prototype, evaluation of pounds of force of the fabric by an elongation rate is the method of choice.

Wearer acceptability methods used by previous researchers were reviewed to assist in developing a wearer acceptability scale. In this study wearer acceptability scales were developed by considering the purpose of the prototype focusing on posture and body shape changes and fit evaluation.

CHAPTER THREE: METHOD

Functional clothing by definition is user-requirement specific. Clothing is designed or engineered to meet the performance requirements of the user under extreme conditions or particular industrial or work-related conditions, protection, medical conditions or athletics (Gupta, 2011). Design theories and structured design processes can help designers to organize the design and task performances in generating new ideas. In this study with the objective of developing a Posture Modification System using Soft materials structures (PMSS), a three-stage design process proposed by LaBat and Sokolowski (1999) was used to systematically address design problems. The theoretical framework includes the following stages: 1) problem definition & research, 2) creative exploration, and 3) implementation. The first stage includes 1) initial problem definition, 2) research, and 3) working problem definition. The second stage includes: 1) preliminary ideas, 2) design refinement, 3) prototype development, and 4) evaluation of prototype. The third stage includes: 1) production refinement, 2) phase 1: immediate production, and 3) phase 2: improvement/refinement. Some stages were modified to meet requirements of this study. Figure 2 presents a flow chart of the design process for this study.

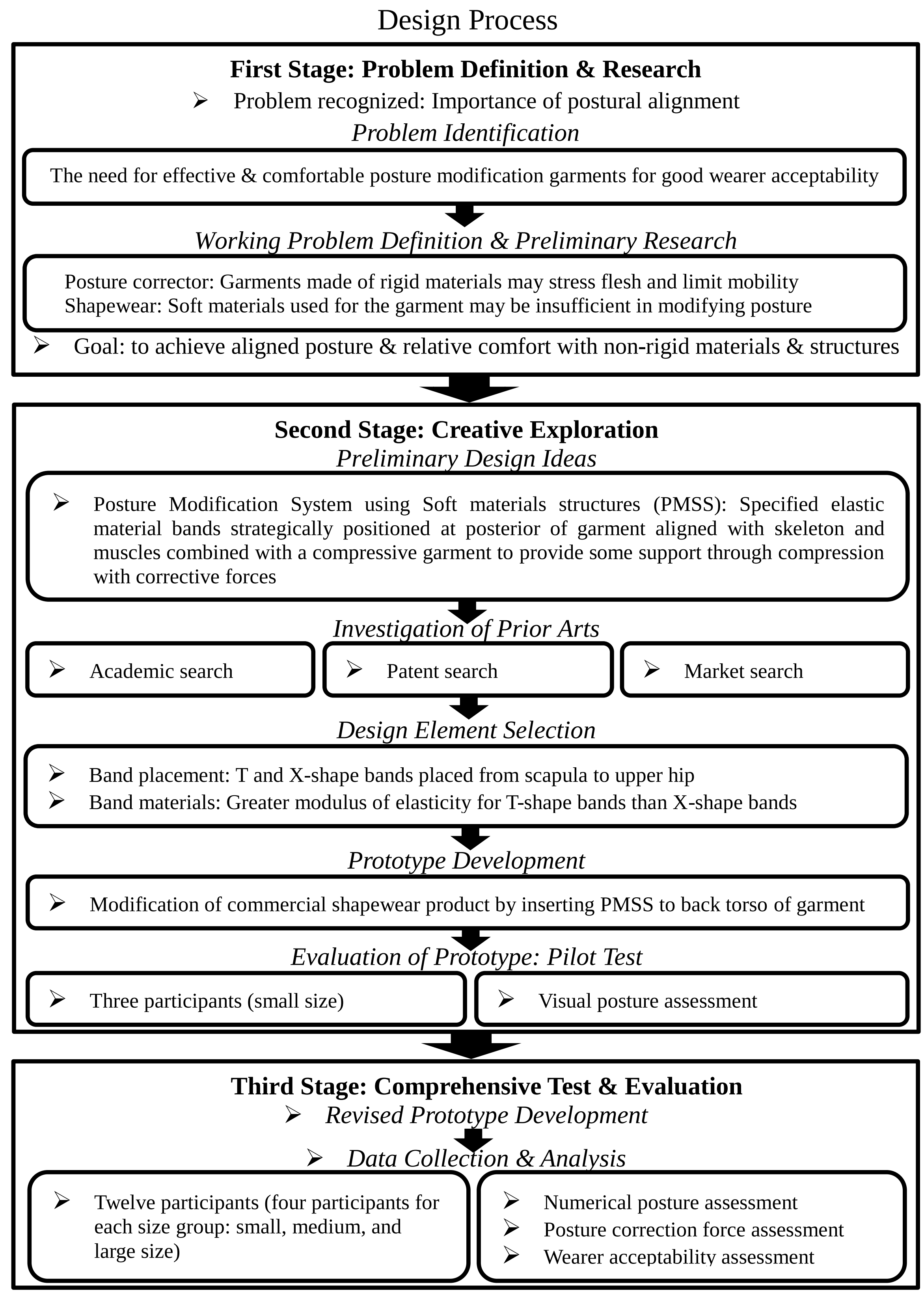


Figure 2. Flow chart for design process of PMSS

Description of Design Process

First Stage: Problem Definition & Research

The first step in designing a product is to identify a problem and begin preliminary research. Dixon (1966) addressed that problem recognition begins with recognition of objectives with a problem statement or a series of sketches. When it comes to scope of the problems, Middendorf (1969) emphasized that physical and practical constraints could influence the final design and should be established at the early conceptual stages. This stage is important because the operational problem definition is a bridge between the conceptual level and the observational level of design with the goal of translating abstract and conceptual problem statements into practical and performable statuses. Lewis and Samuel (1989) highlighted that by establishing objectives, designers should be able to understand and respond to needs for optimal performance. As research proceeds, the problem is often redefined and involves the participation of the user. The problem definition used to launch into creative exploration is labeled the working problem definition (LaBat & Sokolowski, 1999).

First Stage: Problem Definition & Research: Application

Problem Identification

A review of literature indicated that good posture assumes the balanced alignment of the body in physical and social/psychological contexts. Posture modification garments have been designed for each wearing context, with slightly different goals. Some products, often called posture correctors, are designed with health or medical benefits as the paramount concern and are marketed to men and women. Garments designed to achieve social/psychological benefits are typically attempts to achieve an appearance of an ideal figure and are often marketed to women. Posture correctors exhibit low wearer acceptability due to use of uncomfortable materials. While garments designed to achieve the appearance of the ideal figure are less effective in modifying posture. There may be a middle-ground of designing a comfortable, wearable product using soft materials structures that affect shape and posture. Better wearer acceptability than the posture correctors, and possibly short-term effects on posture alignment, might be achieved by modifying currently available shapewear products.

Working Problem Definition & Preliminary Research

The problem to be explored in this research is: can a garment made of textiles be designed to achieve balanced posture?

1) Posture "Correctors" — Commercially Available

There are many types of commercially available posture modification garments called posture correctors or back supporters currently on the market (see Appendix A). The definition of "correct" is to change something so that it is right, true, or proper; or to deal with or take care of a problem or bad situation successfully (Meriem Webster Dictionary, retrieved from http://www.merriam-webster.com/dictionary/correct). So, need for a posture corrector indicates that there is a problem with a person's posture, most often some type of medical or health problem. A review of descriptions of these products shows that materials are often stiff and rigid. According to McRoberts, Black, and Cloud (2015) posture correctors made of rigid materials like plastic boning or non-stretchable and thick fabrics may be uncomfortable limiting mobility while adding to a bulky appearance so everyday use is difficult. Public information on Amazon sites that solicit comments on products and provide rating of products indicated that many users were satisfied with the posture correctors in modifying posture but they experienced skin discomfort with limited mobility while wearing the garments.

2) Shapewear Products — Commercially Available

Shapewear implies that a woman wears the product to make something of her body; most likely relating to social context. In media, catalogs and online shopping sites, some shapewear companies (Amia®, Fitwear®, Leonisa®, and more) advertise that shapewear helps support the back, provides better posture, and improves blood circulation while providing a more pleasing body shape. The postural changes claimed seem to rely solely on overall garment compression on the body and the shapewear companies don't prove that soft materials used for the garments can provide what appear to be health improvement claims. For example, Amia® claims that their shapewear garments are designed to hold the spine straight and keep supporting muscles in place relieving back pain and increasing muscle strength. However, no evidence to substantiate the claims is provided on the website (retrieved November 19, 2014 from http://www.amiashapewear.com/blog/).

To examine the effectiveness of a readily available commercial shapewear product for improving posture, I conducted a simple test using 3D body scanning to visually determine if posture changes were evident. I selected a bodysuit made by Maidenform® called "Self Expressions®" with coverage from upper back to mid-thigh featuring an open bust region. The product was purchased at a Target™ retail outlet. The product is constructed of soft textile materials using overall compression of the body to achieve body change. On viewing scans of a person wearing the product, some changes were very visible, but a distinct change in posture was not evident. I determined that it may be possible to provide some posture modifications by strategically adding support elements made of textile materials to an existing shapewear garment. An added soft materials support structure could be more comfortable and less bulky. The goal of this study is to develop a soft materials structure, added to a typical shapewear compression garment, to align and balance the wearer's posture to more closely resemble the ideal female posture.

Second Stage: Creative Exploration

Creative exploration is used to generate preliminary ideas and then impose constraints in the process of design refinement (LaBat & Sokolowski, 1999). Lewis and Samuel (1989) said that designers can create several design ideas to meet customer requirements. Leech (1972) proposed criteria for developing preliminary design ideas: design function to use specification, design origin, general standards, safety, environment, and functional requirements. This stage leads designers to review existing design solutions or apply existing knowledge to their ideas for high quality solutions by searching academic and technical literature, and prior arts for finding answers to problems. After investigating prior arts, the best design elements can be selected for prototype development (Middendorf, 1969). LaBat and Sokolowski (1999) emphasized that the prototype development stage may require substantial creative input, as ideas are revised. At the evaluation stage, the designers' resources are tested; a formal evaluation is called for at the prototype stage often involving physical tests that lead to further refinement (LaBat &

Sokolowski, 1999). The goal of this stage is to determine if a design will meet needs or not (Medland, 1992).

Second Stage: Creative Exploration: Application

Preliminary Design Ideas

From early observations, it is expected that developing an effective and comfortable posture modification system could be beneficial for some people. The preliminary design elements were defined as: non-rigid textile components to be added to the back of a typical shapewear product to assist back muscles and spine segments (PMSS). Since shapewear garments of any type provide some support through compression of the abdominal muscles, it is expected that the PMSS could provide more support for posture.

A biomimicry approach was used in designing the PMSS. Biomimicry is the imitation of the models, systems, and elements of nature for the purpose of solving complex human problems (Vincent, Bogatyreva, Bogatyrev, Bowyer, & Pahl, 2006). The human body as a biological inspiration was analyzed and the textile system added to a shapewear product was designed to imitate some parts of the human body. Specifically the muscles of the back torso, which play a key role in posture and supporting the spinal column, were focused on for this study as they provide inspiration for the composition, sizes, and positioning of the support system (PMSS). The decision to focus on the muscles of the back does not deny the contributing role of all other muscle and skeletal structures of the body in aligning posture. Compression supplied by the shapewear product in part mimics the role of abdominal muscles in affecting posture.

1) Anatomical Analysis for PMSS Design

- Band-like structures of back muscles and vertebral column

Preliminary study of the anatomical features of the human posterior torso-vertebral column and muscles-revealed that the biological elements exhibit column and band-like shapes, so design experimentations were conducted using bands of textile materials.

- Band placement based on features of the spinal region

To determine reference lines and location of the PMSS elements, the vertebrae in each spinal region were studied. The spine is a column of connected bones called vertebrae (Saladin & McFarland, 2008). There are 24 vertebrae in the spine, plus the sacrum and tailbone (coccyx). Most adults have seven vertebrae in the neck (the cervical region), twelve from the shoulders to the waist (the thoracic region), and five in the lower back (the lumbar region). The sacrum is made up of five vertebrae between the hipbones that are fused into one bone. The coccyx is made up of small fused bones at the tail end of the spine. Figure 3 shows curvatures of the adult vertebral column.

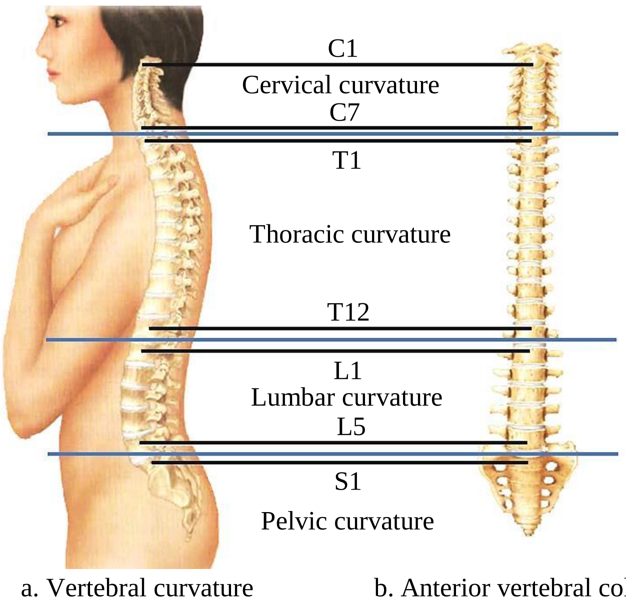


Figure 3. Curvatures of the adult vertebral column (Human anatomy, Saladin, & McFarland, 2008)

Abnormal spinal curvatures can be one of the main symptoms of poor posture (Saladin & McFarland, 2008). It can result from abdominal weight gain in obesity, disease or weakness or paralysis of the muscles of the trunk which is an anatomical term for the central part of human body. Abnormal spinal curvatures are commonly divided into three types (Saladin & McFarland, 2008): 1) scoliosis, 2) kyphosis, and 3) lordosis (Figure 4). Saladin and McFarland (2008) stated that the most common deformity is an abnormal lateral curvature called scoliosis which occurs most often in the thoracic region. Sometimes, it is caused by a developmental abnormality in which the body and the arch of vertebrae fail to develop on one side. Saladin and McFarland (2008) defined kyphosis as an exaggerated thoracic curvature, sometimes called hunch back, that may be evident in elderly people with osteoporosis. An exaggerated lumbar curvature is called lordosis (Swayback). It can result from aging, obesity, or added abdominal weight in pregnancy. Based on the descriptions of abnormal spinal curvatures, the thoracic and lumbar regions seemed a logical focus for placement of the PMSS elements. The early exploration focused on posterior muscles that support the vertebrae, while recognizing that abdominal muscles also play a role in supporting the spine.

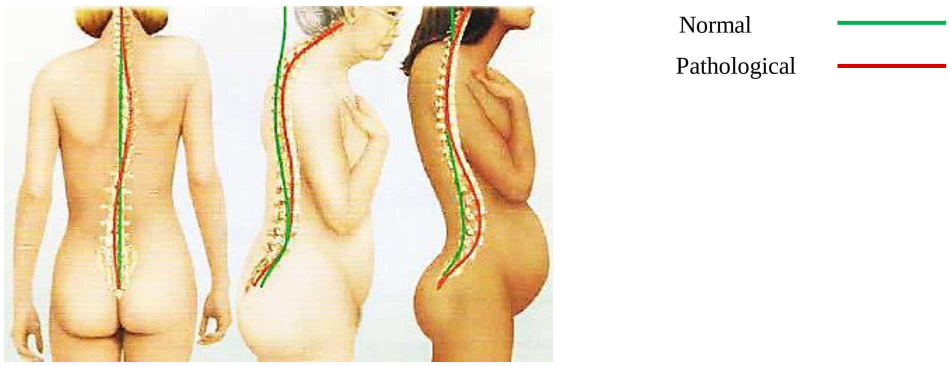


Figure 4. Abnormal spinal curvatures (Human anatomy, Saladin & McFarland, 2008)

- Band design based on posterior muscles

Since the abnormal spinal curvatures may result from weak muscles, posterior muscles which support the spine were chosen to study as inspiration for the PMSS elements. The erector spinae with the serratus posterior inferior and latissimus dorsi were considered for the PMSS design because these muscles play a significant role in supporting the back (Saladin & McFarland, 2008). The muscles attach to skeletal bone at cervical and thoracic areas providing constant tension to hold the body in an erect posture.

- Erector spinae is a bundle of muscles and tendons extending throughout the lumbar, thoracic and cervical regions, and lies in the groove to the side of the vertebral column. The origin arises from vertebrae T9 through T12. It functions to maintain posture, straightening the spine after one bends at the waist or arching the back, and aides in laterally flexing the vertebral column (Saladin &

McFarland, 2008).

Based on understanding of the structure and function of the erector spinae, one of the preliminary ideas was identified: a vertical support element to be added to the overall spinal region extended from the back neck opening to the upper hip area of a shapewear garment. Figure 5 shows muscles with vertical alignment acting on the vertebral column.

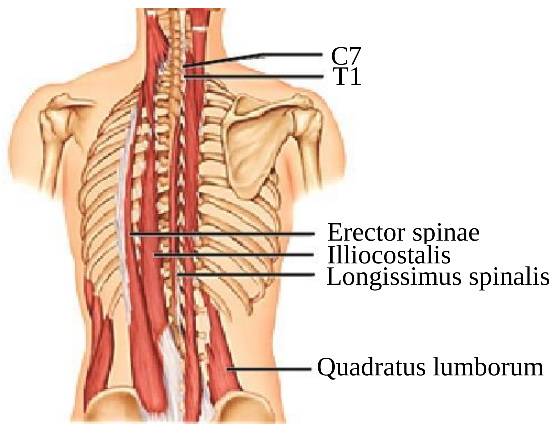


Figure 5. Muscles acting on the vertebral column

- Serratus posterior inferior muscles are deeper layers lying at the junction of the thoracic and lumbar regions. The origin arises from vertebrae T11 through L2. These muscles draw the lower ribs backward and downward to assist in rotation and extension of the trunk.
- Latissimus dorsi muscles are the superficial muscles with the origin that arises from vertebrae T7 through T12. These muscles are responsible for extension, adduction, transverse extension also known as horizontal abduction, and lateral flexion (anterior fibers) of the lumbar spine, that assists as a muscle of both forced expiration (anterior fibers) and as

accessory muscles of inspiration (posterior fibers) (Saladin & McFarland, 2008). Since Latissimus dorsi connects the spine to the humerus, tightness in this muscle can manifest as either sub-optimal glenohumeral joint (shoulder) function which leads to chronic pain or tendinitis in the tendinous fasciae connecting the latissimus dorsi to the thoracic and lumbar spine (Francis, 1999).

To add support to the lower spinal column, a support element for the lumber region was identified: a cross shape band supporting the serratus posterior inferior and the latissimus dorsi to be added to the thoracic and the lumbar region extended between the underarm and the upper hip area of a shapewear garment. Figure 6 shows neck, back, and gluteal muscles with a horizontal orientation (Saladin & McFarland, 2008).

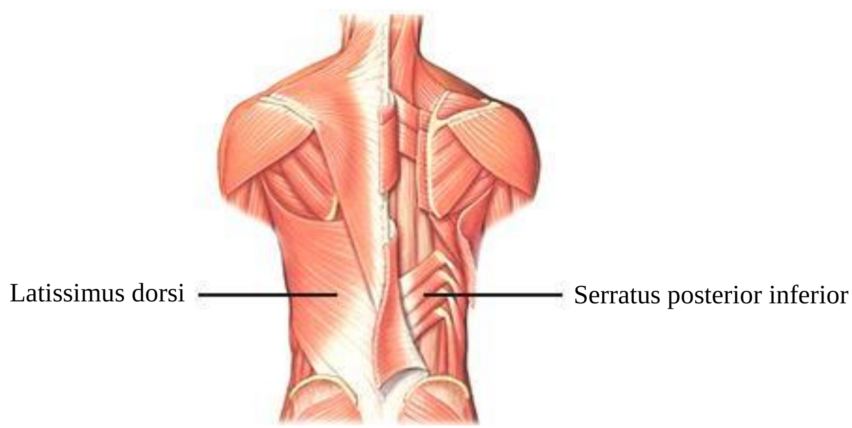


Figure 6. Neck, back, and gluteal muscles

- Band width based on vertebral body diameter

The spine is a very complex structure with the vertebrae acting independently but relying on alignment to provide postural structure. To balance the spine, a decision was made to place support bands aligning with the vertebral column acting as an additional column. To determine band width, the average vertebral body diameter in lumbar (A) was considered (Figure 7). Eisenstein (1976) measured the spinal canal and the vertebral bodies in 2 racial groups (113 “white” Caucasoid skeletons: 78 male and 35 female and 162 “black” Negroid skeletons: 108 males and 54 females) using lateral radiograph. The measurements of the transverse diameters of the vertebral bodies in Caucasoid females indicated (mm): L1: 34, L2: 35, L3:37, L4: 39, and L5: 42 and in Negroid females indicated (mm): L1: 35, L2: 37, L3:38, L4: 41, and L5: 43. The average vertebral body transverse diameter of lumbar area for both groups was 38.1 mm and showed gradual increase in measurement from L1 to L5 vertebral levels regardless of race.

To support the spinal column, at least a covering of the largest lumbar vertebral body diameter (L5, 43mm, is the biggest diameter of vertebral body in the thoracic and lumbar region.) was indicated. Figure 7 shows the second lumbar vertebra.

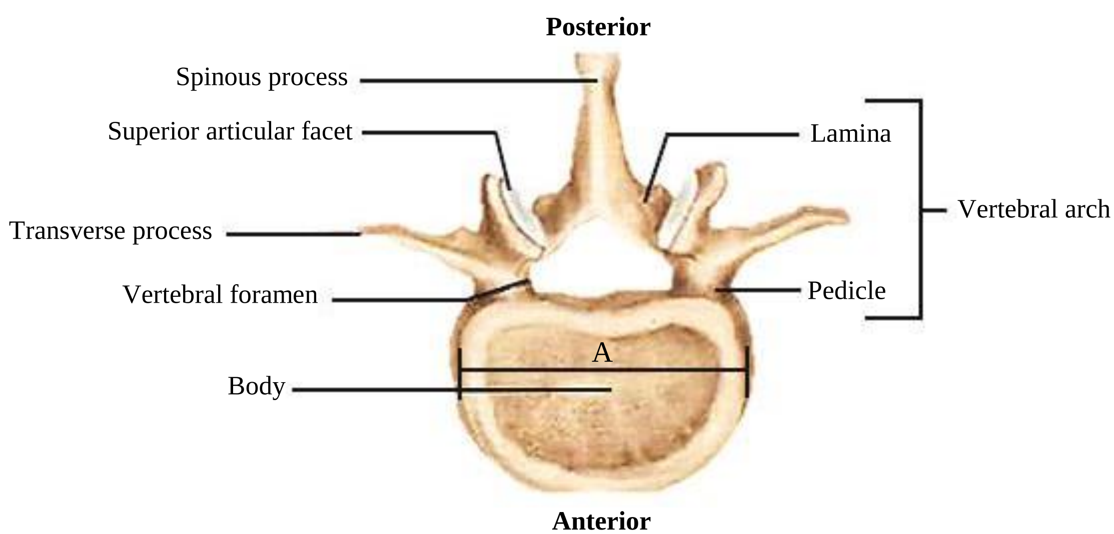


Figure 7. Second lumbar vertebra (Human anatomy, Saladin & McFarland, 2008)

2) Preliminary Band Design

To provide an additional support/strength to spine and muscles, four support bands were designed for the PMSS.

- Band placement

Figure 8 presents the location of the PMSS elements (grey lines) on the posterior muscles referring to the spinal regions (from far left illustration; lateral view of vertebral column, middle illustration; posterior view of vertebral column, and right illustration; band location on the posterior muscles). In the Figure 8, three horizontal lines indicate the reference lines between spinal regions: reference line A between cervical and thoracic, reference line B between thoracic and lumbar, and reference line C between lumbar and sacrum. Refer to Figure 8 with designator numbers showing the location of the bands (PMSS) and alphabet showing reference lines.

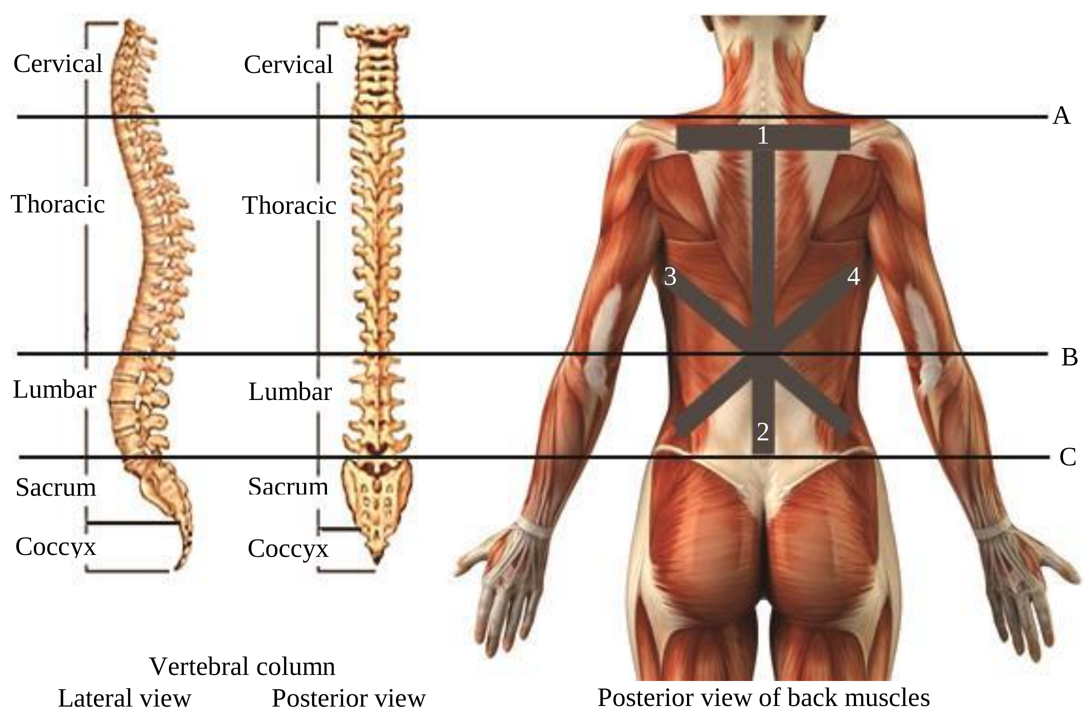


Figure 8. Band placement

To provide an additional support/strength to the erector spinae, two support bands **1** and **2** were inserted from shoulder blades to the reference line **C** to cover the thoracic and lumbar region, define, e.g., a T-shape; the T-shape defined by the horizontal support band **1** and vertical support band **2** may provide support to the erector spinae by potentially improving abnormal curvatures of the spine. To provide an additional support to serratus posterior inferior and latissimus dorsi muscles, the other two support bands **3** and **4** were aligned with these muscles across from each other at the reference line **B**. The two support bands **3** and **4** may extend all the way from a seam on one side of the shapewear garment to a seam on the opposite side of the shapewear garment, define, e.g., an X-shape; The X-shape bands **3** and **4** may provide a dual support to the spinal curvature by supporting the overall thoracic and lumbar region.

- Band materials

A variety of band materials were researched through Google, online market (e.g. Amazon), and a retail market search (e.g. Hancock fabrics). The key words were used for the market search: pliable (or stretchable/elastic/flexible/spandex/polyurethane) textiles (or fabrics/bands). Specific band materials were not selected at this stage.

- Band width

A diverse range of band widths were explored through Google, online market (e.g. Amazon), and a retail market search (e.g. Hancock Fabrics); 0.5, 0.75, 1, 1.25, 1.5, 2, 2.5, and 3 inch elastic bands currently on the commercial market. To support the spinal column, at least a covering of the largest vertebra width which is 43 mm (1.69 inch) was considered (Eisenstein, 1976): a choice of 2 to 3 inches in width. A specific band width was not decided at this stage.

From the anatomical approach and market search, a preliminary PMSS design was developed: T and X-shape bands made of soft structural materials added to the back of a typical shapewear garment to assist back muscles and spine.

I acknowledge that the bands cannot function independently but must be incorporated into a shapewear garment or a compression garment. When the bands are anchored to the garment, at least part of the posture modification is provided by combining compression of the suit itself.

Investigation of Prior Arts

Prior arts were investigated to determine research and development for posture support items that may replicate or influence design of the PMSS. A literature review of academic theses was conducted. A patent search was also conducted to find ideas or technologies similar to the PMSS. The shapewear market was also examined to determine the scope and success of shapewear products focusing on posture modification systems sold as shapewear.

An online search was conducted using keywords such as posture (or back/body) support (or supportive/improvement/shaping) system (or bands/straps) or garment (or foundation garment/shapewear/swimwear/underwear/lingerie) for academic research, patent, and market searches without specifying the range of published years. Typically, Google and Google Scholar were used but sometimes general web searching (e.g. Amazon/eBay/Target or information on news letters or personal blogs) was used as well.

1) Academic Search

The academic search resulted in only two proposed designs and these were for upper body (neck to waistline) only. The prototype development and evaluations were conducted by one undergraduate and one doctoral student. Results of the studies were documented in unpublished theses. See Appendix B.

2) Patent Search

The Google and Google Scholar search produced some relevant results: a full body garment (e.g. shapewear/swimwear/foundation garment) with posture modification system like an extra lining or posture support element. Eight patents were found and compared to the design idea proposed in this study. It was difficult to conclude that designs related to posture support elements submitted for patents were similar to the PMSS developed in this study since the system designs and claims are different. See Appendix C.

3) Market Search

The market search was conducted using Google and general web searching (e.g. Amazon/eBay/Target). The market search resulted in some shapewear products that claim posture support; Invisupport®, Braologie®, Instant figure®, Cortland®, Dare to flaunt®, and Creation shapewear®, shapewear companies in the current market in United States, claim that their products have a posture support function by using X-shape bands mostly for upper torso or by changing the knit gauge of the textile used for the products to provide posture support. Through the market search, I determined that existing shapewear products which claim posture support are not similar to the PMSS design for this study. A few support systems designed with X-shape bands positioned at the upper torso are apparently not related to anatomical muscle structures acting to support the spine. See Appendix D.

Design Element Selection

Design elements selected in this early stage are described here. The following descriptions for band placement and band materials are from U.S. Non-Provisional Patent Application *No. 14/924,261, Posture Improvement Shapewear Garment and System*, developed by Lyu (2015).

1) Band Placement

Figure 9 illustrates the embodiments of the PMSS. Refer to Figure 9 with designator numbers showing location of support bands on a typical back torso lining.

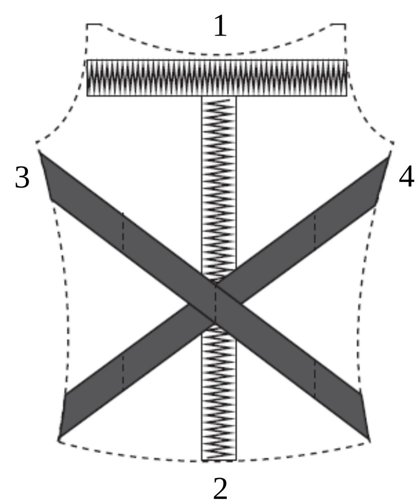


Figure 9. PMSS

- First band

A first support band **1** of the four support bands may extend between the right and left arm openings on the rear portion of the torso body. The first support band **1** may be oriented such that the first support band **1** is substantially horizontal when a wearer is standing upright.

- Second band

A second support band **2** of the four support bands may extend from the low waist region toward the neck opening on the rear portion of the body. The second support band **2** may be oriented such that the second support band **2** is substantially vertical when a wearer is standing upright. The second support band **2** may extend from a shoulder blade region of the shapewear garment to an upper hip line of the shapewear garment. In some embodiments, the second support band **2** may extend between the low waist region and a center of the neck opening on the rear portion of the torso body.

The first and second support bands **1, 2** may be transverse to one another. As used herein to describe the orientation of bands and other components with respect to each other, the term "transverse" includes perpendicular as well as nearly perpendicular (e.g., + 10 degrees from perpendicular).

- Third band

A third support band **3** of the four support bands may extend from the left underarm region toward the right waist region on the rear portion of the torso body.

- Fourth band

A fourth support band **4** of the four support bands may extend from the right underarm region toward the left waist region on the rear portion of the torso body. In some embodiments, the third and fourth support bands **3, 4** may extend all the way from a seam on one side of the shapewear garment to a seam on an opposite side of the shapewear garment. The third and fourth support bands **3, 4** may intersect proximate an intersection point.

Four flexible bands **1** through **4** are combined each other (e.g., the X-shape defined by the third and fourth support bands **3, 4** in combination with the T-shape defined by the first and second support bands **1, 2**).

2) Band Materials

Band materials for the PMSS may have a modulus of elasticity that is greater than the modulus of elasticity of the fabric or fabrics used to construct the torso body to which the support bands are attached (where the fabric or fabrics are of the same width as the support bands–with width being measured transverse to the direction of elongation). In other words, the resistance to elastic elongation along their length of the support bands is greater than the resistance to elastic elongation of the garment fabric. T-shape bands may also have a modulus of elasticity that is greater than the modulus of elasticity of the fabric used for X-shape bands to provide stronger support for the erector spinae.

3) Band Width

Based on biomimicry reasoning, support band width may be greater than the largest vertebra width, average 1.69 inches (Eisenstein, 1976), to provide extra support to the spinal column. The band width can be selected between 2 and 3 inches but wearer acceptability needs to be considered.

Preliminary Prototype Development

After all design elements of the PMSS were determined, a preliminary prototype for a pilot test was developed by modifying a commercially available shapewear product.

1) Prototype Construction

A commercially available shapewear product was chosen for modification; a bodysuit, by “Self Expressions®” by Maidenform®, with coverage from upper back to mid-thigh featuring an open-bust region. The open-bust design was selected to avoid undue compression of breast tissue which is likely to vary person to person. This design admittedly reduces reliance on total torso compression to add to postural support. The fabric was described by the producing company as “firm” and made of 81% nylon and 19% elastane. This product was chosen because it is price competitive and is designed to provide overall definition of the middle part of the body. The modified shapewear was developed by experimenting with inserted band designs that might provide additional posture support.

- Descriptions of commercial shapewear garment

As shown in the Figures 10 and 11, the shapewear garment comprises a strapped one-piece foundation. Torso panels are equipped with adjustable shoulder straps **2** made of approximately 0.6 inches elastic trims. Front torso panel **3** is seamed at back torso side panel **6.** The upper back panel **4** is seamed at each upper front panel **1.** Two single top zigzag stitches are seamed at the seam of the upper back panel **5** and both side panels **4** with an inner lining. The front bottom panel **8** and back bottom panel **9** are sewn up and then bottom panels are sewn up with the completed torso panels. The shapewear garment is equipped with an opening crotch **10** for toileting use.

- Descriptions of PMSS

Approximately 2 inch posture support bands (PMSS) **11** through **14** were inserted to the inside back of the garment, spanning from shoulder across the back to the opposite side seam. The band width (2 inches) was chosen to cover at least the largest vertebra and provide comfort as well; a wider band may limit mobility compared to a thinner band and pull the lower part of the garment upward resulting in lower wearer acceptability and fit.

The horizontal band **11** was placed 0.1 inch below the back neck opening horizontally and the vertical band was placed under the horizontal band **11** perpendicularly to the end of the back torso line around the upper hip region. Approximately 1.6 inches elastic band was added to under horizontally laid flexible support band **11** and a half-length of the same elastic band was added to lower part of the vertical band **12** to exert more control to support spine. The placement of vertical band **12** was determined by considering wearer acceptability. Although the band can be extended between the neck opening and the upper hip region, it in fact relies on anchoring at the crotch seam while not actually extending beyond the waist. Extending band **12** beyond the waist level to the crotch/inseam intersection could compress soft tissues of the buttocks deforming shape and reducing comfort. X-shape bands **13** and **14** were placed from 0.6 inches below underarm opening to 0.6 inches above at the end of the side seam around the low waist region by being crossed each other. Since the commercial shapewear was a completely constructed product, the PMSS was placed on the lining instead of under a lining. To prevent the bands rolling up because of friction while wearing the garment, the cross section **15** of the two flexible bands laid across the back was stitched vertically on the vertically laid band **12** and at four intermediate locations **16** through **19** of each strap on the back torso of the X-shape support bands.

Figure 10 illustrates the commercial shapewear garment showing anterior view (a) and posterior view (b). Figure 11 illustrates the PMSS shown out of place for convenience of illustration (a) and the posterior view of the full length commercial shapewear garment comprising the PMSS (b) to show the places of the bands. Refer to Figures with designator numbers and alphabet showing location of support bands. Specifications of the shapewear garment and the PMSS are presented in Table 2 and Table 3 respectively. Refer to small size in the tables and Figure 16 illustrating specifications of the PMSS (a) indicated with lower case letters and the shapewear garment specifications (b) indicated with capital letters.

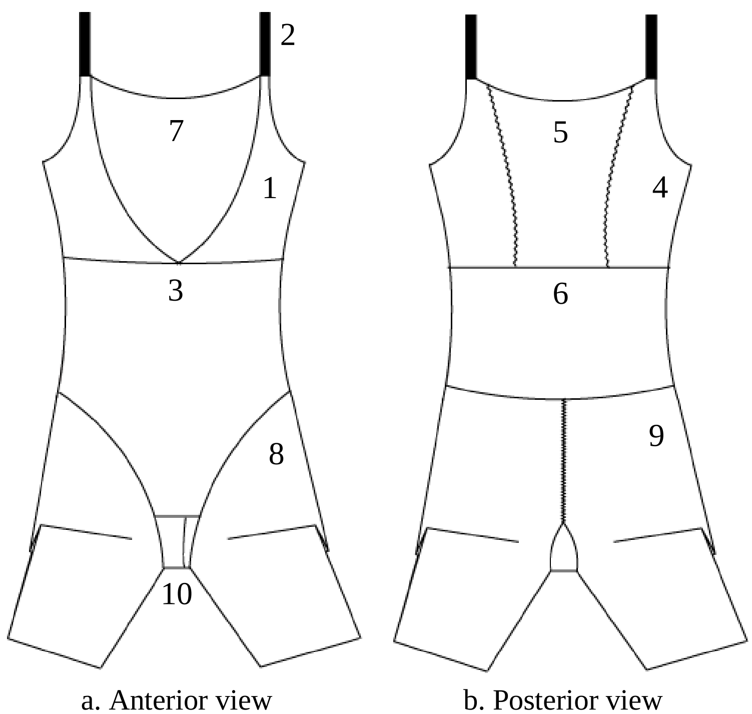


Figure 10. Prototype, external

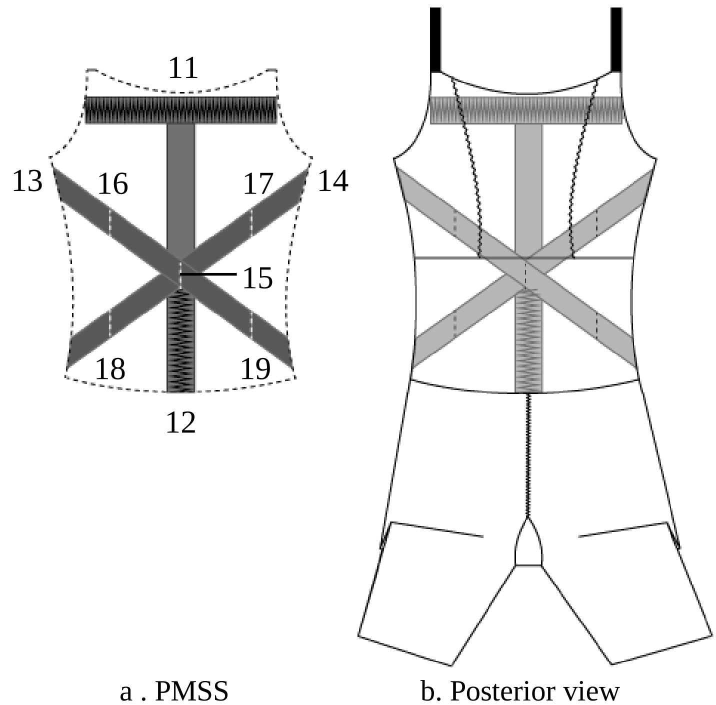
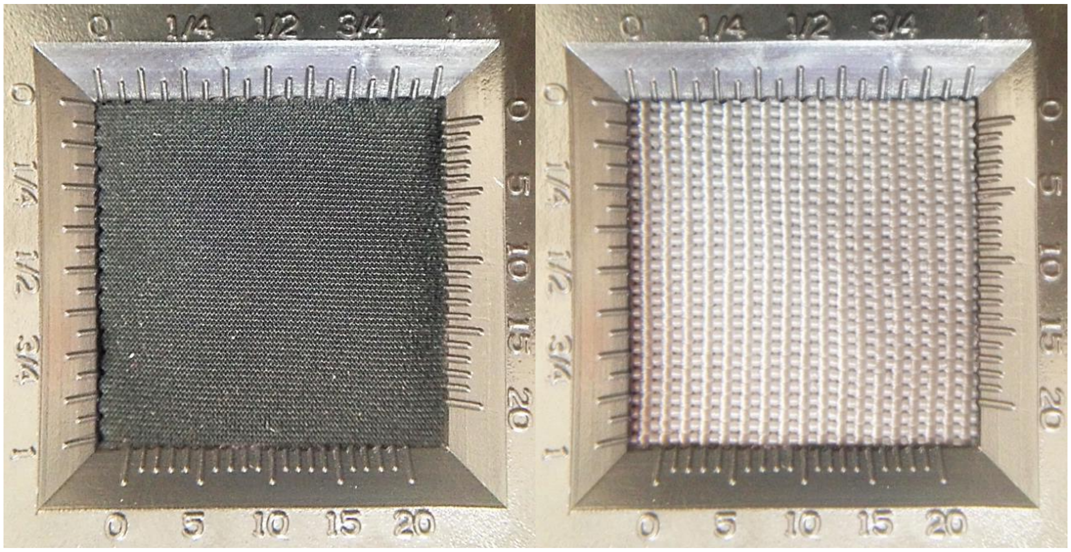


Figure 11. Prototype with PMSS

- Band materials

A knitted fabric made of 68% nylon and 32% elastane was used to construct the bands **11** through **14** (Figure 12a). Woven elastic made of polyester and elastomer was used as the layered elastic bands under bands **11** and **12** shown in the Figure 12(b). The elastomer is core spun, covered with polyester textured top. In the Figures, the measuring dimension is 1x1 inch square; the upper ruler indicates inches and the lower line indicates millimeters. T-shape band material was covered with an extra fabric which is the same material with the X-shape bands to provide greater forces acting on the body with physical comfort.



a. X-shape band material b. T-shape band material

Figure 12. Band materials

Evaluation of Prototype: Pilot Test

A pilot test was conducted to determine if the PMSS had potential for further design refinement and testing.

1) Sampling Procedure — Pilot Test

Three participants volunteered for the pilot test. All participants were Asian, ages 25 to 28 representing typical shapewear users who according to Jones and Guilbault (2014) are ages 25 to 35. All participants wore the smallest size.

2) Data Collection Procedure — Pilot Test

Participants were scanned using a 3D Human Solutions body scanner in the Human Dimensioning© Lab at the University of Minnesota. Participants were each scanned three times in: 1. no shapewear, 2. a commercial shapewear, and 3. the prototype. Participants wore their own underwear for all scanning processes. Before scanning, landmarks were placed on the cervicale which is the tip of the spinous process of the seventh cervical vertebra and both shoulder points referring to Gupta and Zakaria (2014) using a type of earring backing that projects slightly from the body surface (see Appendix I).

Participants performed a variety of positions. Although posture is often assessed by looking at a person in the typical standing anatomical position, for the pilot test a more comprehensive look at position was warranted. A variety of positions were selected to assess how posture might be affected by the wearing conditions (no shapewear, a commercially available shapewear product, and the prototype) in differing stances; from a standard anatomical position, active position, and the standard anatomical position while carrying an item. Diverse handbag positions in carrying an item positions were chosen because handbag carrying can cause spine problems such as scoliosis by carrying it on only one side of the shoulder or hand. The bag loads were designed as approximately 10% of their body weight (Harman, Hoon, Frykman, & Pandorf, 2000).

To assess posture, posterior and lateral views of virtual photographic images in each position were generated for each participant and the same positions were compared among three wearing conditions.

3) Data Analysis Procedure — Pilot Test

- Posterior view

Shoulder and spine angles were visually analyzed based on reference lines. To generate the reference lines, reference points were selected from "Anthropometry, apparel sizing and design" by Gupta and Zakaria (2014). The selected reference lines based on the reference points included: vertical line referring to the crotch point, center line connected from the crotch point to the cervicale, triangular-shape lines connected from the crotch point to each shoulder point, and two horizontal lines on the cervicale and the lowest shoulder point among three wearing conditions on the posterior view of standing position. For the walking up a stair position in the active position, the vertical line refers to the inside of the malleolus by considering the center of gravity.

- Lateral view

Center of gravity and spinal curvatures were analyzed based on reference lines on the lateral view of the virtual photographic images in each position. The selected reference lines included: vertical line referring to the intermediate point of the feet, horizontal line referring to the buttock point, back line connected from buttock point to the shoulder blades region, and polygonal-shape line connecting left shoulder point, breast point, convex point of the thoracic region, and the middle point of the buttock depth. Based on the reference lines, the curvatures of the thoracic region were analyzed.

4) Results — Pilot Test

Posture changes were observed for all participants wearing the prototype which is the modified shapewear appearing to provide posture modification compared to the commercial shapewear and no shapewear for most scan positions. The angles of spine and shoulders were aligned when wearing the prototype also providing a balanced center of gravity. Figure 13 shows visual analysis of a standard anatomical position from a posterior view (a) and a lateral view (b), with left figure wearing her own underwear, middle figure wearing the commercial shapewear, and right figure wearing the prototype. The location of each wearing condition is the same throughout the illustrations. Figure 14 shows the same participant walking up a stair and Figure 15 shows the same participant carrying a back with the right hand.

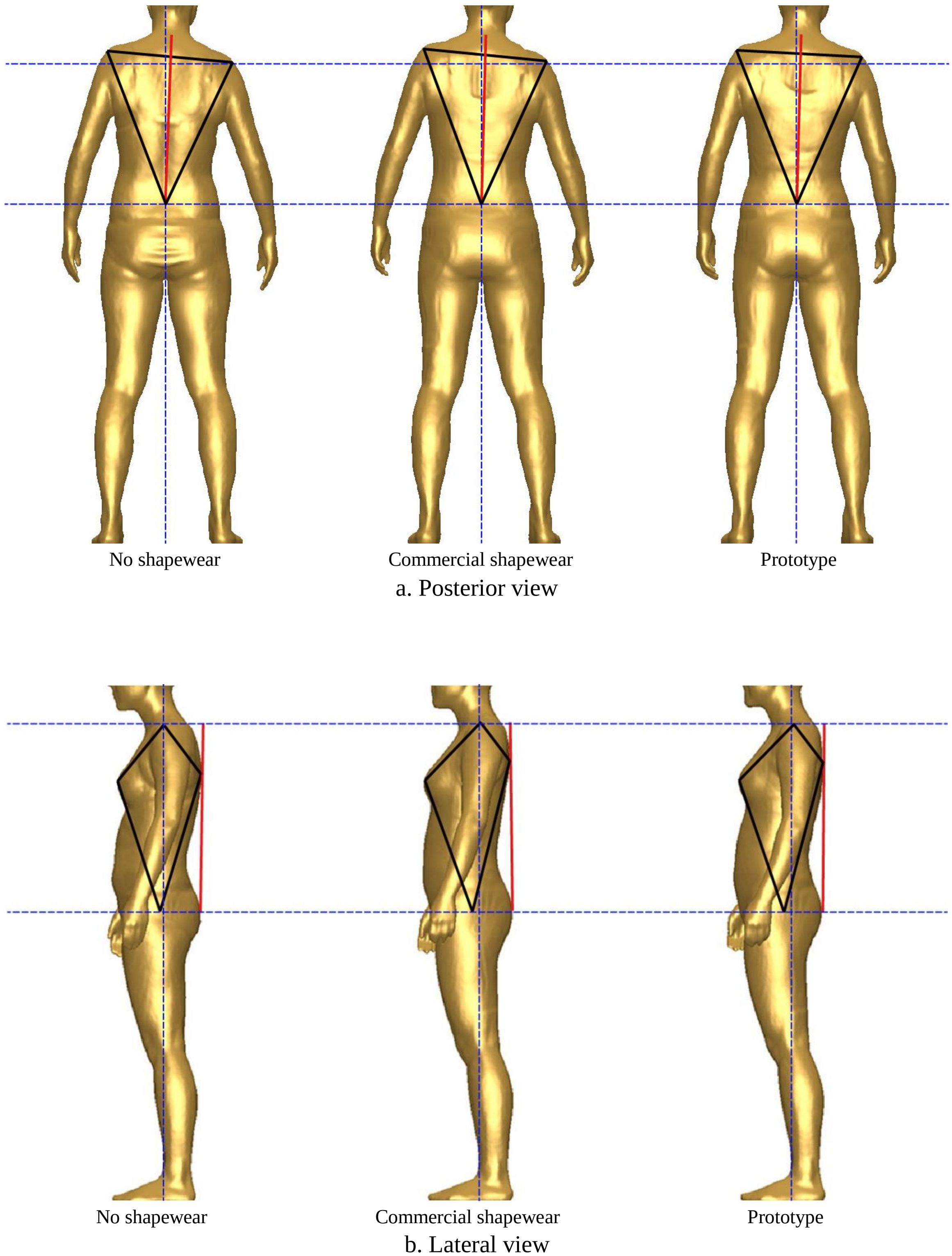


Figure 13. Visual analysis of standard anatomical position

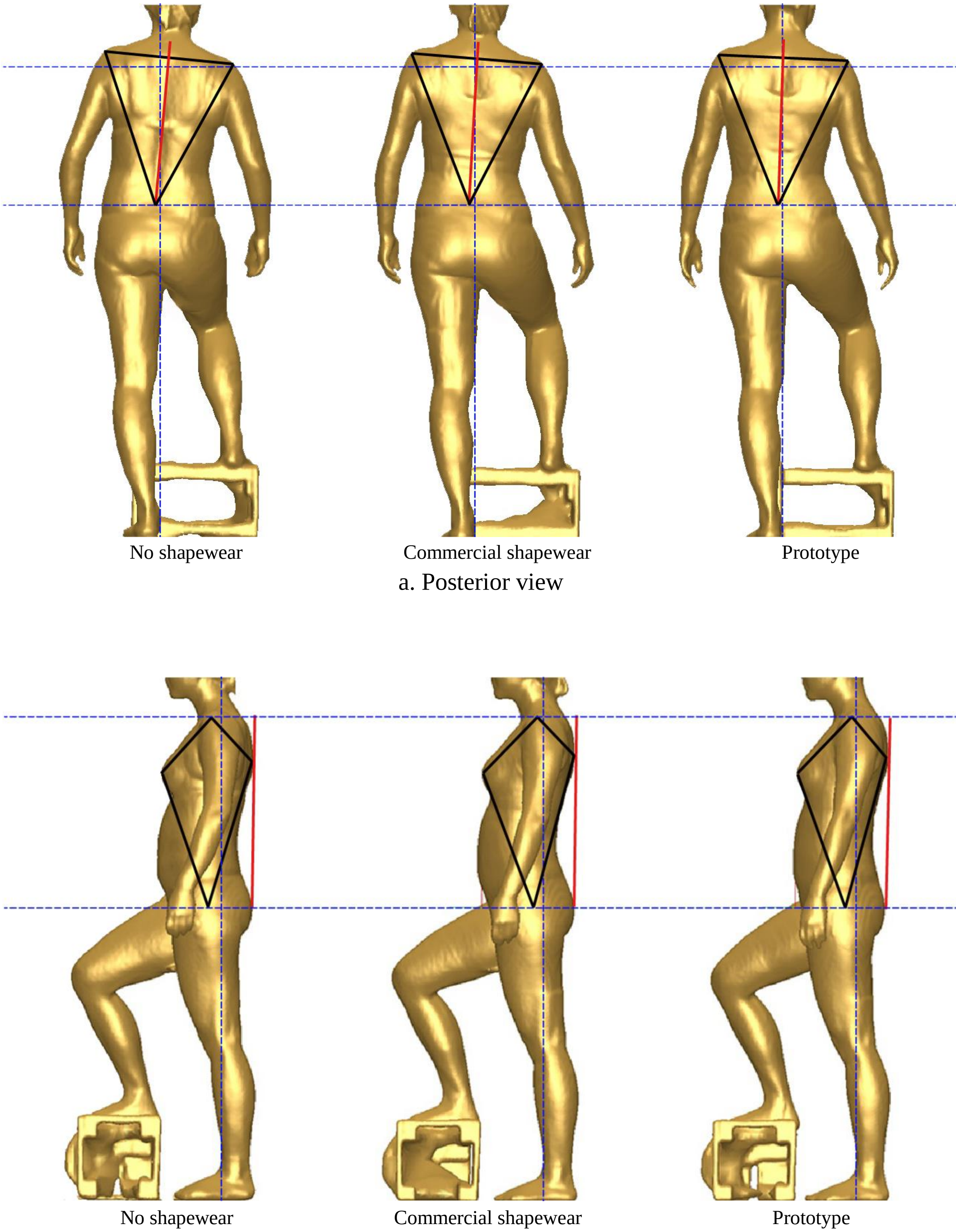


Figure 14. Visual analysis of walking up a stair position

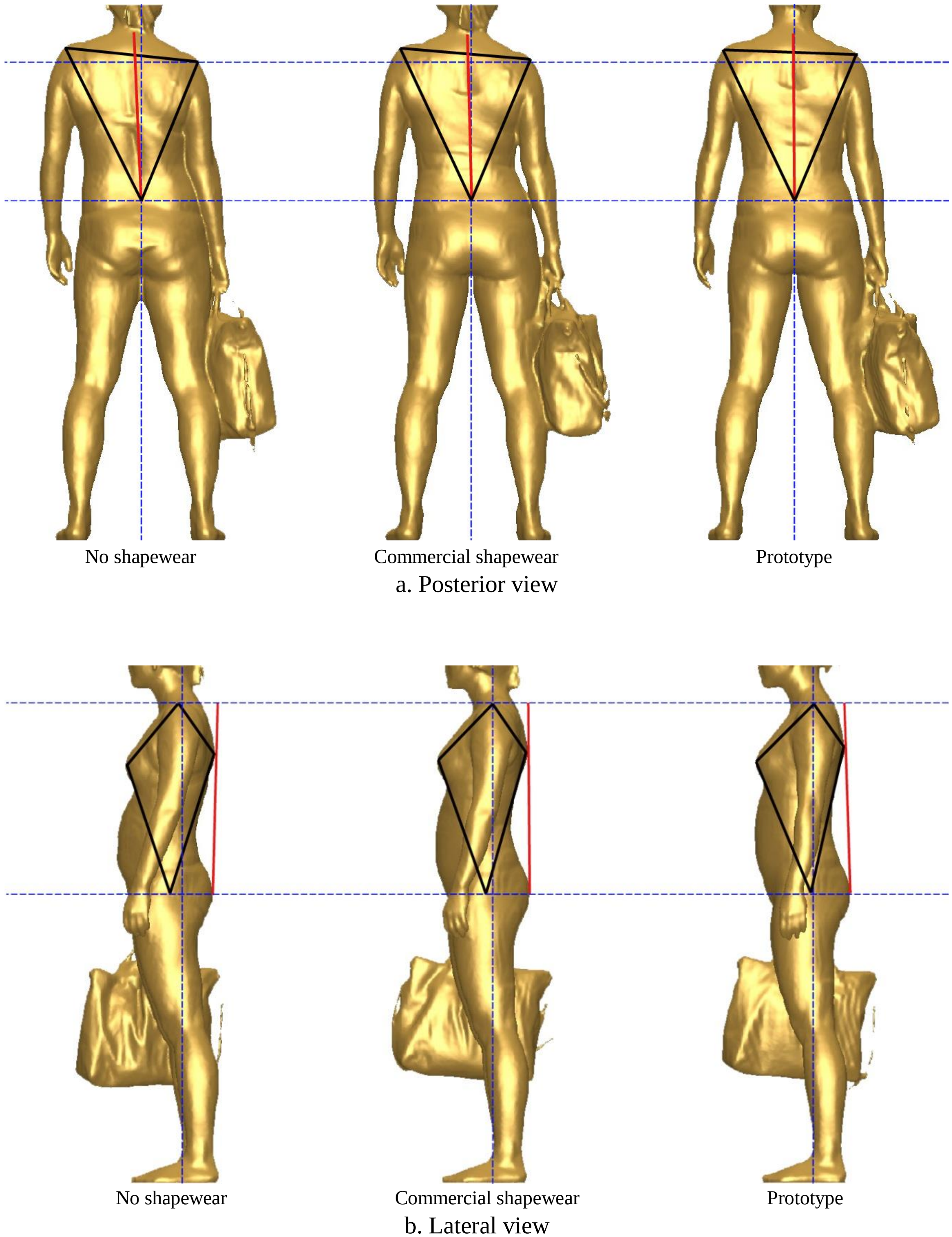


Figure 15. Visual analysis of carrying an item position with the right hand

Third Stage: Comprehensive Test and Evaluation

As a final stage of the design process, design reviews are used to find errors in the final form (Lewis & Samuel, 1989). Designers need to refine designs to prevent negative consequences and to improve performance. By correcting errors, the idea can be produced in a final form (Chapman, Bahill, & Wymore, 1992). LaBat and Sokolowski (1999) divided this stage into two phases: 1) immediate production and 2) improvement/refinement. They stated that immediate production incorporates changes that can be worked into current production methods while the improvement/refinement incorporates further refinement with a more drastic change in product or return to earlier stages of research. This step involves physical tests to determine if the revised design will meet needs or not and it may lead to further refinement if necessary.

Third Stage: Comprehensive Test and Evaluation: Application

Results from the pilot test seemed promising: the PMSS was developed and pilot tested with three participants and the results showed aligned shoulder and spine angles with balanced center of gravity when wearing the prototype. The continued study is delineated in the sections to follow starting with the third stage, comprehensive test and evaluation of the revised prototype.

At the third stage, a refined prototype was developed. For the third stage the PMSS was applied to a broader range of sizes (small, medium and large) using the same commercial brand, Self Expressions® by Maidenform® (refer to Table 1). Twelve participants were recruited from university staff, faculty members and students to wear-test the refined prototype to assess posture changes when wearing the prototype. To determine posture correction force of the soft structural system in modifying posture, standard laboratory materials tests were conducted; materials elongation test results and reaction of the materials when incorporated into the garment both off the body (flat measured) and on the body were used to determine force effects of the PMSS on modifying posture. To get participants' in-depth perceptions of acceptability of the shapewear garment combined with the PMSS, questionnaires were administrated. After the laboratory tests, in-depth analyses including numerical posture assessment, posture correction force analysis, and wearer acceptability analysis were conducted.

Revised Prototype Development

1) Design Specifications

A commercially available shapewear product, Self Expressions® by Maidenform®, the same type of shapewear garment used in the pilot test, was used as the base prototype garment with the addition of the PMSS inserted at the back of the garment torso. The small, medium, and large size shapewear garments were used. Table 1 presents the Maidenform® size chart.

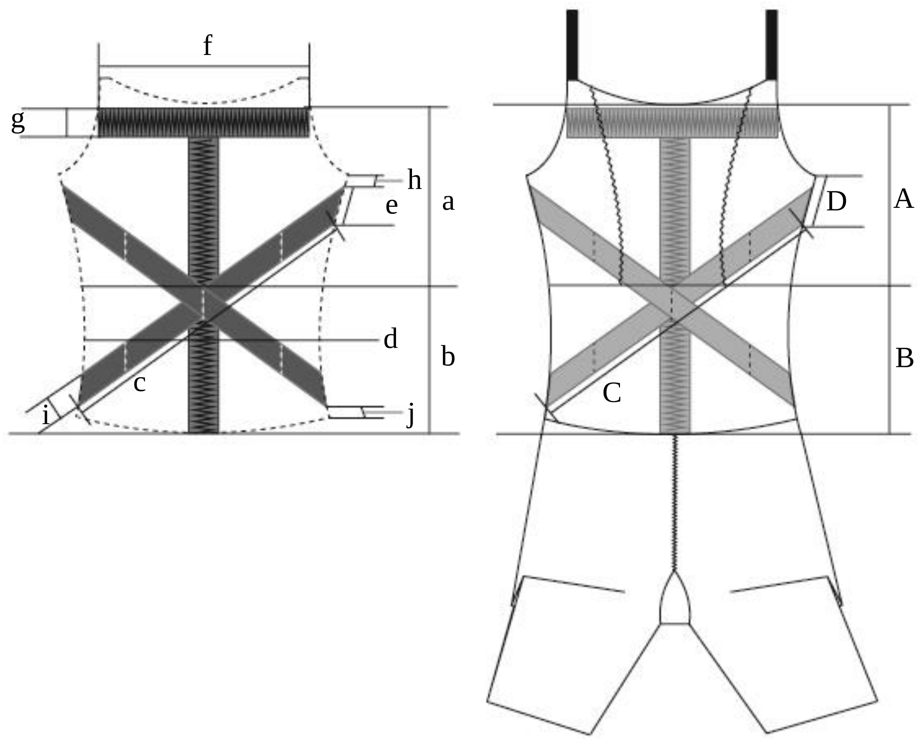
Table 1

Size Chart by Maidenform®

Size	Dress size	Hip size (inch)
S	4-6	36-38”
M	8-10	39-41”
L	12-14	42-44”
XL	16-18	45-47”
2XL	20-22	48-50”

- Design specifications

Figure 16 illustrates the PMSS specifications (a) indicated with lower case letters and illustrates the shapewear garment specifications (b) indicated with capital letters. Table 2 shows the shapewear garment specifications referring to the designator capital letters. Table 3 shows the PMSS specifications referring to the designator lower case letters.



a. PMSS specifications   b. Garment specifications

Figure 16. PMSS and shapewear garment specifications

Table 2

Specifications of Commercial Shapewear Garment

	Shapewear garment	Small	Medium	Large (inch)
A.	Back torso length (Thoracic)	5.625	5.625	5.75
B.	Back torso length (Lumbar)	6. 25	6.25	6.625
C.	Diagonal band line length	13	14	15
D.	Under arm point to lower point of the band attachment on the side seam	2.5	2.5	2.5

Table 3

Specifications of PMSS

	PMSS	Small	Medium	Large (inch)
a.	Back torso length (Thoracic)	5.5	5.625	5.875
b.	Back torso length (Lumbar)	5.5 (0.5 inches (11.53%) shortened from 6.25 inches of the back torso length **A**)	5.5 (0.5 inches (11.53%) shortened from 6.25 inches of the back torso length **A**)	5.8 (0.76 inches (11.53%) shortened from 6.625 inches of the back torso length **A**)
c.	Diagonal line length	12.5 (0.5 inches (3.84%) shortened from 13 inches of the back torso side seam **D**)	13.25 (0.75 inches (5.35%) shortened from 14 inches of the back torso side seam **D**)	14 (1 inches (6.66%) shortened from 15 inches of the back torso side seam **D**)
d.	Waistline length	10	11	12
e.	Band attachment length on the side seam	2.25	2.25	2.25
f.	Horizontal band length	8.75	8.75	8.75
g.	Horizontal band width	2	2	2
h.	Underarm point to upper point of the band attachment	0.6	0.6	0.6
i.	X-shape band width	2	2	2
j.	Lower point of the band attachment to the end of the side seam	0.6	0.6	0.6

- Band materials

The same materials used for the pilot test prototype were used for the revised prototype and comprehensive tests. The major revisions of the prototype include the extended vertical elastic band (refer to Figure 12b) from shoulder blades to upper hip to exert more control to support the spine and 0.6 inches of elastic trim attached to each side seam from underarm to the end of the torso for stability of the side seam. Since the resistance to elastic elongation along the length of the PMSS is greater than the resistance to elastic elongation of the garment fabric, the need for support materials to each side seam for stability was indicated from the pilot test.

Sampling Procedure

Twelve women, 19 to 28 years old, were recruited. The average age was 21.25 years old for small size group, 20.5 years old for medium size group, and 24 years old for large size group. Participants were recruited at the University of Minnesota from undergraduate students, graduate students, university staff and faculty. Participants were recruited by posting recruitment flyers in selected buildings on campus and by sending a recruiting email (see Appendix E and Appendix F).

Volunteers who responded to the recruiting methods were screened to determine selection for the final test. The requirements to participate were: the woman fit the dimensions of each size shapewear garment (small, medium, and large) and demonstrated shoulder imbalance. People were categorized according to the hip circumference for each size group based on the Maidenform® shapewear size chart (Table 1). To determine shoulder imbalance, each volunteer was scanned one wearing her own underwear in the standard anatomical position. As a criterion in determining posture imbalance, shoulder angles were assessed because imbalanced shoulders can be an indicator of abnormal spinal curvature (Saladin & McFarland, 2008). Thus, shoulder imbalance may indicate overall posture imbalance. At this stage, the objective value of an abnormal spinal curvature is difficult to determine because the spine angle is often assessed in each spinal region using radiographic images otherwise the spine angle is often qualitatively assessed on the photographic images with a subjective value of the spinal curvatures (Fedorak, Ashworth, Marshall, & Paull, 2003). Therefore, instead of the spine angle, the shoulder angle which is an angle between the line connecting the highest points of the shoulders and the horizontal plane on the virtual photographic images taken from 3D scans were assessed. Once the participant met the criteria (hip size and shoulder imbalance), the main test was conducted.

Data Collection Procedure

The study protocol for participants included completing consent forms (Appendix H), 3D scanning, manual tape measuring and completing questionnaires. The details of the protocol are in Appendix G. After gathering 3D scan data, posture data was acquired from 3D body scan data. Posture correction force data was calculated from a standard material test using the Instron® tensile tester and Instron Series IX software. Wearer acceptability data were gathered from the questionnaires. Statistical analyses were conducted using the SPSS 23 statistical package for posture assessment and posture correction force measurement. Content analysis was conducted for open-ended questions for wearer acceptability of the prototype.

1) Posture Data Collection Procedure

- 3D Scan

Before 3D scanning, participants were landmarked using a type of earring backing that projects slightly from the body surface. These markers were placed directly on the body on the cervicale and both shoulder points (acromion). The reference points were measured referring to the book “Anthropometry, apparel sizing and design” by Gupta and Zakaria (2014). The authors proposed a standardization of the anthropometric measurements for apparel sizes based on the ISO 7250-1 and ISO 8599. The measuring criteria for the cervicale and the shoulder points are provided in Appendix I.

Each participant was scanned three times in: 1. no shapewear, 2. the commercial shapewear product, and 3. the prototype using the 3D Human Solutions body scanner in the University of Minnesota Human Dimensioning© Lab. Participants were scanned wearing their own underwear (bra and panties) first and then the test garments were randomly assigned.

People stand in various positions move, and often carry items during the course of a day so a variety of positions were performed by participants to determine the effectiveness of the prototype in achieving a more balanced posture while in different positions. Along with a standard anatomical position, several common load carrying positions were selected to determine if the PMSS is effective in aligning posture in load carrying situations. Participants performed eight scanning positions (P1 - P5) including right-side load (R) and left-side load (L) respectively for P3, P4, and P5 (Table 4). The bag loads were designed as approximately 10% of the average body weight of each group (Harman et al., 2000). See Appendix J and Appendix K. The active positions used for the pilot test were not performed due to difficulties of consistently performing the positions for the scanning duration time. This study relied on observations of a single scan per position. Scanning each subject multiple times in each position would allow seeing if the garment has a consistent effect or if it's an artifact of variability in body position.

During scanning (approximately 11 seconds), participants were asked to look forward, breathe normally, and hold the position without moving for each scanning position. Each participant completed all scanning processes within 1.5 hours on the same day.

Table 4

Scanning Positions

Position No.	Descriptions
P1	Standing in the anatomical pose face forward and feet placed at shoulder width without carrying any item
P2	Carrying a backpack
P3	Carrying a shoulder bag on the right shoulder (P3R) and the left shoulder (P3L)
P4	Carrying a bag cross-body with a strap placed on the left shoulder to place the weight at the hip level on the right side (P4R) and the strap and handbag placed in the opposite direction (P4L)
P5	Carrying a bag with the right hand (P5R) and the left hand (P5L)

2) Posture Correction Force Data Collection Procedure

- Standard laboratory materials tests

To assess posture correction force of the PMSS incorporated into the prototype acting on the body, materials were tested off the body and on the body. Characteristics of the PMSS soft materials were assessed using standard laboratory materials tests. Pounds of force of the fabric by elongation rate were measured using an Instron® tensile tester. Stretch of the materials under a particular load or the load at a particular amount of stretch was determined (Merkel, 1991). After a load-elongation curve was recorded, pounds of force were calculated according to the elongation rate of the garment measured on the body. Selected garment dimensions were measured on the garment placed flat on a table and then marked areas on the garment were measured using a standard tape measure when the participant was wearing the garment. Differences between the two measured lengths (flat and on the body) were calculated. These dimensions include: 1) garment torso length at location of the PMSS soft materials (thoracic and lumbar regions respectively), 2) garment torso diagonal lengths where the PMSS soft materials are placed diagonally from underarm to opposite side seam at waist, and 3) waist circumference which may be used to determine possible compression of materials at the waistline. The measuring procedures were repeated for each garment.

3) Wearer Acceptability Data Collection Procedure

- Administration of questionnaires

To assess wearer acceptability of the shapewear garment combined with the PMSS, participants were asked to complete three questionnaires: shapewear study questionnaire for background information and shapewear product evaluation questionnaire for each shapewear garment. Questionnaires are presented in Appendix L and Appendix M. Participants completed the background information questionnaire before 3D scanning. After scanning, participants completed two evaluation questionnaires. Participants evaluated their body scans in the standing position (P1) as seen on the computer screen by comparing three wearing conditions. Respondents used a Likert-type scale (seven scales) to evaluate their body shape and posture changes and fit of each shapewear garment. Open-ended questions were administered under each question category to gain more information. Evaluation questionnaires for the prototype garment and the commercial shapewear garment were identical.

Data Collection

1) Posture Data

Numerical body angles were calculated using the coordinates of the reference points on the 3D scanned body images obtained from ScanWorX™. The system is based on the VITUS coordinate system which is a right-handed coordinate system. The orientation of the axes is as follows when seen in frontal perspective (ScanWorX™ user guide, 2009). Figure 17 illustrates the VITUS coordinate system with each axis specified including: X-axis running from bottom to top, Y-axis running from back to front, and Z-axis running from left to right. The planes formed by the XZ, XY, and YZ axes correspond to the frontal, sagittal, and horizontal planes respectively.

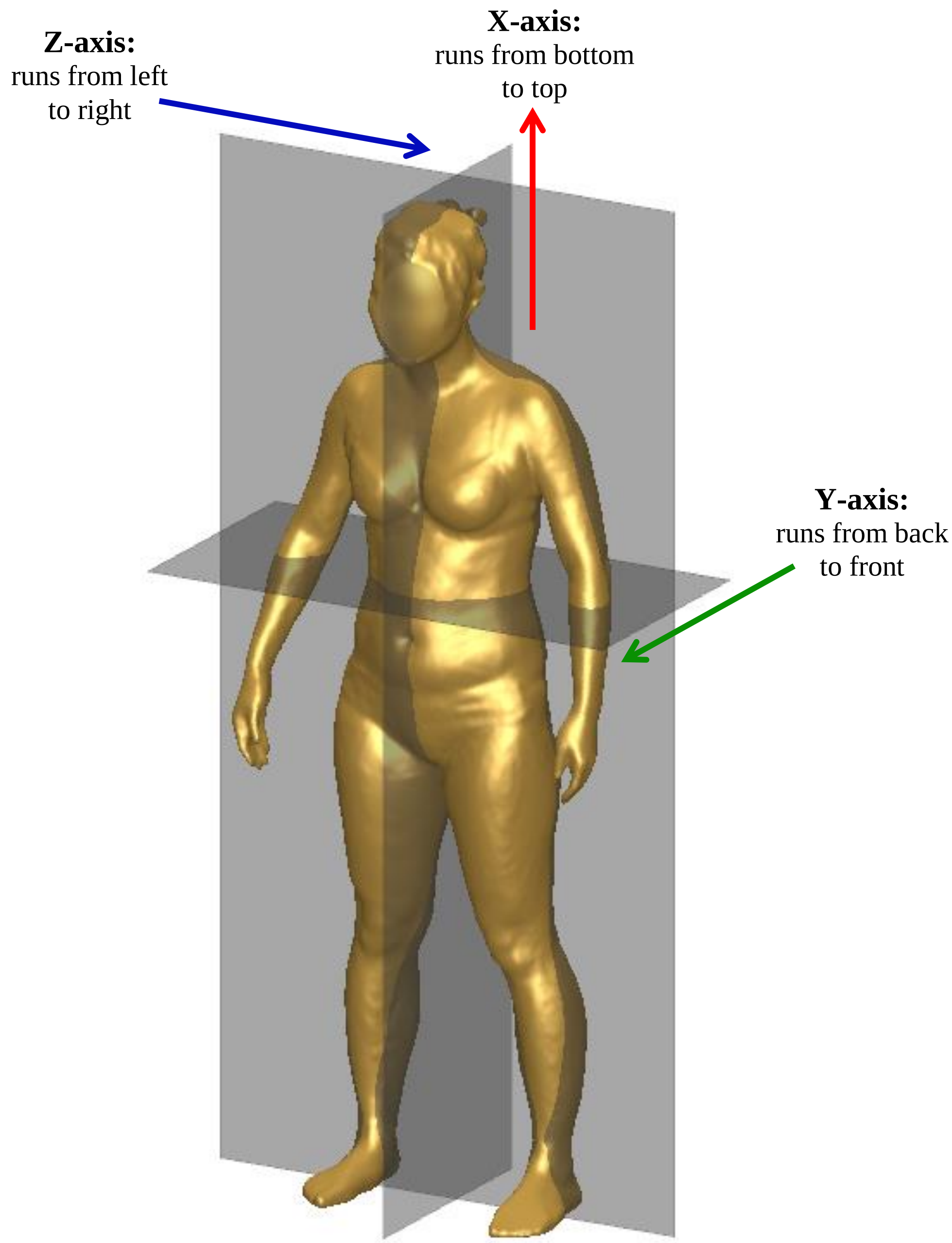


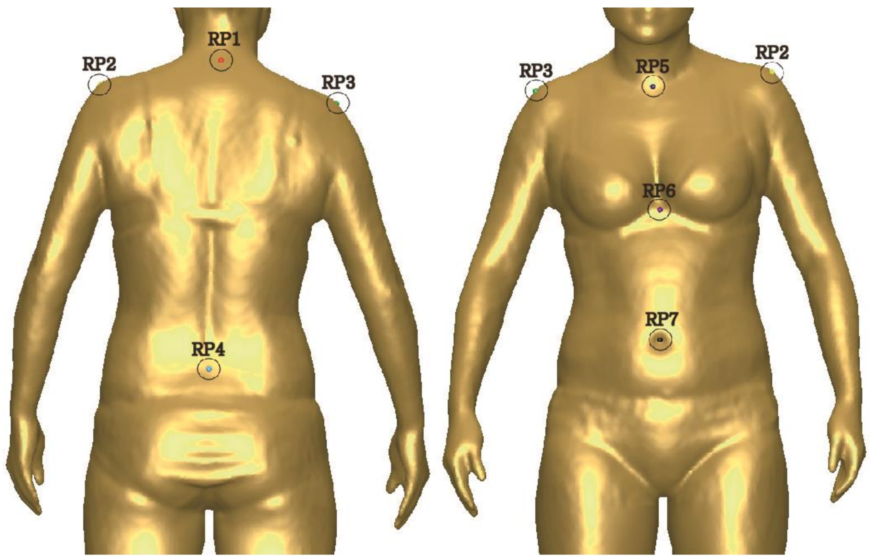
Figure 17. The VITUS coordinate system (P1)

To calculate body angles, seven reference points (RP1 – RP7) were manually selected on each 3D scanned body (Table 5). Figure 18 shows reference points on a 3D scanned body.

Table 5

Terms for Reference Points

Reference point No.	Terms for the study	Anatomical terms
RP1	Back neck point	Cervicale
RP2	Left shoulder point	Left acromial point
RP3	Right shoulder point	Right acromial point
RP4	Junction of L3-L4 vertebrae	Junction of lumbar vertebrae 3 and 4
RP5	Front neck point	Upper edge of the sternal notch
RP6	Middle point of each breast on the bra	Middle point of sternum
RP7	Navel	Umbilicus



a. Posterior view b. Anterior view

Figure 18. Reference points

- Body angles

Five body angles were calculated for each scan position (eight positions total) for all participants. Among five body angles, some body angles were determined referring to the New York Posture Rating Chart (New York State Education Department, 1958) with others determined using alternative reference points on the 3D scanned body.

Body angles visible and measurable on topical body scans were used as indications of internal anatomical structures acknowledging that many bone, muscle and ligament structures influence topical features.

Based on the coordinates of the reference points from ScanWorX™, body angles were calculated. For the convenience, I denote body angles by θ and the spatial information of RP i ($1 \leq i \leq 7$) by (X_i, Y_i, Z_i). The selected body angles are then as follows:

- θ_A is an acute angle between the horizontal line referring to RP2 and the line connected with RP2 and RP3 on the frontal plane (Figure 19a). RP2 (left shoulder point) is the intersection of the two lines. This angle shows a shoulder level and the lower shoulder point varies for each participant. A positive value indicates a high right shoulder while a high left shoulder is indicated as a negative value. The posterior view (a) in Figure 19 shows an example of a negative value of θ_A exhibiting a high left shoulder. This angle was calculated by

$$\theta_A = -\operatorname{atan} \frac{\overline{X_2 X_3}}{\overline{Z_2 Z_3}} \ . \qquad (1)$$

- θ_B is an acute angle between the vertical line referring to RP4 and the line connected with RP1 and RP4 on the frontal plane (Figure 19a). RP4 (junction of L3-L4 vertebrae) is the intersection of the two lines. This angle shows a spine line exhibiting the lateral center of gravity changes resulting from wearing a garment or carrying a load. The back neck point location varies for each participant. A positive value indicates the back neck point tilted to the left side compared to the junction of L3-L4 vertebrae while a negative value shows the back neck point tilted to the right side. The posterior view (a) in Figure 19 shows an example of a negative value of θ_B exhibiting the back neck point tilted to the right side. As a RP4, a lower spinal vertebra was selected to define the spine line based on the literature that the L3-L4 and L4-L5 discs are important factors indicating abnormalities of the spine (Pritchett & Bortel, 1993). This angle was calculated by

$$\theta_B = \text{atan}\,\frac{\overline{Z_1 Z_4}}{\overline{X_1 X_4}}\ . \tag{2}$$

- θ_C is an obtuse angle between the line connected with RP6 and RP7 and the line connected with RP7 and RP8 on the frontal plane (Figure 19b). RP7 (middle point of each breast) is the endpoint where the line of RP6 (front neck point) and the line of RP8 (navel) come together. This angle shows lateral curvature of the spine. Since selecting reference points for a spine curvature on the posterior view with no visible landmarks on the surface of the 3D scanned body is difficult, the reference points were selected on the anterior view showing visible landmarks as described. An aligned lateral spine curvature assumes 180° of θ_C. An angle smaller than 180° indicates a left-side curvature and larger than 180° indicates a right-side curvature of the spine. The anterior view (b) in Figure 19 shows an example of a left-side spine curvature. Note that due to using 3D scan data instead of radiographic images, this angle does not indicate an exact spine curvature obtained for clinical purposes such as Cobb angles calculated on the radiographic images (Cobb, 1948). However, a tendency of posture changes can be interpreted from this angle for non-clinical purposes. This angle was calculated by

$$\theta_C = \pi + \text{atan}\,\frac{\overline{Z_6Z_7}}{\overline{X_6X_7}} - \text{atan}\,\frac{\overline{Z_7Z_8}}{\overline{X_7X_8}}\ . \tag{3}$$

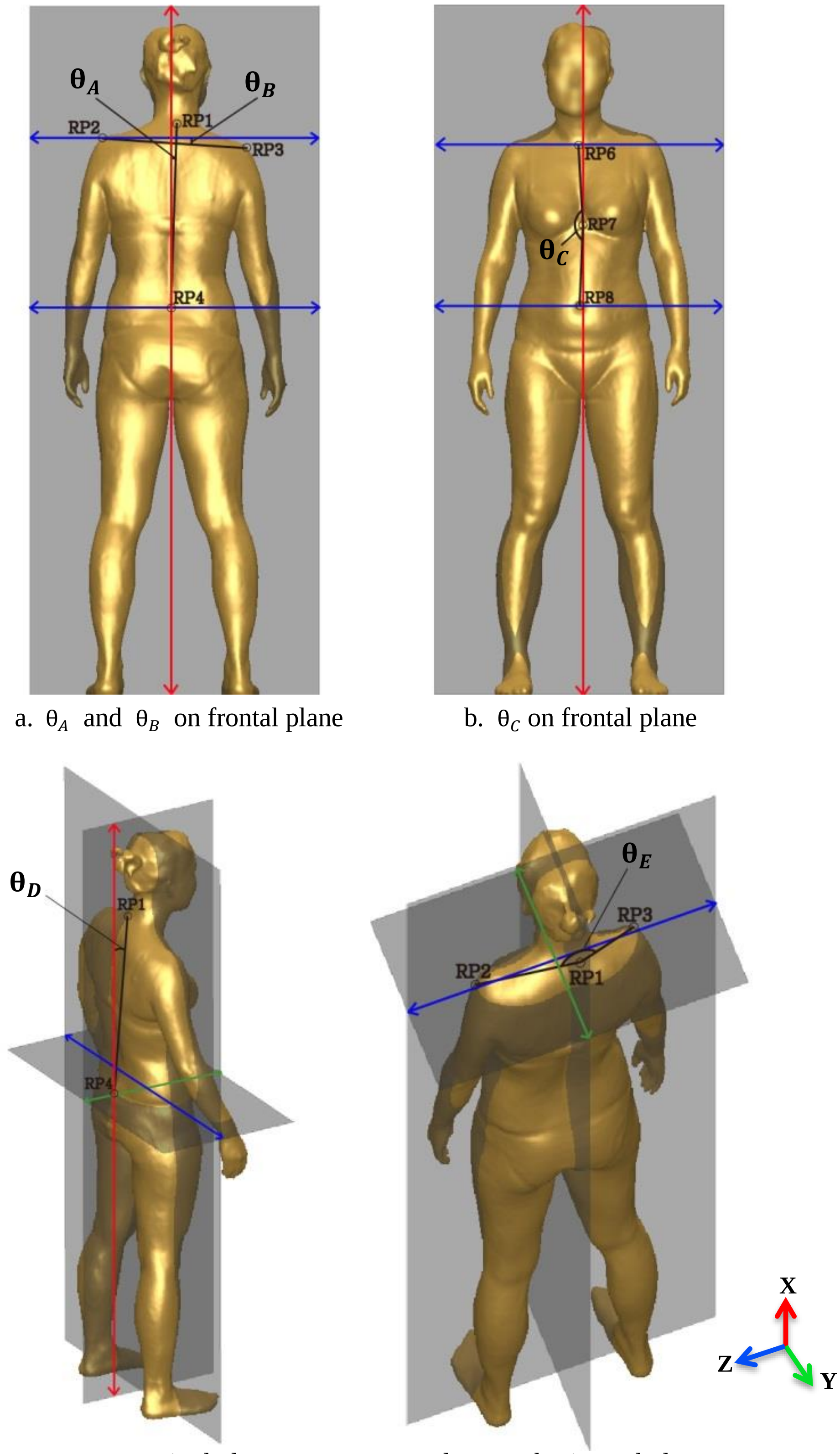
- θ_D is an acute angle between the vertical line referring to RP4 and the line connected with RP1 and RP4 on the sagittal plane (Figure 19c). RP4 (junction of L3-L4 vertebrae) is the intersection of the two lines. This angle shows trunk inclination based on the forward/backward movement of the back neck point. This angle is obtained as a negative value. A smaller angle (absolute value) assumes smaller imbalances. This angle was calculated by

$$\theta_D = -\,\text{atan}\,\frac{\overline{Y_1Y_4}}{\overline{X_1X_4}}\ . \tag{4}$$

- θ_E is an obtuse angle between the line connected with RP1 and RP2 and the line connected with RP1 and RP3 on the horizontal plane (Figure 19d). RP1 (back neck point) is the endpoint where the line of RP2 (left shoulder point) and the line of RP3 (right shoulder point) meet. This angle shows the forward/backward movement of the shoulder points resulting from a load placement. A common posture misalignment is what is commonly termed “hunched shoulders” with the shoulder points forward along the horizontal plane giving a rounded upper spine. A smaller angle assumes more hunched shoulders while a larger angle assumes straighter shoulders. This angle was calculated by

$$\theta_E = \pi - \text{atan}\,\frac{\overline{Y_2Y_1}}{\overline{Z_2Z_1}} + \text{atan}\,\frac{\overline{Y_1Y_3}}{\overline{Z_1Z_3}}\ . \tag{5}$$

There are clear criteria to determine posture imbalance by analyzing changes of θ_A, θ_B, and θ_C while θ_D and θ_E are not a factor determining balance or imbalance of posture but shows a tendency of posture changes by wearing a shapewear garment.



a. θ_A and θ_B on frontal plane

b. θ_C on frontal plane

c. θ_D on sagittal plane

d. θ_E on horizontal plane

Figure 19. Body angles

2) Posture Correction Force Data

- Materials tests

Posture correction force was measured based on each band length and waist circumference off the body and on the body. Refer to Figure 20 with designator alphabets showing each band location. Table 6 shows specimen sizes in inch for each part and Table 7 shows descriptions of test materials. Since part d was tested on the actual garment, the values were obtained from 2 layers of the garment. To compare loads by extension for each specimen, the values were divided by 2 (see Table 15).

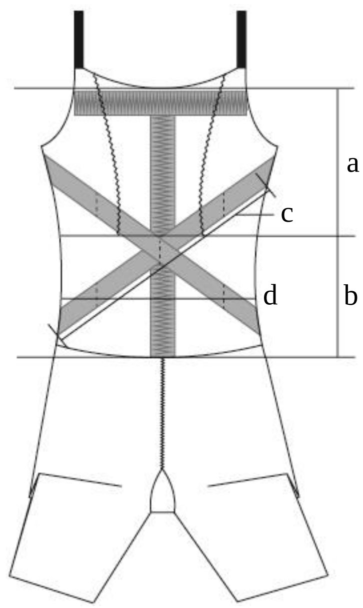


Figure 20. Parts of specimens for PMSS

Table 6

Specimen Sizes (Medium Size Based)

C (inch)				P (inch)		
a	b	c	d	a	b	c
5.625*2	6.25*2	14*2	11*2	6*2	5.5*2	13.25*2

Table 7

Descriptions of Test Materials

Part	Fabric direction	Number of layers	Descriptions of layers
a	Lengthwise	3	1. Double-layered knitted fabric made of 68% nylon and 32% elastane 2. Woven elastic made of polyester 3. Garment fabric made of 81% nylon and 19% elastane
b	Lengthwise	2	1. Double-layered knitted fabric made of 68% nylon and 32% elastane 2. Garment fabric made of 81% nylon and 19% elastane
c	Lengthwise	1	1. Double-layered knitted fabric made of 68% nylon and 32% elastane
	Bias	1	1. Garment fabric made of 81% nylon and 19% elastane
d	Crosswise	1	1. Garment fabric made of 81% nylon and 19% elastane (Note. the actual garment was tested (2 layers total, front and back bodice of the garment).

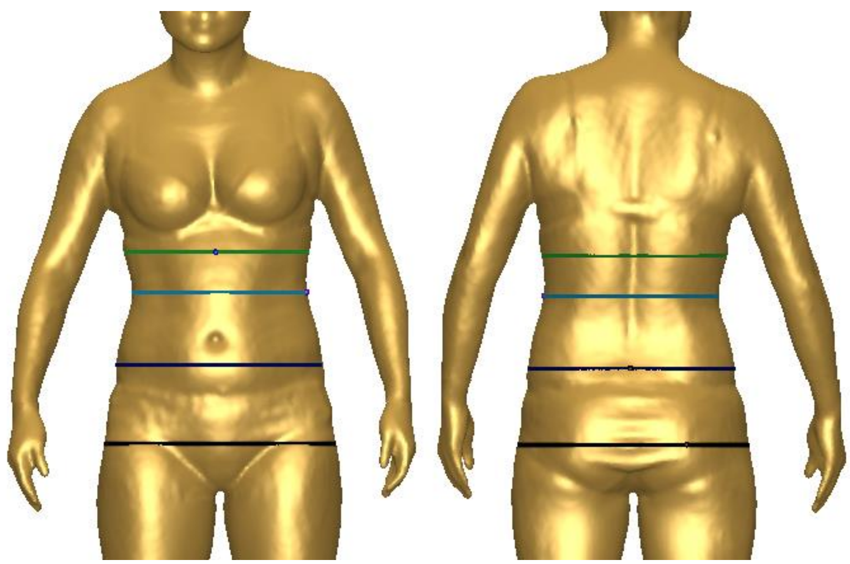
- Posture correction force
    - Force of PMSS: Selected garment dimensions were measured on the garment placed flat on a table and then marked areas on the garment were measured using a standard tape measure when a participant was wearing each garment. Differences between the two measured lengths (flat and on the body) were calculated for part a, b, and c (right side and left side bands respectively) and then pounds of force were calculated according to the elongation rate of the garment.
    - Garment compression: Pounds of force were calculated for the waistline from the material test results. To see possible effects of garment compression on posture modification, four body circumferences were measured on the scanned body (Table 8). Among four body circumferences, some dimensions were determined referring to the Anthropometric Survey of US Army Personnel

(Gordon, Chrchill, Clauser, Bradtmiller, & McConville, 1989) with others determined using alternative reference points on the 3D scanned body. Figure 21 shows body circumferences on a scanned body.

Table 8

Body Circumferences

Circumference dimension	Descriptions
Under-bust	The horizontal circumference of the chest at the level of inferior juncture of the lowest breast with the rib cage (note: this dimension was measured at the point that 1 inch below the described point to avoid effects of blurred scanning areas under arm)
Waist	The horizontal circumference of the waist at the level of its natural indentation
Upper-hip	The horizontal circumference of the lower back at the level of RP4
Hip	The horizontal circumference of the trunk at the level of the maximum protrusion of the right buttock



a. Anterior view b. Posterior view

Figure 21. Body circumferences

3) Wearer Acceptability Data

Three acceptability items including posture changes, body shape changes, and fit of each shapewear garment were assessed using a Likert type scale (seven scales). Open-ended questions were asked to get more details about participants' opinions (see Appendix K and Appendix L).

Data Analysis Procedure

1) Statistical Analysis

Paired t-tests were conducted to examine the mean difference of each dependent variable between 1) no shapewear and the prototype and/or 2) the commercial shapewear product and the prototype to analyze posture changes and posture correction force.

In this study with a small sample size (12 participants), the *t* distribution at a significance level of .10 was used for statistical analyses. When dealing with small samples ($n < 30$), significance level needs to be considered to handle the risks of making type I and type II errors when conducting hypothesis tests. If the consequences of making one type of error are more severe than making the other type of error, then it is possible to choose a level of significance and a power for the test reflecting the relative severity of those consequences. When the sample size is small, a significance level of .10 may be preferred to decrease type II errors (Verbeek, 2008; Rubin, 2012). The following conditions were set for statistical analyses; the critical t with 11 degrees of freedom, $\alpha = .10$, and one-tailed is 1.363 and two-tailed is 1.796. Null hypothesis for all statistical analysis was: $\mu_{d(difference)} = 0$. Descriptions of alternative hypotheses, critical t, and variables for body angle changes and posture correction force are shown in Table 9. In the tables, terms were determined for categories: BA: Body angle changes, PFM: Pounds of force of materials, EM: Extension of materials on the body, PF: Pounds of force on the body, and BC: Body circumference and pairs: N: No shapewear, C: Commercial shapewear, and P: Prototype.

Table 9

Descriptions of Statistical Analyses

Category	Alternative hypothesis	Critical *t*	Items (Dependent variable)	Pairs (Independent variable)
BA	Ha_1: $\mu_d > 0$	1.363	θ_A, θ_B and θ_C	N – P C – P
	Ha_2: $\mu_d < 0$	-1.363	θ_D and θ_E	N – P C – P
PFM	Ha_3: $\mu_d < 0$	-1.363	Part a, b, and c	C – P
EM	Ha_4: $\mu_d \neq 0$	l1.796l	Part a, b, cR, cL, and d	C – P
PF	Ha_5: $\mu_d < 0$	-1.363	Part a, b, and c	C – P
	Ha_6: $\mu_d \neq 0$	l1.796l	Part d	C – P
BC	Ha_7: $\mu_d \neq 0$	l1.796l	Under-bust, waist, upper-hip, and hip	C – P
	Ha_8: $\mu_d < 0$	-1.363	Under-bust, waist, upper-hip, and hip	N – C N – P

2) Content Analysis

Content analysis was conducted for the questionnaire open-ended questions. The data were analyzed by identifying patterns in individuals' accounts of their feelings, perspectives, and understandings. The major themes were derived from participants' perceptions toward their body and acceptability of the shapewear garments combined with the PMSS.

Summary

At the problem definition and research stage, a problem was identified: the need for development for an effective posture modification design element using soft structural materials to more closely resemble the ideal body and provide better comfort for better wearer acceptability. Problems of existing posture modification garments were defined: posture correctors/back supporters exhibit effective posture support but little comfort while shapewear garments are less evident in modifying posture but are relatively comfortable. In an attempt to solve these problems an existing shapewear product was modified using additional soft materials (textiles) added to the back torso of the garment. This system is called the Posture Modification System using Soft materials (PMSS). The goal of the PMSS was identified: to achieve modified posture and relative comfort using non-rigid materials and structures.

At the creative exploration stage, the initial PMSS design was developed. The key element of the PMSS design was soft structural bands (T and X-shape bands) inserted to the inside back of a typical shapewear garment. The preliminary design ideas were compared to existing technology through academic, patent, and market searches to determine whether it is novel and can achieve desired vertical alignment of a wearer's torso. Some design elements were selected and a prototype was developed by modifying a commercial shapewear product. In a pilot test, the prototype was tested with three volunteers. They were scanned three times in 1) no shapewear, 2) a commercial shapewear product, and 3) the prototype. Posture modification was observed for all participants wearing the prototype compared to the commercial shapewear product and no shapewear for most positions. A possibility of posture modification while wearing the prototype was identified at early-stage development warranting a comprehensive study with a refined prototype tested on more participants.

At the third stage, refined prototypes were developed for a broader range of size groups for generalization of the results in regard to posture modification effects. The revised prototypes were tested expanding the participant pool to 12 women who fit the dimensions of the small, medium, and large size shapewear garments. To assess posture changes when wearing the prototype, five body angles were analyzed and standard laboratory materials tests were conducted to determine posture correction force of the PMSS in modifying posture including materials elongation test results and reaction of the materials when incorporated into the garment both off the body (flat measured) and on the body. To get participants' in-depth perceptions of acceptability of the shapewear garment combined with the PMSS, qualitative analysis was conducted using shapewear evaluation questionnaires.

CHAPTER FOUR: RESULTS AND DISCUSSION

This chapter presents a report and discussion of the results that are related to the analysis of quantitative body angle and posture correction force data as well as qualitative data analysis for the questionnaires. The chapter is divided into three sections: 1) demographic information, 2) quantitative evaluations, and 3) qualitative evaluations. The second section is divided into two parts: 1) posture modification effects and 2) posture correction force. The third section is divided into two parts: 1) background information and 2) wearer acceptability.

Demographic Information

Twelve female participants, 19 to 28 years old (average age 21.917 ± 2.610 years), were recruited from university staff, faculty members, and students. Seven participants were Caucasian and five participants were Asian. People were categorized according to the hip circumference for each size group. Table 10 shows the sampling descriptions for each size group.

Table 10

Sampling Descriptions

		Age (year)		Hip girth (inch)		Weight (lb)		Height (inch)	
Size	N	M	SD	M	SD	M	SD	M	SD
S	4	21.25	1.258	38.063	0.826	133.350	5.239	64.353	1.911
M	4	20.5	1.000	41.094	1.028	155.250	5.524	65.490	3.985
L	4	24	3.651	45.594	0.313	189.550	7.535	68.128	1.250

Quantitative Evaluations

Statistical analyses were conducted to assess posture changes in each wearing condition and to analyze posture correction force based on the standard laboratory materials tests. Throughout the study the complex and interconnected factors of body posture and a garment worn on the body are acknowledged.

Posture Modification Effects

To determine whether there are significant differences between the sample means of the body angles, paired t-tests were conducted by comparing each body angle in 1) no shapewear (N) with the prototype (P) and 2) the commercial shapewear (C) with the prototype (P). In each scan position, five body angles were analyzed using a one-tailed paired t-test (Ha = $M_d > 0$ for θ_A, θ_B, and θ_C and Ha = $M_d < 0$ for θ_D and θ_E). Refer to Table 9. Significant sample mean differences were found for most of the body angles for each scan position. The figures in this section illustrate the posterior view (a) and lateral view (b) including each wearing condition respectively: no shapewear (left), the commercial shapewear (middle), and the prototype (right). The location of each wearing condition is the same throughout the illustrations.

Body Angle Changes in Position 1

In the standard anatomical position (P1), a highly significant difference between sample means greater than zero were observed for θ_A ($M_d > 0$, $t > 1.363$, and $p < .01$) and statistically significant sample mean differences were observed for θ_C ($M_d > 0$, $t > 1.363$, and $p < .05$) and θ_E ($M_d < 0$, $t < -1.363$, and $p < .05$) with θ_B ($M_d > 0$, $t > 1.363$, and $p < .10$ on the boundary of the statistical significance) for the pairs of N and P. On the other hand, a t-test failed to reveal a statistically reliable sample mean difference for θ_D for the same pair (M_d = -.339, SD = 1.379, t (11) = -.853, and p = .206). It indicates that smaller imbalances on the shoulder level, lateral center of gravity, and lateral spine curvatures were observed when wearing the prototype with observation of straighter shoulders on the horizontal plane compared to no shapewear. There was no significant difference on the trunk inclination between the two wearing conditions.

Pairs of C and P also showed significant differences between sample means for θ_A ($M_d > 0$, $t > 1.363$, and $p < .01$, highly significance), θ_B, and θ_C ($M_d > 0$, $t > 1.363$, and $p < .05$, statistical significance) with θ_E ($M_d < 0$, $t < -1.363$, and $p < .05$) while θ_D exhibited no significant sample mean difference (M_d = -.097, SD = 1.787, t (11) = -.188, and p = .427). The prototype provided more balanced shoulder level and lateral center of gravity and less excessive lateral spine curvatures as well as straighter shoulders on the horizontal plane compared to the commercial shapewear. However, it was observed that the trunk inclination is not significantly affected by both shapewear garments in this position. The results of the paired t-tests for all body angles in P1 are shown in Table 11. Figure 22 shows posture changes of a medium size participant in P1.

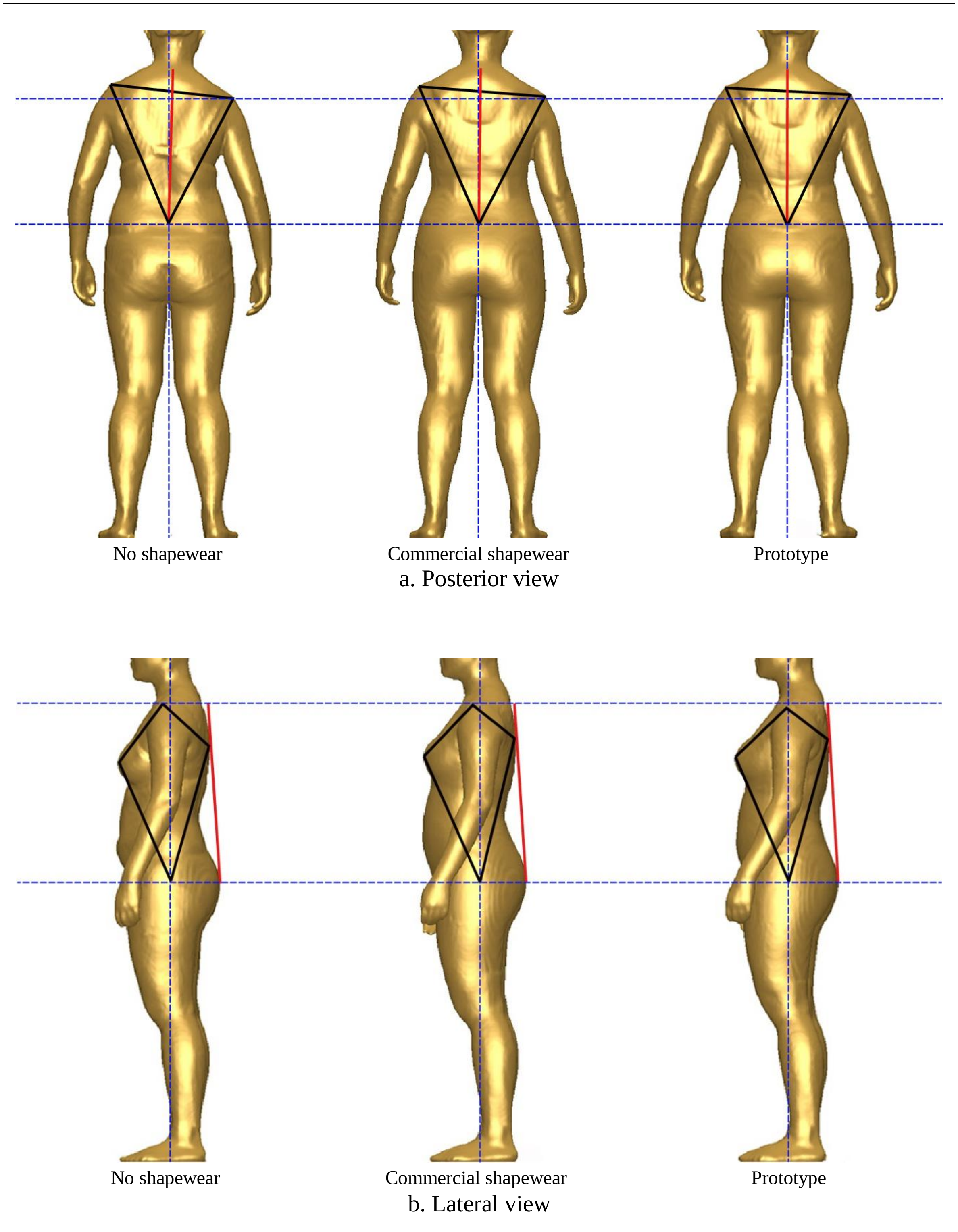


Figure 22. Posture changes of a medium size participant in P1

Body Angle Changes in Position 2

When carrying a symmetrical load carriage (P2), an increase in forward inclination of the trunk is expected because of an extra weight applied to the back of the body (Li and Hong, 2004). This phenomenon is a body response to an extra weight applied to the body by adjusting its posture in the opposite direction to restore equilibrium. To assess trunk inclination, obtaining RP1 and RP4 on the L3-L4 vertebrae is necessary. However, in this position, L3-L4 vertebrae region (RP4) is invisible when performing carrying a backpack so that θ_B and θ_D were not acquired. Although some angles were not assessed, the test results for the rest of body angles (θ_A, θ_C, and θ_E) exhibited significant sample mean differences.

For the pairs of N and P, statistically significant sample mean differences were observed for θ_C ($M_d > 0$, $t > 1.363$ and $p < .05$) and θ_E ($M_d < 0$, $t < -1.363$, and $p < .05$) and a marginally significant difference of sample means greater than zero was observed for θ_A ($M_d > 0$, $t > 1.363$ and $p < .10$). The pairs of C and P exhibited highly significant sample mean differences for all angles ($p < .01$).

The test results indicate that participants' shoulder level and the lateral spine curvatures showed smaller imbalances when wearing the prototype. Straighter shoulders on the horizontal plane were also exhibited in the prototype compared to no shapewear and the commercial shapewear in this position. The results of the paired t-tests for all body angles in P2 are shown in Table 11. Figure 23 shows posture changes of a small size participant in P2.

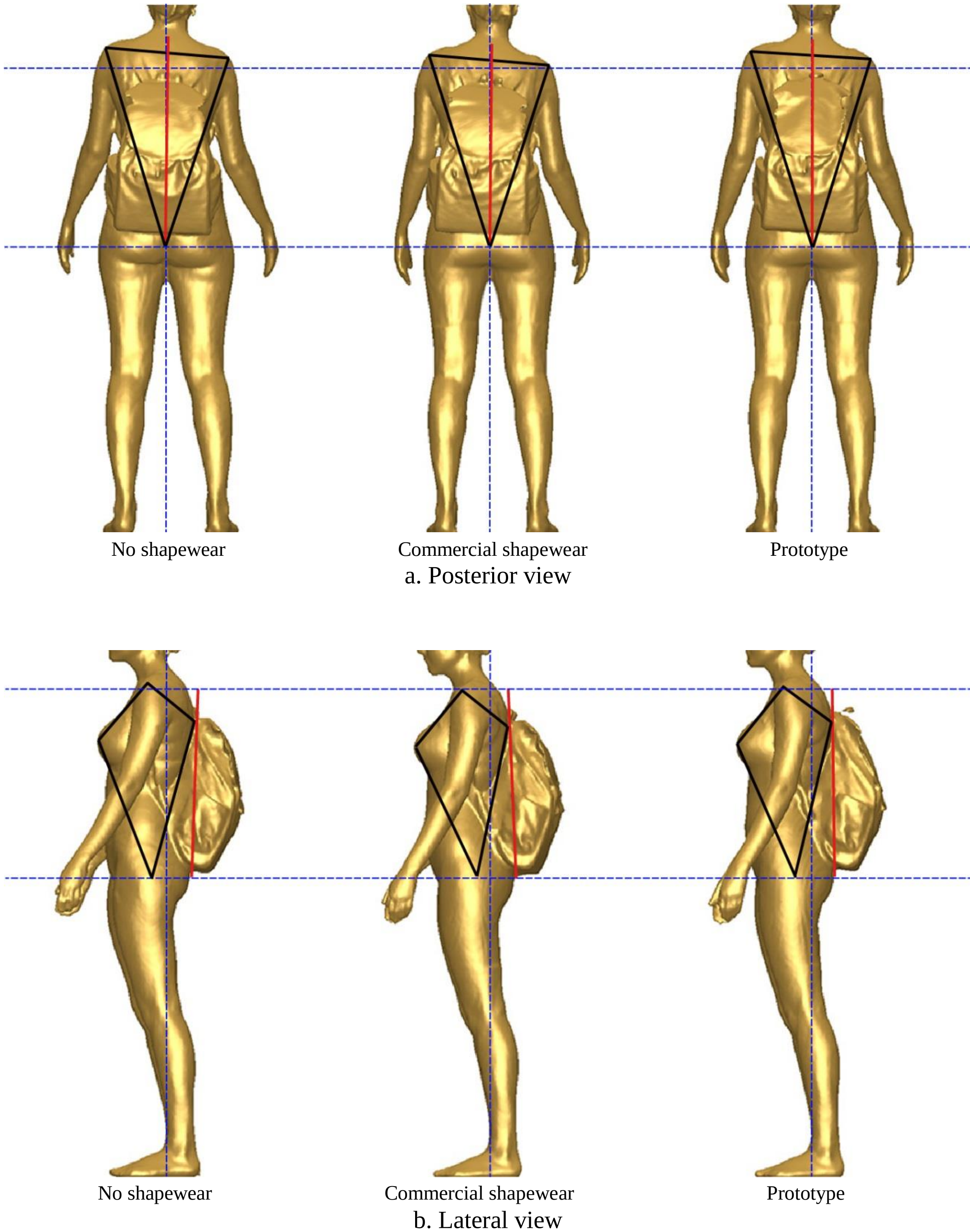


Figure 23. Posture changes of a small size participant in P2

Body Angle Changes in Position 3R

When carrying a shoulder bag on the right shoulder (P3R), highly significant differences of sample means greater than zero were observed for θ_A, θ_B, and θ_C ($M_d > 0$, $t > 1.363$ and $p < .01$) for the pairs of N and P. It was also observed that there was a statistically significant mean difference for θ_D ($M_d < 0$, $t < -1.363$, and $p < .05$). While a t-test failed to reveal a statistically reliable difference of the sample mean of θ_E between the two wearing conditions ($M_d = .211$, SD = 4.146, $t\,(11) = .177$, and $p = .431$). The test results indicate smaller imbalances on the shoulder level, lateral center of gravity, and lateral spine curvatures with straighter spines indicating less trunk inclination when wearing the prototype compared to no shapewear. However, in this position, no evidence was found that wearing the prototype is effective in straitening the shoulder on the horizontal plane.

Pairs of C and P also showed a highly significant difference of sample means greater than zero for θ_B ($M_d > 0$, $t > 1.363$ and $p < .01$) and a marginal significance for θ_C ($M_d > 0$, $t > 1.363$ and $p < .10$). However, no significant angle differences were observed for θ_A ($M_d = .445$, SD = 1.721, $t\,(11) = .896$, and $p = .195$), θ_D ($M_d = .095$, SD = 1.343, $t\,(11) = .246$, and $p = .405$), and θ_E ($M_d = .521$, SD = 2.398, $t\,(11) = .753$, and $p = .233$). It is assumed that the prototype worked better in modifying posture on the lateral center of gravity and lateral spine curvatures compared to the commercial shapewear in this position. The results of the paired t-tests for all body angles in P3R are shown in Table 11. Figure 24 shows posture changes of a small size participant in P3R.

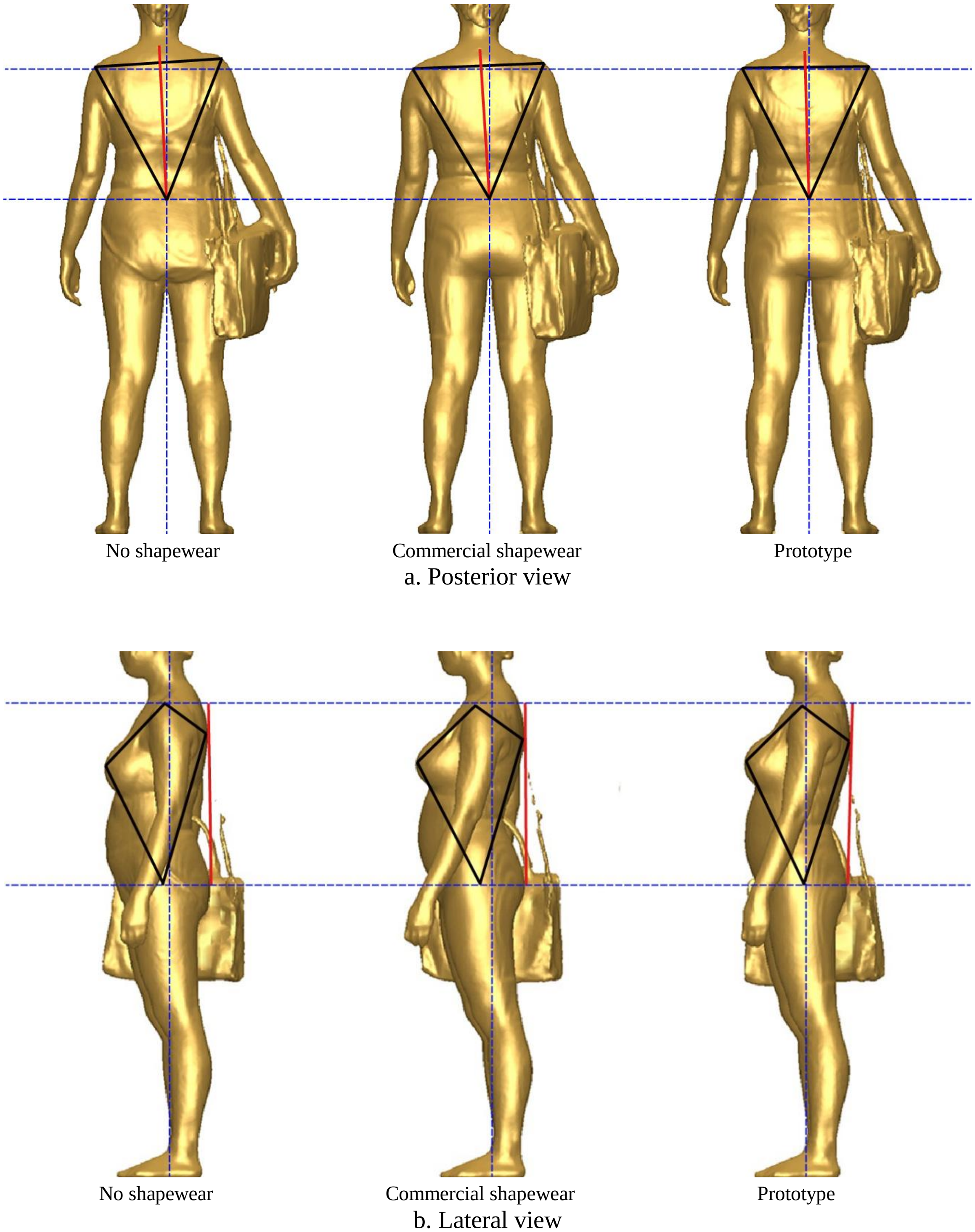


Figure 24. Posture changes of a small size participant in P3R

Body Angle Changes in Position 3L

When carrying a shoulder bag on the left shoulder (P3L), highly significant differences of sample means greater than zero were observed for θ_A, θ_B, and θ_C ($M_d > 0$, $t > 1.363$, and $p < .01$) with a statistically significant mean difference for θ_D ($M_d < 0$, $t < -1.363$, and $p < .05$) for the pairs of N and P. For θ_E, no significant sample mean difference was observed ($M_d = -.645$, SD = 2.791, $t\ (11) = -.801$, and $p = .220$). The results showed that the participants wearing the prototypes exhibited smaller imbalances on the shoulder level, lateral center of gravity, and lateral spine curvatures as well as straighter spines compared to no shapewear. However, no evidence was found that it is effective in straitening the shoulder on the horizontal plane while wearing the prototype in this position.

When comparing the body angles in C to P, the test results showed a highly significant sample mean difference for θ_C ($M_d > 0$, $t > 1.363$, and $p < .05$) and statistically significant sample mean differences for θ_A, θ_B, ($M_d > 0$, $t > 1.363$, and $p < .05$), and θ_E ($M_d < 0$, $t < -1.363$, and $p < .05$) with no significant difference for θ_D ($M_d = .124$, SD = 1.143, $t\ (11) = .376$, and $p = .357$). The results indicate that the prototype provided less imbalanced shoulder level and better lateral center of gravity and prevented excessive lateral spine curvatures. The prototype also straightened the shoulder on the horizontal plane compared to the commercial shapewear in this position. The results of the paired t-tests for all body angles in P3L are shown in Table 11. Figure 25 shows posture changes of a medium size participant in P3L.

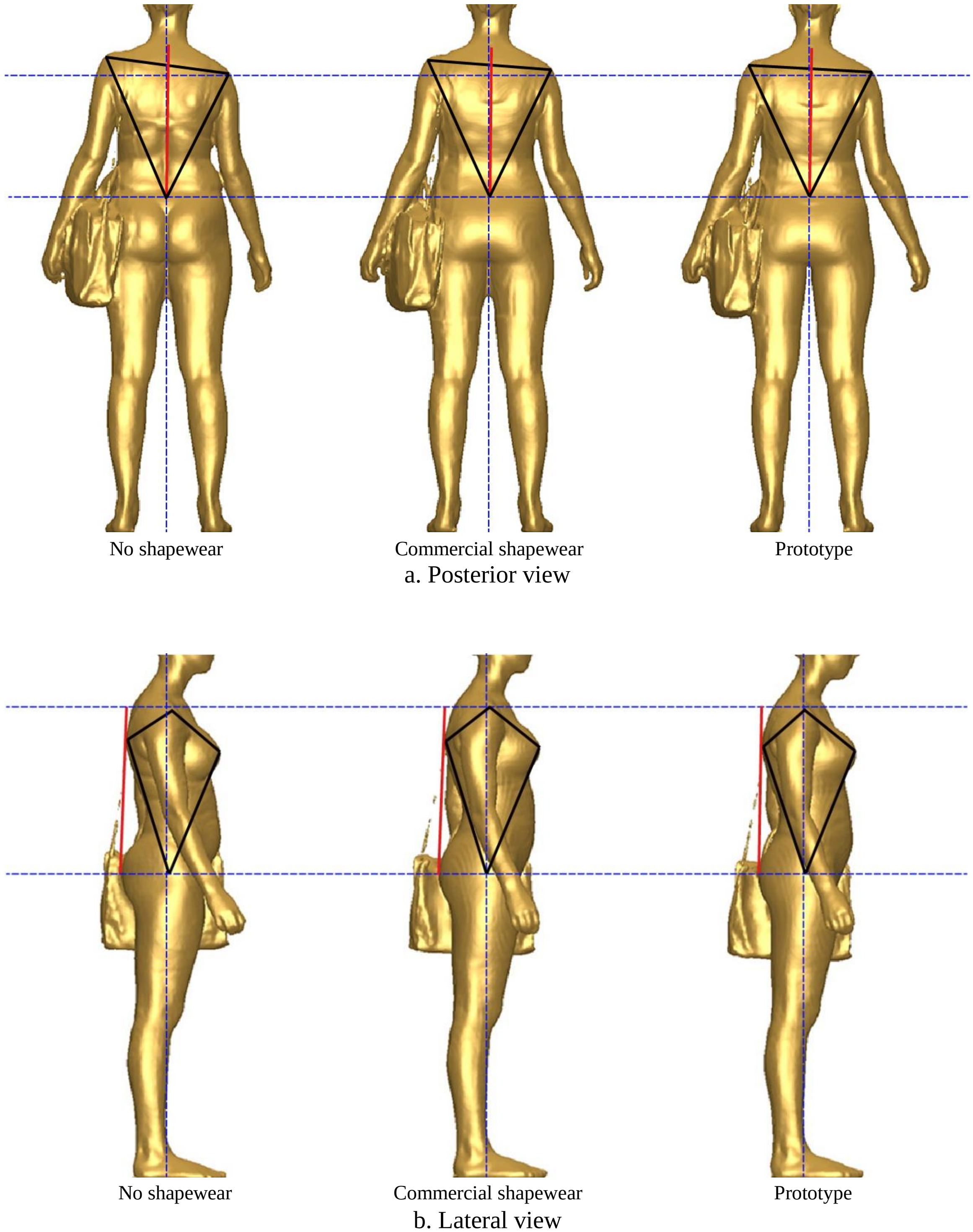


Figure 25. Posture changes of a medium size participant in P3L

Body Angle Changes in Position 4R

When carrying a bag cross-body with a strap placed on the left shoulder to place the weight at the hip level on the right side (P4R), highly significant differences of sample means greater than zero were observed for θ_A and θ_B ($M_d > 0$, $t > 1.363$, and $p < .01$) between N and P. Marginally significant sample mean differences on the boundary of the statistical significance were observed for θ_C ($M_d > 0$, $t > 1.363$, and $p < .10$) and θ_D ($M_d < 0$, $t < -1.363$ and $p < .10$). On the other hand, a t-test failed to reveal a statistically reliable sample mean difference for θ_E for the same pair ($M_d = .077$, SD = 5.195, $t\ (11) = .052$, and $p = .480$). It indicates that the participants wearing the prototype exhibited smaller imbalances on the shoulder level, lateral center of gravity, and lateral spine curvatures with less trunk inclination. However, it showed no effects in straightening the shoulder on the horizontal plane in this position.

For the pairs of C and P, a highly significant sample mean difference for θ_B ($M_d > 0$, $t > 1.363$ and $p < .01$) and statistically significant sample mean differences for θ_A and θ_C ($M_d > 0$, $t > 1.363$, and $p < .05$) with no significant sample mean differences for θ_D ($M_d = -.157$, SD = 1.020, $t\ (11) = -.533$, and $p = .302$) and θ_E ($M_d = .015$, SD = 2.280, $t\ (11) = .023$, and $p = .491$) were observed. Participants wearing the prototypes exhibited more balanced shoulder level and lateral center of gravity and less excessive lateral spine curvatures. However, it was not evident that the prototype is effective in providing less trunk inclination and straightening the shoulder on the horizontal plane. The results of the paired t-tests for all body angles in P4R are shown in Table 11. Figure 26 shows posture changes of a large size participant in P4R.

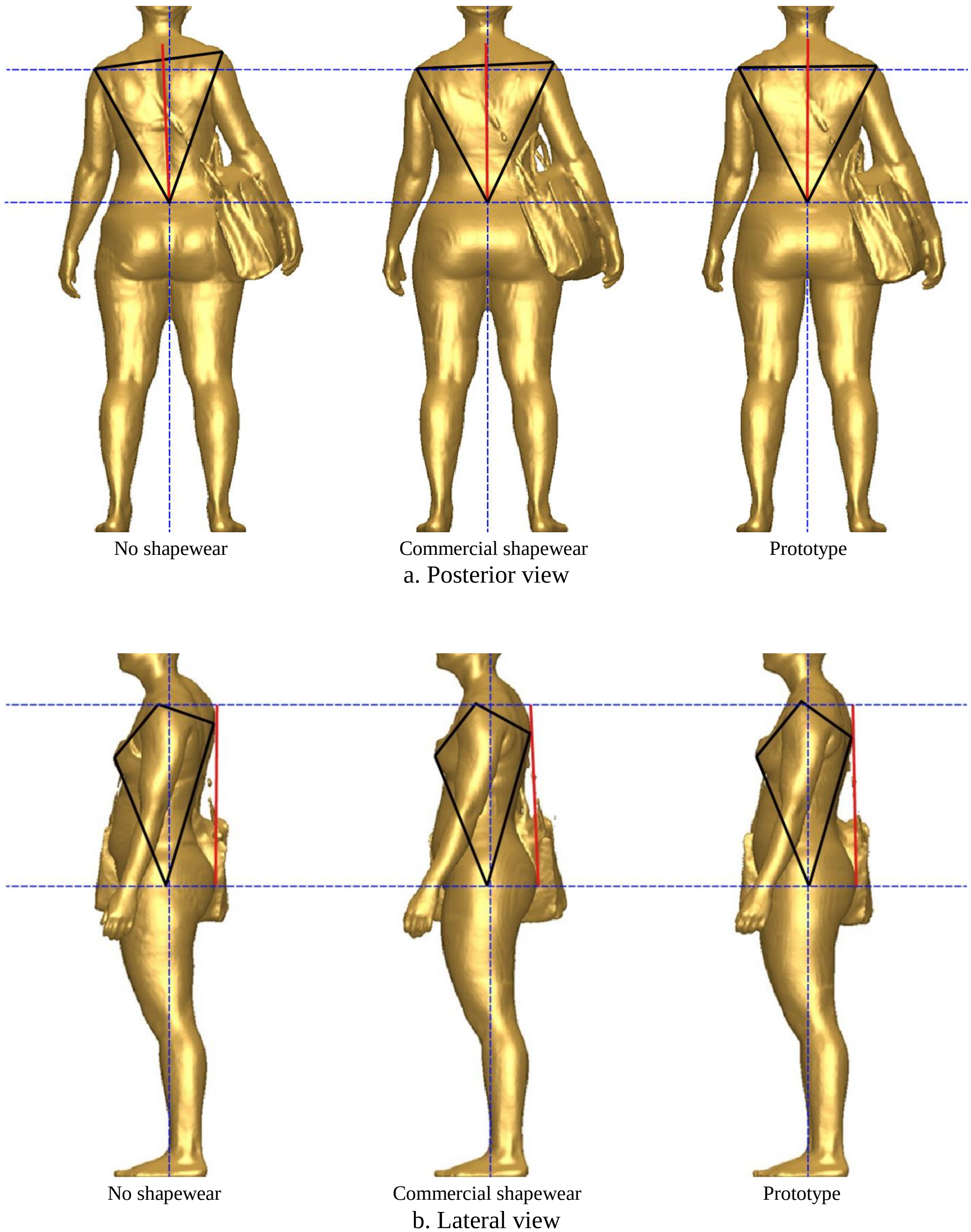


Figure 26. Posture changes of a large size participant in P4R

Body Angle Changes in Position 4L

When carrying a bag cross-body with a strap placed on the right shoulder to place the weight at the hip level on the left side (P4L), a statistically significant sample mean difference greater than zero was observed for θ_A ($M_d > 0$, $t > 1.363$, and $p < .05$) for the pairs of N and P. Highly significant sample mean differences were observed for θ_B, θ_C ($M_d > 0$, $t > 1.363$ and $p < .01$), and θ_D ($M_d < 0$, $t < -1.363$ and $p < .01$) for the same pairs. While no significant sample mean difference was observed for θ_E ($M_d = .817$, SD = 2.728, $t(11) = 1.038$, and $p = .161$).

When comparing the body angles in C to P, the same tendency was observed for some body angles. Highly significant differences between sample means greater than zero were found for θ_A, θ_B, and θ_C ($M_d > 0$, $t > 1.363$ and $p < .01$). On the other hand, no significant sample mean difference for θ_E ($M_d = -.211$, SD = 2.126, $t(11) = -.344$, and $p = .368$) was observed with the greater θ_D ($M_d > 0$, $t > 1.363$ and $p < .10$) in the prototype. The test results indicate that the participants wearing the prototypes exhibited smaller imbalances on the shoulder level, lateral center of gravity, and lateral spine curvatures compared to no shapewear and the commercial shapewear. However, prototype was less effective in improving the trunk inclination than the commercial shapewear and exhibited no effectiveness in straitening the shoulder on the horizontal plane compared to both wearing conditions in this position. The results of the paired t-tests for all body angles in P4L are shown in Table 11. Figure 27 shows posture changes of a medium size participant in P4L.

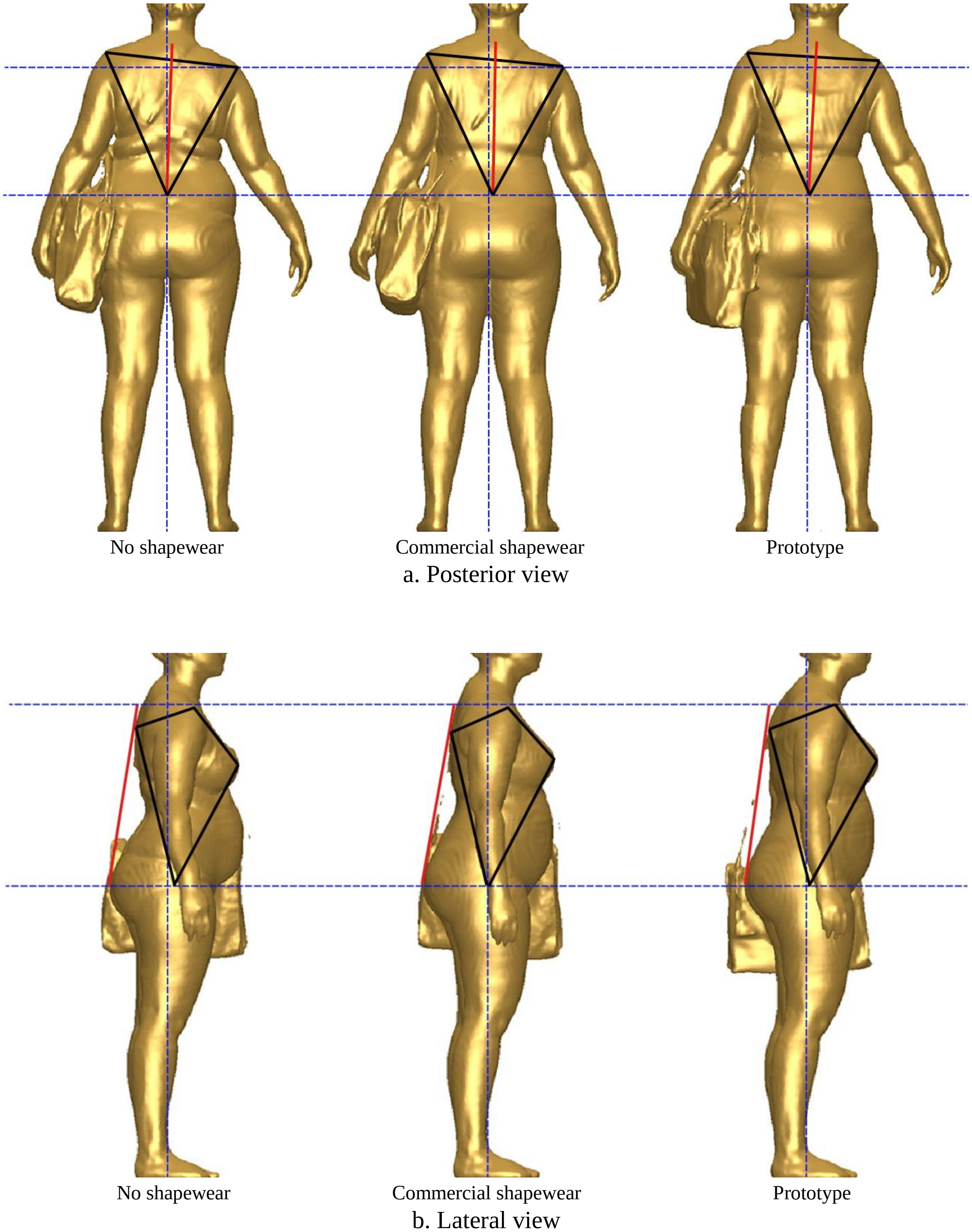


Figure 27. Posture changes of a medium size participant in P4L

Body Angle Changes in Position 5R

When carrying a bag with the right hand (P5R), significant differences of sample means between N and P were observed for θ_C ($M_d > 0$, $t > 1.363$, and $p < .05$) and θ_E ($M_d < 0$, $t < -1.363$, and $p < .05$) with θ_B ($M_d > 0$, $t > 1.363$, and $p < .10$ on the boundary of statistical significance). θ_A ($M_d = .070$, SD = 1.376, t (11) = .178, and $p = .431$) and θ_D ($M_d = -.562$, SD = 2.001, t (11) = -.973, and $p = .176$) didn't exhibit significant sample mean differences. It showed that the participants wearing the prototype exhibited better lateral center of gravity, less excessive lateral spine curvature, and straighter shoulders on the horizontal plane while no changes were observed for the shoulder level and trunk inclination in this position.

Highly significant differences between two sample means greater than zero were observed for θ_B and θ_C ($M_d > 0$, $t > 1.363$ and $p < .01$) for the pairs of C and P. No significant mean differences were observed for θ_A ($M_d = .122$, SD = 1.130, t (11) = .375, and $p = .357$), θ_D ($M_d = .030$, SD = 1.617, t (11) = .066, and $p = .474$), and θ_E ($M_d = -.879$, SD = 2.864, t (11) = -1.063, and $p = .155$). The test results indicate that the participants wearing the prototype exhibited smaller imbalances on the lateral center of gravity and lateral spine curvatures compared to the commercial shapewear. However, it was not evident that the prototype is more effective in modifying shoulder level, trunk inclination, and shoulder line on the horizontal plane than the commercial shapewear. The results of the paired t-tests for all body angles in P5R are shown in Table 11. Figure 28 shows posture changes of a large size participant in P5R.

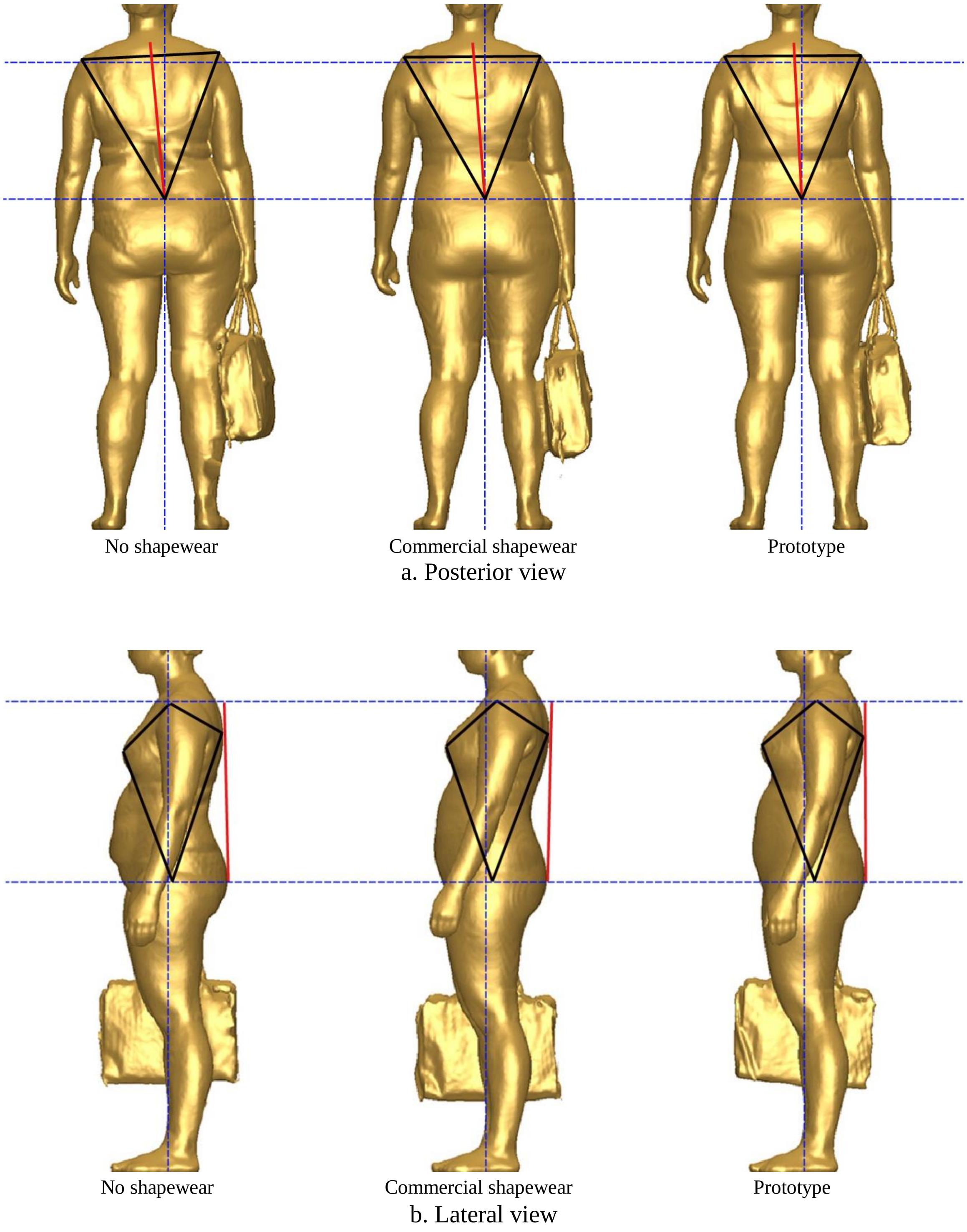


Figure 28. Posture changes of a large size participant in P5R

Body Angle Changes in Position 5L

When carrying a bag with the left hand (P5L), marginally significant differences of sample means between N and P were observed for θ_A, θ_B ($M_d > 0$, $t > 1.363$ and $p < .10$), and θ_E ($M_d < 0$, $t < -1.363$ and $p < .10$) while no significant sample mean differences for θ_B ($M_d = .350$, SD = 1.215, t (11) = .999, and $p = .169$) and θ_D ($M_d = -.469$, SD = 1.220, t (11) = -1.332, and $p = .105$) were observed. It indicates that the prototype provided smaller imbalances on the shoulder level and lateral spine curvatures and straighter shoulders on the horizontal plane compared to no shapewear. However, there was no evidence that the prototype is effective in modifying the lateral center of gravity and the trunk inclination in this position.

Pairs of C and P also showed statistically significant differences between sample means greater than zero for θ_A, θ_B, and θ_C ($M_d > 0$, $t > 1.363$ and $p < .05$). On the other hand, no significant sample mean difference for θ_D ($M_d = -.117$, SD = .906, t (11) = -.449, and $p = .331$) was observed with the greater θ_E ($M_d > 0$, $t > 1.363$ and $p < .10$) at the marginal significant level in the prototype. The test results indicate that participants wearing the prototype exhibited smaller imbalances on the shoulder level, lateral center of gravity, and lateral spine curvature. However, wearing the prototype showed less straight shoulders on the horizontal plane and no significant difference for the trunk inclination compared to the commercial shapewear in this position. The results of the paired t-tests for all body angles in P5L are shown in Table 11. Figure 29 shows posture changes of a large size participant in P5L.

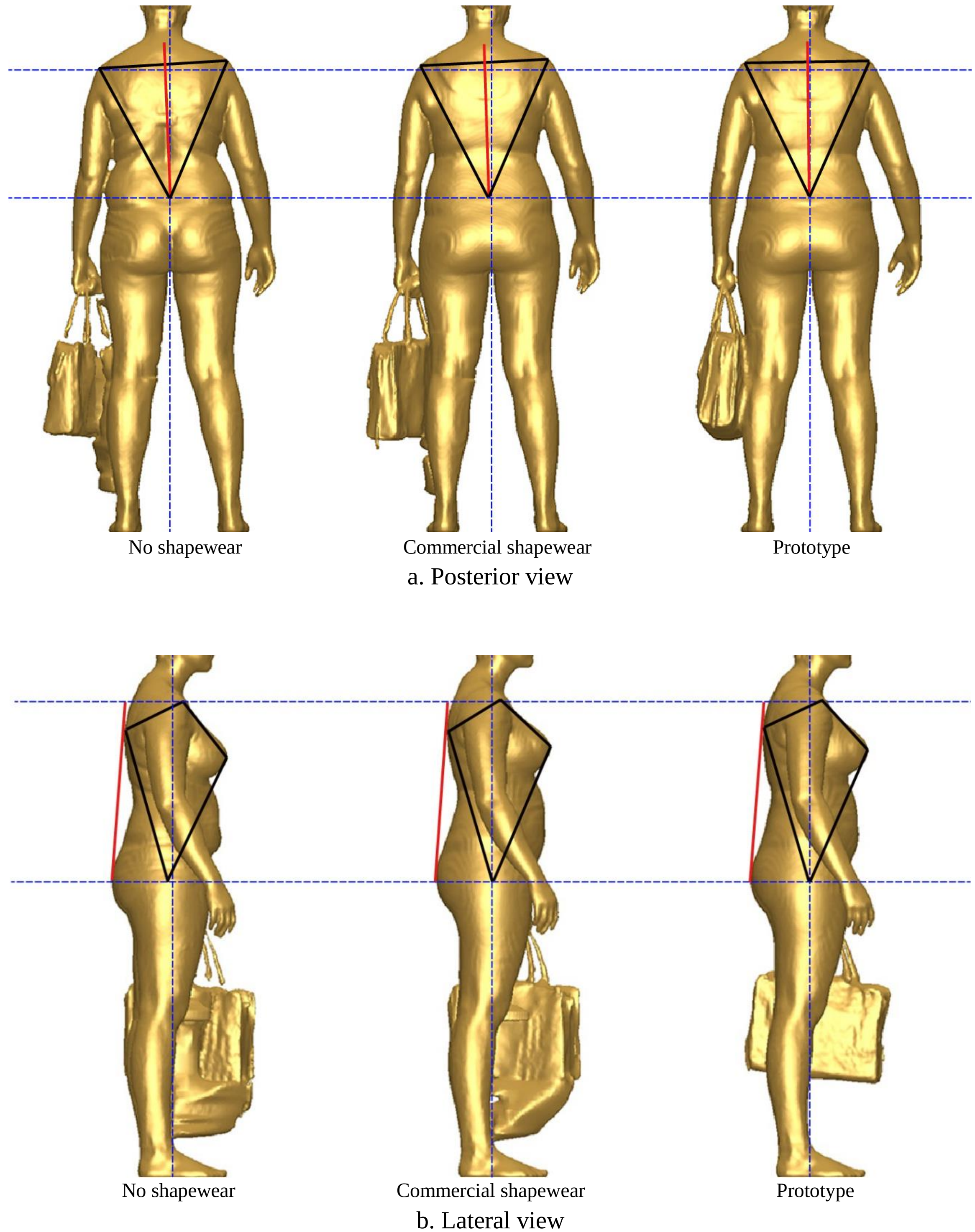


Figure 29. Posture changes of a large size participant in P5L

Table 11

Paired T-Test for Body Angle Changes

		Pair N – P				Pair C – P			
Position	Angle	M_d (°)	SD (°)	*t* (11)	*p*	M_d (°)	SD (°)	*t* (11)	*p*
P1	θ_A	.867	.755	**3.976**	.001	.577	.585	**3.412**	.003
	θ_B	.422	.830	**1.762**	.053	.259	.457	**1.966**	.037
	θ_C	1.369	2.072	**2.290**	.021	1.321	1.732	**2.644**	.011
	θ_D	-.339	1.379	-.853	.206	-.097	1.787	-.188	.427
	θ_E	-2.012	2.826	**-2.466**	.015	-1.705	2.817	**-2.096**	.030
P2	θ_A	.376	.787	**1.657**	.063	.425	.473	**3.116**	.005
	θ_C	1.148	1.459	**2.726**	.010	.997	1.042	**3.316**	.003
	θ_E	-1.980	3.548	**-1.933**	.039	-2.755	1.748	**-5.459**	.000
P3R	θ_A	1.852	1.332	**4.814**	.000	.445	1.721	.896	.195
	θ_B	.575	.684	**2.913**	.007	.831	.958	**3.007**	.006
	θ_C	2.108	2.348	**3.110**	.005	.835	1.836	**1.575**	.071
	θ_D	-.980	1.880	**-1.806**	.049	.095	1.343	.246	.405
	θ_E	.211	4.146	.177	.431	.521	2.398	.753	.233
P3L	θ_A	1.900	1.062	**6.195**	.000	.727	1.298	**1.942**	.039
	θ_B	.959	.659	**5.039**	.000	.700	1.233	**1.968**	.037
	θ_C	3.694	3.720	**3.440**	.003	1.261	1.309	**3.336**	.003
	θ_D	-.974	1.595	**-2.116**	.029	.124	1.143	.376	.357
	θ_E	-.645	2.791	-.801	.220	-1.451	1.840	**-2.731**	.010
P4R	θ_A	1.277	1.484	**2.981**	.006	.551	.867	**2.204**	.025
	θ_B	.924	1.146	**2.792**	.009	.579	.307	**6.537**	.000
	θ_C	1.479	2.926	**1.752**	.054	1.403	2.371	**2.050**	.032
	θ_D	-1.030	2.017	**-1.770**	.052	-.157	1.020	-.533	.302
	θ_E	.077	5.195	.052	.480	.015	2.280	.023	.491
P4L	θ_A	.955	1.316	**2.514**	.014	1.013	1.041	**3.371**	.003
	θ_B	.868	.759	**3.961**	.001	.797	.822	**3.362**	.003
	θ_C	4.630	1.600	**10.024**	.000	1.662	1.827	**3.151**	.004
	θ_D	-.736	.912	**-2.797**	.008	.576	1.335	**1.497**	.081
	θ_E	.817	2.728	1.038	.161	-.211	2.126	-.344	.368
P5R	θ_A	.070	1.376	.178	.431	.122	1.130	.375	.357
	θ_B	.459	.918	**1.732**	.055	.792	.959	**2.862**	.007
	θ_C	1.486	2.322	**2.217**	.024	2.075	2.531	**2.840**	.008
	θ_D	-.562	2.001	-.973	.176	.030	1.617	.066	.474
	θ_E	-2.008	3.782	**-1.840**	.046	-.879	2.864	-1.063	.155
P5L	θ_A	.500	1.183	**1.464**	.085	.337	.504	**2.317**	.020
	θ_B	.350	1.215	.999	.169	.548	.836	**2.273**	.022
	θ_C	1.476	3.215	**1.591**	.070	.639	1.162	**1.905**	.041
	θ_D	-.469	1.220	-1.332	.105	-.117	.906	-.449	.331
	θ_E	-1.319	3.198	**-1.429**	.090	.843	1.990	**1.466**	.085

Note. $|t| > 1.363$ are in boldface.

In most cases the test results proved that the sample mean differences for θ_A, θ_B, and θ_C between no shapewear and the prototype and the commercial shapewear and the prototype are statistically significant. These angles show the balance of the body exhibiting clear criteria in assessing posture; an aligned shoulder level and lateral center of gravity assumes 0° of θ_A and θ_B respectively and an aligned lateral spine curvature assumes 180° of θ_C. Thus, smaller angles from zero for θ_A and θ_B with a smaller angle subtracted from 180° for θ_C indicate more aligned posture.

The test results showed that θ_A exhibiting the shoulder level was smaller when wearing the prototype in 87.5% of the scan positions compared to no shapewear and in 75% of the scan positions compared to the commercial shapewear. θ_B exhibiting the lateral center of gravity was smaller in the prototype in 85.7% of the scan positions compared to no shapewear. Participants wearing the prototype exhibited smaller θ_B for all scan positions compared to the commercial shapewear. In all scan positions, more aligned lateral spine curvatures were observed (θ_C close to 180°) when wearing the prototype compared to no shapewear and the commercial shapewear.

From the observations, by adding an extra soft materials support (textile bands) to the back of a commercial shapewear product, effectiveness of the prototype was found in modifying the shoulder level, lateral center of gravity, and lateral spine curvature while standing and carrying an item compared to both no shapewear and commercial shapewear conditions.

In regard to θ_D and θ_E, there are no clear criteria in assessing posture as these angles are not the factors determining balance or imbalance of posture but show a tendency of posture changes by wearing a shapewear garment.

In the test results, greater θ_D in the prototype was observed in 57.1% of the scan positions compared to no shapewear. It indicates that participants exhibited straighter spines on the sagittal plane indicating less trunk inclination in more than a half of the scan positions when wearing the prototype compared to no shapewear while participants exhibited no difference on θ_D in 42.9% of the scan positions. The pairs of the commercial shapewear and the prototype exhibited no significant sample mean differences for θ_D for six scan positions with greater θ_D ($M_d > 0$) in P4L. It indicates that the prototype didn't make any significant differences for the trunk inclination in the most of the scan positions compared to the commercial shapewear.

Straighter shoulder lines (greater θ_E) on the horizontal plane were observed in 37.5% of the scan positions when wearing the prototype compared to no shapewear. There were no significant sample mean differences in a half of the scan positions with greater θ_E ($M_d > 0$) observed in P5L for the pairs of the commercial shapewear and the prototype.

The test results for θ_D and θ_E indicate that the prototype is effective in straitening the spine on the sagittal plane and the shoulders on the horizontal plane with lower chances (≤ 50%) compared to no shapewear and the commercial shapewear conditions.

To sum up, the test results show that there is sufficient evidence to conclude that wearing the prototype provides instant posture modification effects for θ_A, θ_B, and θ_C for most of the scan positions with lower chances (≤ 50%) in modifying posture on θ_D and θ_E at the significance level of .10. Table 12 shows a summary of the statistical analysis for posture modification effects of the prototype.

Table 12

Summary of Statistical Analysis for Posture Modification Effects of Prototype

		Number of positions (%)			
		Pair N – P		Pair C – P	
Angle	Ha	Rejecting Ho	Failing to reject Ho	Rejecting Ho	Failing to reject Ho
θ_A	$M_d > 0$	7/8 (87.5)	1/8 (12.5)	6/8 (75)	2/8 (25)
θ_B	$M_d > 0$	6/7 (85.7)	1/7 (14.3)	7/7 (100)	0/7 (0)
θ_C	$M_d > 0$	8/8 (100)	0/8 (0)	8/8 (100)	0/8 (0)
θ_D	$M_d < 0$	4/7 (57.1)	3/7 (42.9)	0/7 (0) 1/7 (14.3, $M_d > 0$)	6/7 (85.7)
θ_E	$M_d < 0$	4/8 (50)	4/8 (50)	3/8 (37.5) 1/8 (12.5, $M_d > 0$)	4/8 (50)

Although some angles exhibited a lower chance in modifying posture with the prototype; based on the statistical analysis, wearing the prototype is expected to provide effects in aligning shoulder and spine posture. Since the sample size is small, the power of the tests is low but the observation of coherent and consistent posture changes or no change through a variety of scan positions for each participant should provide sufficient information on effects of the PMSS. More tests with a larger number of participants wearing a broader range of sizes are indicated for future study.

Posture Correction Force

Standard laboratory materials tests were conducted to determine force effects of the PMSS on modifying posture. Materials elongation test results and reaction of the materials when incorporated into the garment both off the body (flat measured) and on the body were used to analyze the posture correction force. For statistical analysis, terms were determined (see Table 13). The first letter indicates each part of the PMSS: a, b, c, and d. Refer to Figure 20 with designator alphabets showing each band location. The second capital letter means wearing condition: C (commercial shapewear) and P (prototype). Note that terms were used for posture correction force analysis: cCR which is part c of the commercial shapewear from right under arm to left side seam around upper hip, cCL which is part c of the commercial shapewear from left under arm to right side seam around upper hip, cPR which is part c of the PMSS placed at the right under arm to left side seam around upper hip on the prototype, and cPL which is part c of the PMSS placed at the left under arm to right side seam around upper hip on the prototype.

Table 13

Terms for Statistical Analysis for Posture Correction Force

Item	Commercial shapewear (C)	Prototype (P)
Part a	aC	aP
Part b	bC	bP
Part c	cC	cP
Part d	dC	dP

The materials tests results showed that the pounds of force of all flexible bands (a, b, and c) on the prototype were greater than the materials of the commercial shapewear garment alone. It was also found that there were greater pounds of force acting on the body while wearing the prototype compared to the commercial shapewear.

Pounds of Force — Material Properties

Pounds of force of each specimen were compared at the same extension levels (0.5, 1, 1.5, and 2 inches, Table 14). The test results showed that the specimens from the prototype exhibited greater pounds of force than the commercial shapewear.

For the specimens of the prototype, the highest values were found for aP at the same extension levels. This is because the band aP consists of multi-layered fabrics including an elastic band and extra fabrics covering the elastic band. Since all edges and the center line of the materials are sewn on the garment fabric, the threads provide extra forces under tension.

The band bP also showed great pounds of force compared to other specimens except for aP due to the multi-layered fabrics providing extra forces. Although, the materials of aP and bP are identical, smaller pounds of force were exhibited on bP than aP because of no sewn parts on the bands.

The band cP showed the smallest pounds of force at the same level of extension compared to aP and bP since it consists of soft and thin fabrics in a bias direction without the elastic band.

For the specimens of the commercial shapewear, the greatest pounds of force were observed for bC while the smallest pounds of force were observed for aC. The shapewear garment consists of a double-layered fabric for the overall back torso (bC, cC, and dC) except for the thoracic region (aC) made with a single fabric. Thus, aC exhibited the smallest force when stretched. Since the materials are identical for bC, cC, and dC, the directions of stretch caused differences of the degree of pounds of force. Figure 30 shows loads by extension of materials.

Table 14

Loads (lbf) by Extension of Materials

Extension (inch)	C				P		
	aC	bC	cC	dC	aP	bP	cP
0.5	0.167	0.365	0.372	0.263	2.033	1.731	0.496
1.0	0.263	0.837	0.542	0.495	3.167	2.501	0.710
1.5	0.366	1.455	0.732	0.791	5.159	3.456	0.916
2.0	0.487	2.108	0.929	1.137	8.161	4.693	1.149

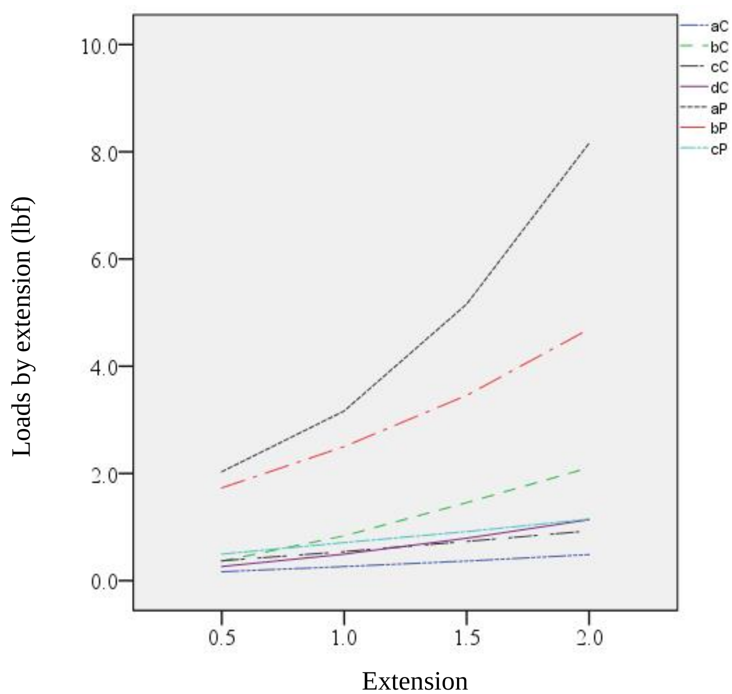


Figure 30. Loads by extension of materials

<u>*Pounds of Force — Posture Correction Force*</u>

1) Extension of Materials on the Body

The material test results showed that the specimen dC provides a small value of pounds of force at the chosen extension levels (0.5, 1, 1.5, and 2 inches). However, the range of extension of the part d on the body (waist circumference) exhibited the largest values (Table 15). The lengthwise parts (a and b) showed small values in extension on the body. The results from the paired t-tests for band extension on the body showed no significant differences of sample means between two wearing conditions (p >.10) for all pairs. Figure 31 shows boxplots for extension of materials on the body.

Table 15

Descriptive Statistics of Extension of Materials on the Body

	C		P	
Part	M (inch)	SD (inch)	M (inch)	SD (inch)
a	0.406	0.338	0.344	0.170
b	0.385	0.714	0.510	0.247
cR	3.469	0.819	3.635	0.534
cL	3.759	0.797	3.834	0.672
d	9.250	1.606	9.469	1.611

Note. The value of part d was calculated by subtracting 20 inch (flat value of the shapewear garment at the waistline*2) from the value of waist circumference in each wearing condition.

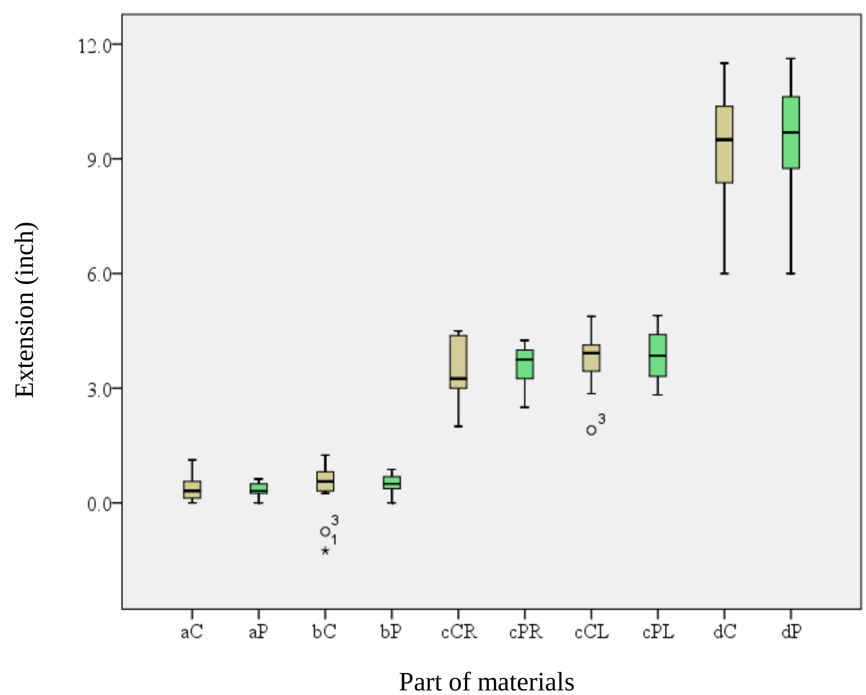


Figure 31. Extension of materials on the body

2) Force of Materials on the Body

The results of paired t-tests for posture correction force on the body showed highly significant differences of sample means ($M_d < 0$, $t < -1.363$ and $p < .01$) for part a, b, and c (right side and left side respectively) between the commercial shapewear and the prototype at the significance level of .10 (Table 16). The test results are consistent with the results of the band extension in the above section. Since the extension of the garment on the body is not different for both shapewear garments, greater pounds of force are exhibited in the prototype based on the material properties. Although, greater pounds of force were observed in the prototype, as acknowledged, at least part of the posture modification is provided by combining compression of the garment itself when the bands are attached to the garment.

The results from the paired t-tests for posture correction force around the waistline on the body showed no significant sample mean difference between the commercial shapewear and the prototype ($M_d = -.359$, SD = .834, $t\ (11) = -1.552$, and $p = .147$). The test results indicate that the prototype doesn't provide greater compression around the waistline than the commercial shapewear. Figure 32 shows boxplots for force of materials on the body.

The test results above are consistent with the paired t-test results for body circumferences (Table 17). It means that the participants exhibited similar waist circumferences when wearing each garment. Also no significant sample mean differences were found in the under-bust and hip circumferences. Only the upper-hip circumference showed a highly significant sample mean difference between the commercial shapewear and the prototype ($M_d > 0$, $t > 1.796$ and $p < .01$); smaller upper-hip circumferences were found in the prototype compared to the commercial shapewear. This may be related to the amount of posture changes and body shape changes while wearing the prototype. Explanations and figures showing effects of prototype in improving body shape (mid-torso) are presented in the next section, qualitative evaluation.

Table 16

Paired T-Test for Force of Materials on the Body

Pair		M (lbf)	SD (lbf)	*t* (11)	*p*
Pair 1	aC-aP	-1.244	0.539	**-7.992**	0.000
Pair 2	bC-bP	-0.980	0.436	**-7.792**	0.000
Pair 3	cCR-cPR	-0.841	0.387	**-7.532**	0.000
Pair 4	cCL-cPL	-1.104	0.959	**-3.987**	0.001
Pair 5	dC-dP	-0.359	0.834	-1.552	0.147

Note. *t* <-1.363 are in boldface for pairs 1 to 4.

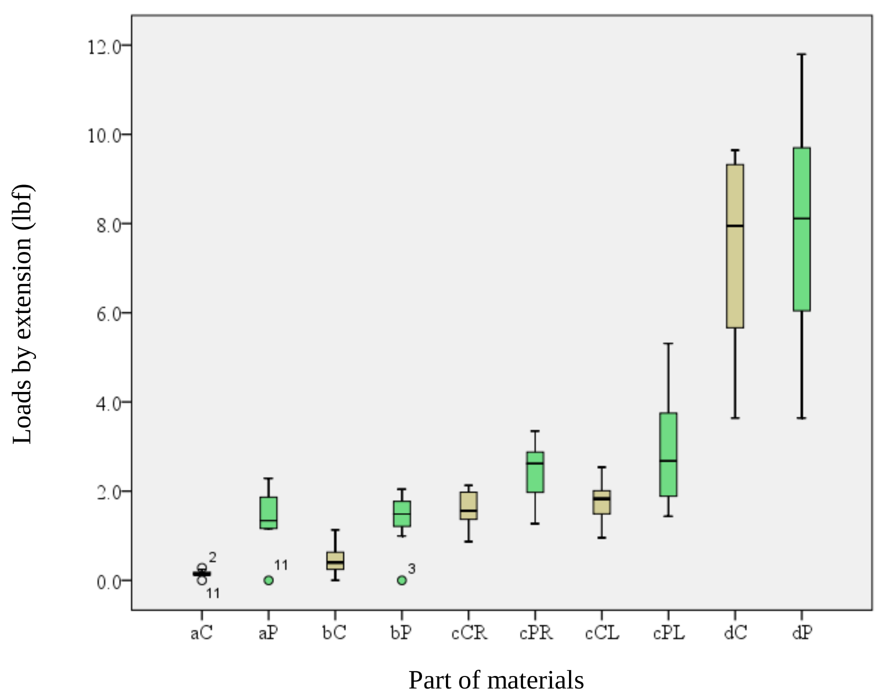


Figure 32. Force of materials on the body

Table 17

Paired T-Test for Body Circumferences (C – P)

Dimension (Circumference)	M (inch)	SD (inch)	*t* (11)	*p*
Under-bust	-0.136	0.321	-1.468	0.170
Waist	-0.158	0.662	-0.829	0.425
Upper-hip	0.329	0.150	**7.596**	0.000
Hip	0.063	0.235	0.934	0.370

Note. l*t*l values > 1.796 are in boldface.

Although no significant sample mean differences of most of body circumferences between the prototype and the commercial shapewear were found, highly or statistically significant sample mean differences ($M_d > 0$, $t > 1.363$ and $p < .05$) were observed from the comparison of no shapewear and each shapewear garment (Table 18). Since more aligned posture is observed when wearing a shapewear garment compared to no shapewear, it is assumed that the compression of the shapewear garment may affect to the posture changes.

Table 18

Paired T-Test for Body Circumferences (N – C and N – P)

	Pair N – C				Pair N – P			
Dimension (Circumference)	M_d (inch)	SD (inch)	*t* (11)	*p*	M_d (inch)	SD (inch)	*t* (11)	*p*
Under-bust	0.770	0.438	**6.084**	0.000	0.634	0.402	**5.460**	0.000
Waist	0.550	0.794	**2.400**	0.018	0.392	0.742	**1.829**	0.048
Upper-hip	0.392	0.531	**2.559**	0.014	0.721	0.613	**4.072**	0.001
Hip	0.378	0.471	**2.778**	0.009	0.441	0.341	**4.474**	0.001

Note. *t* values > 1.363 are in boldface.

To sum up, greater pounds of force were acting on the body when wearing the prototype compared to the commercial shapewear. Thus, it is concluded that greater pounds of force of the PMSS may affect greater posture changes as more aligned posture was observed for most scan positions while wearing the prototype.

In designing the posture support band system, the supportive band location is important as much as material properties. Most of all, it is necessary to understand that the combination of several band elements may have greater effects on posture balance with greater forces than only one design element (I/T/Y/X bands) based on structural mechanics. The PMSS was developed according to the principle by combining a few design elements to provide stronger effects on overall body balance, refer to X, Y, and Z axes (Figure 33); the horizontal band may provide overall balance of the body by adjusting the shoulder level (X and Z axes); the vertical band may provide a strong support for all bands combined with the band by adjusting the spine from the posterior/anterior/lateral view (X, Y, and Z axes); the symmetrical X bands may provide a lower back support by adjusting an imbalanced mid-torso (Y and Z axes) and straightening the body. In the comprehensive test, it was proved that the PMSS was effective in modifying posture in accordance with the hypotheses in some ways. However, each imbalanced body part may be affected by all of the bands with different degrees of force from each band and many variations such as material properties of the garment and supportive bands, degrees of garment compression, pattern and size of the garment, band width, band shape, band location, body conditions of participants, garment construction errors, etc. To investigate more accurate mechanisms and factors affecting posture changes, further research and tests need to be conducted.

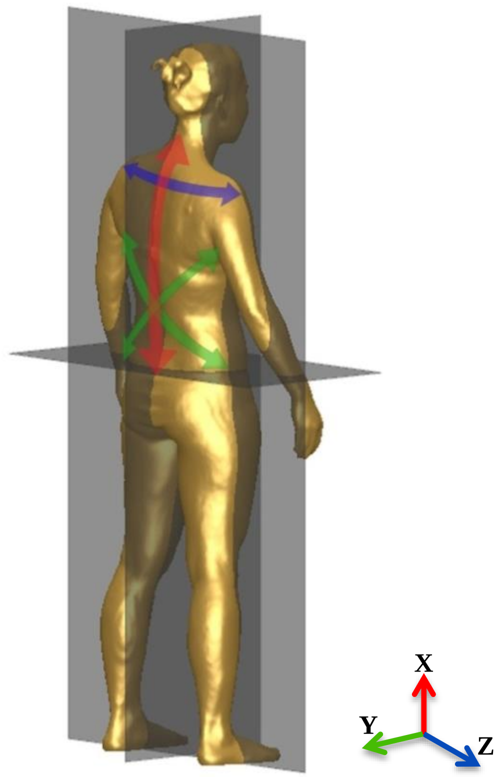


Figure 33. Coordinate system and force directions of the PMSS

Qualitative Evaluations

Participants were asked to complete three questionnaires including background information and wearer acceptability related to their posture and body shape changes in the shapewear garment they tried on and were scanned in and fit of each shapewear garment.

Background Information

In the questionnaire for background information, participants were asked to describe their experience wearing shapewear. Eight out of twelve participants had experience wearing shapewear. For the participants who had shapewear wearing experience, follow-up questions were asked about the type of shapewear that they wore (multi-choice) and how often they wore shapewear. Mid-thigh and high-waist or cincher type shapewear garments were worn by 62.5% of participants and 50% of participants had experience wearing camisole and slip or tank type shapewear garments. Bodysuit type shapewear garments were worn by 25% of participants. Most of participants selected multiple items. All participants answered that they wear a shapewear garment for special occasions only. The types of shapewear garments that were worn by participants are shown in Table 19.

Table 19

Types of Shapewear Garments Previously Worn by Participants

Type	Frequency	Percentage
Mid-thigh	5	62.5
High-waist/cincher	5	62.5
Camisole	4	50
Slip/tank	4	50
Bodysuit	2	25

Participants were asked about the body areas that they would want to change when wearing a shapewear garment and the six categories were found based upon the participants answers: 1) below breasts, 2) stomach, 3) waist, 4) abdomen, 5) “love handles”, 6) hip, and 7) thighs.

As a follow-up question, participants were asked how they would want those areas to change (ex. smaller/larger/slimmer/balanced, etc.). Participants described only two categories: 1) slimmer and 2) smaller.

From the results, it was found that participants wear shapewear to make middle areas of the body slimmer and smaller.

Wearer Acceptability

Participants evaluated their posture, body shape and fit of the shapewear garment on the 3D scans as seen on the computer screen. The scans of participants wearing the commercial shapewear and the prototype referred to the designator names: WOC and ISG respectively. The mean score of each category (seven scales) is higher for the prototype compared to the commercial shapewear.

Posture Changes

A higher mean score of posture changes while wearing the prototype was observed compared to the commercial shapewear (Table 20). When comparing the mean scores by groups, a higher mean score of posture changes in the prototype was observed for small and large size groups with a lower mean score for the medium size group. Table 21 shows comparison of posture changes by groups.

Table 20

Comparison of Posture Changes

	C				P			
Rating	F	P (%)	M	SD	F	P (%)	M	SD
1(Not at all changed)	2	16.7	3.330	1.723	1	8.3	3.583	1.564
2	3	25			3	25		
3	1	8.3			1	8.3		
4	2	16.7			3	25		
5	3	25			3	25		
6	1	8.3			1	8.3		
7(Extremely changed)	0	0			0	0		
Total	12	100			12	100		

Note. F: Frequency, P (%): Percentage

Table 21

Comparison of Posture Changes by Groups

		C		P	
Size	n	M	SD	M	SD
S	4	3.500	1.732	4.500	1.732
M	4	4.500	1.732	3.500	1.732
L	4	2.000	.816	2.750	.957

For the open-ended questions asking about what differences participants noticed compared to their posture in each shapewear garment, most (75%) answered that their back is straightened and shoulder is more balanced when wearing the prototype. Example statements were as follows:

> "I stand taller with more confidence (in the prototype). My back is straight. I wasn't hunching as in my underwear position."

> "(Prototype) made me stand up straight. Shoulders aren't slouched. It fixed my left shoulder."

> "(Posture) appear(s) more symmetrical and less "off-balance"(in the prototype). In the underwear picture, posture seems tilted to one side (right shoulder is lower) and is more even in the shapewear (prototype)"

However, one participant (8.3%) said that the prototype didn't have much effect on her posture and two participants (16.7%) said the prototype "slightly" helped back support.

In the questionnaire for the commercial shapewear, one participant (8.3%) commented the garment made her body more aligned and four participants (33.3%) described their posture changes as "slight/a little bit" straighter in the commercial shapewear. One participant (8.3%) mentioned better effects of the prototype by saying that the shoulder node was less aligned in the commercial shapewear than the prototype. Some participants (25%) indicate no positive effects of the commercial shapewear garment on their posture.

Body Shape Changes

A higher mean score of body shape changes in the prototype was observed compared to the commercial shapewear (Table 22). When comparing the mean scores by groups, a higher mean score of posture changes in the prototype was observed for the small size group with the same mean score for the large size group and a lower mean score for the medium size group. Table 23 shows comparison of body shape changes by groups.

Table 22

Comparison of Body Shape Changes

	C				P			
Rating	F	P (%)	M	SD	F	P (%)	M	SD
1(Not at all changed)	0	0	4.083	1.443	0	0	4.250	0.965
2	2	16.7			0	0		
3	2	16.7			2	16.7		
4	4	33.3			4	33.3		
5	1	8.3			3	25		
6	3	25			1	8.3		
7(Extremely changed)	0	0			0	0		
Total	12	100			12	100		

Note. F: Frequency, P (%): Percentage

Table 23

Comparison of Body Shape Changes by Groups

		C		P	
Size	n	M	SD	M	SD
S	4	3.500	1.290	4.250	1.258
M	4	5.000	1.154	4.750	.500
L	4	3.750	1.707	3.750	.957

For the open-ended question about what differences participants noticed compared to their body shape in each shapewear garment, participants evaluated their scanned body focusing on the smoother/slimmer stomach, waist, and hip when wearing the prototype while slimmer/smaller upper hip and thigh with lifted breasts were mentioned for those wearing the commercial shapewear. Except for the thigh area exhibiting no changes, participants commented that the shapewear garments positively affected their body shape. However, more participants emphasized “slight” effects in improving body shape for the commercial shapewear; four (33.3%) participants mentioned that the commercial shapewear is “slightly” effective in improving some parts of their body shape while one participant (8.3%) said that the prototype had “slight” effects on body shape improvement.

Table 24 shows descriptions of body shape changes. The major themes were derived from participants’ perceptions toward their body shape in each shapewear garment. Note that the frequency of the items (body area) for the detailed answers is in the parenthesis under the “Descriptions” in the table.

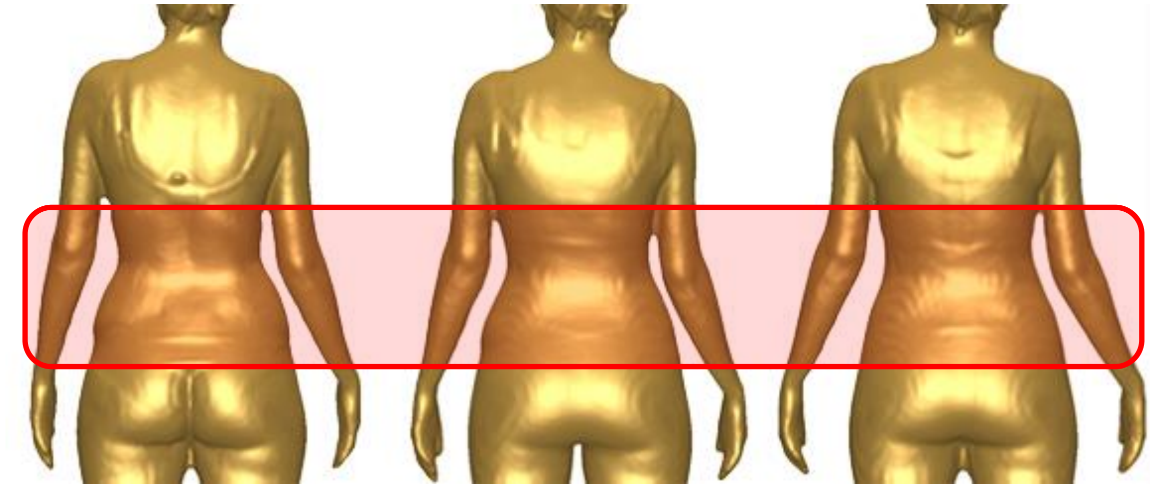
Table 24

Descriptions of Body Shape Changes

	C			P		
Body area	F	P (%)	Descriptions	F	P (%)	Descriptions
Breast	3	25	Lifted (3)	2	16.7	Lifted (3)
Stomach	5	41.7	Slimmer, smoother (5)	6	50	Slimmer, smoother, flatter (6)
Waist	3	25	Slimmer, smaller (3)	5	41.7	Slimmer, smaller, curves on the waist (5)
Belly	3	25	Less fat (2) No change (1)	3	25	Flatter (3)
Upper hip	2	16.7	Smoother (2)	1	8.3	Smoother (1)
Hip	2	16.7	Smaller, smoother (2)	3	25	Smaller, smoother (3)
Thigh	7	58.3	Smaller, slimmer (6) No change (1)	5	41.7	Smaller (4) No change (1)
Overall body shape	2	16.7	Smoother, less fat (2)	2	16.7	Smoother, less fat (2)
Sideline	3	25	Smoother (3)	3	25	Smoother (3)

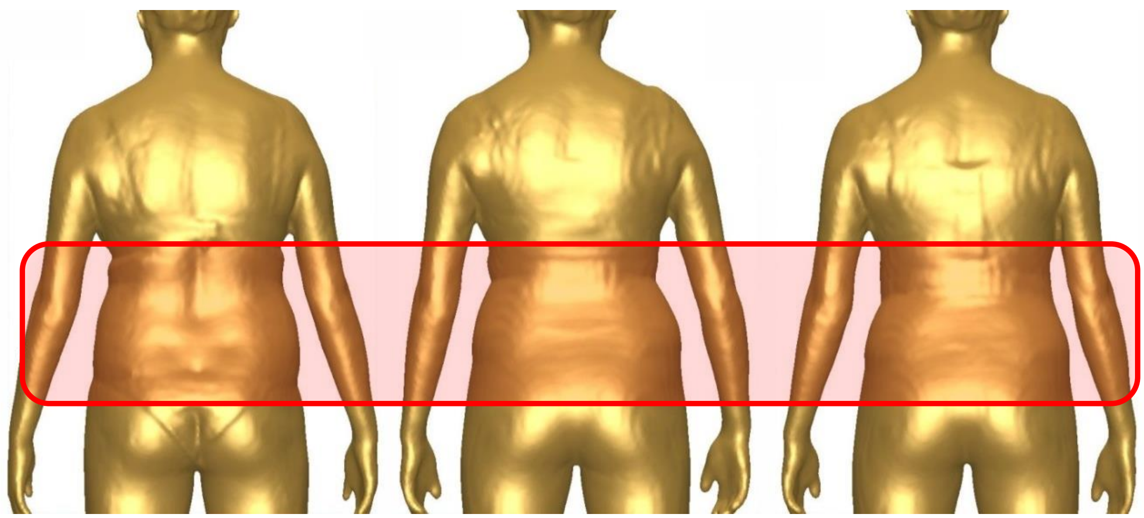
Note. F: Frequency, P (%): Percentage

Although participants were not aware of significant differences for their mid-torso shape changes, it was observed from scans in many cases that the overall shape of the mid-torso was smoother in the prototype compared to the commercial shapewear and much smoother than no shapewear. Refer to Table 18. This is a critical finding because the major purpose of shapewear is to improve body shape by making the form smoother and thinner to resemble the ideal figure. The challenge in developing shapewear with posture support elements is to not negatively affect body shape. Figure 34 to 36 show examples of body shape differences for small, medium, and large size participants respectively.



No shapewear Commercial shapewear Prototype

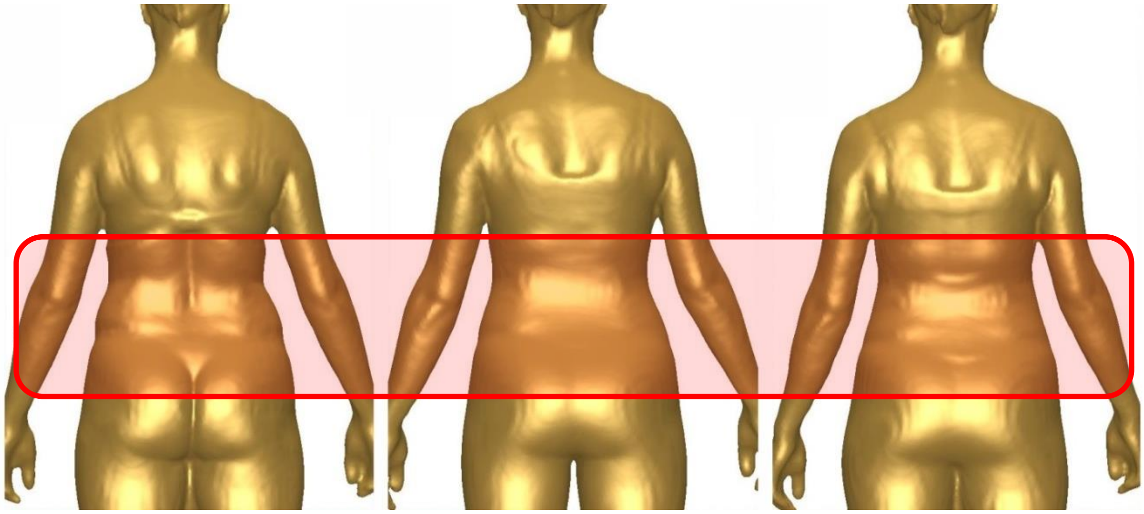
a. Example 1



No shapewear Commercial shapewear Prototype

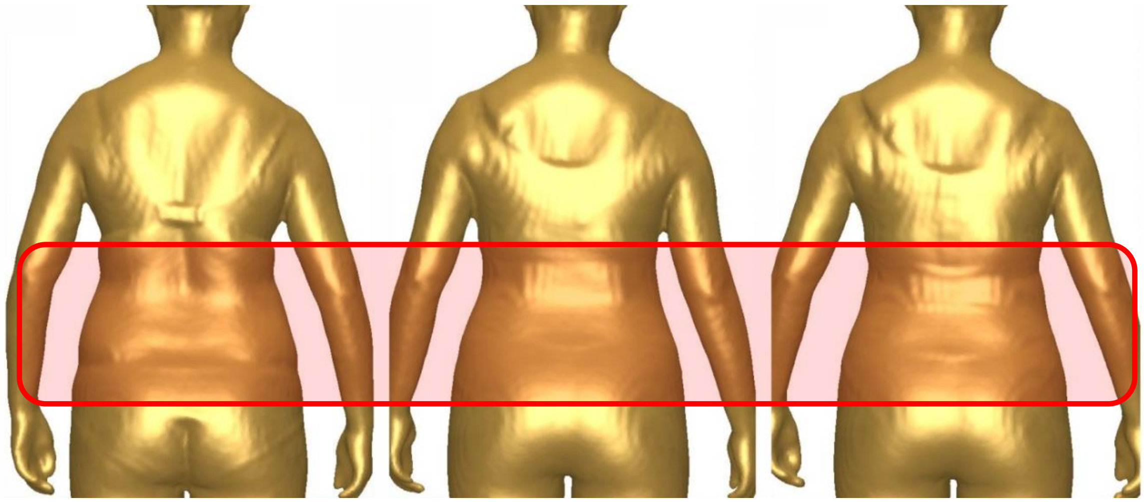
b. Example 2

Figure 34. Examples of body shape differences for small size



No shapewear | Commercial shapewear | Prototype

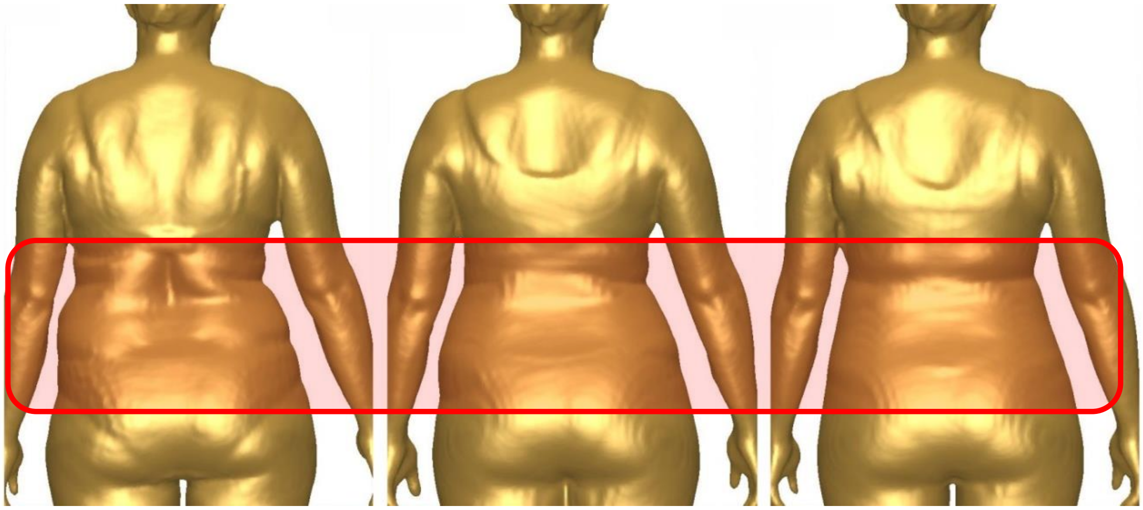
a. Example 1



No shapewear | Commercial shapewear | Prototype

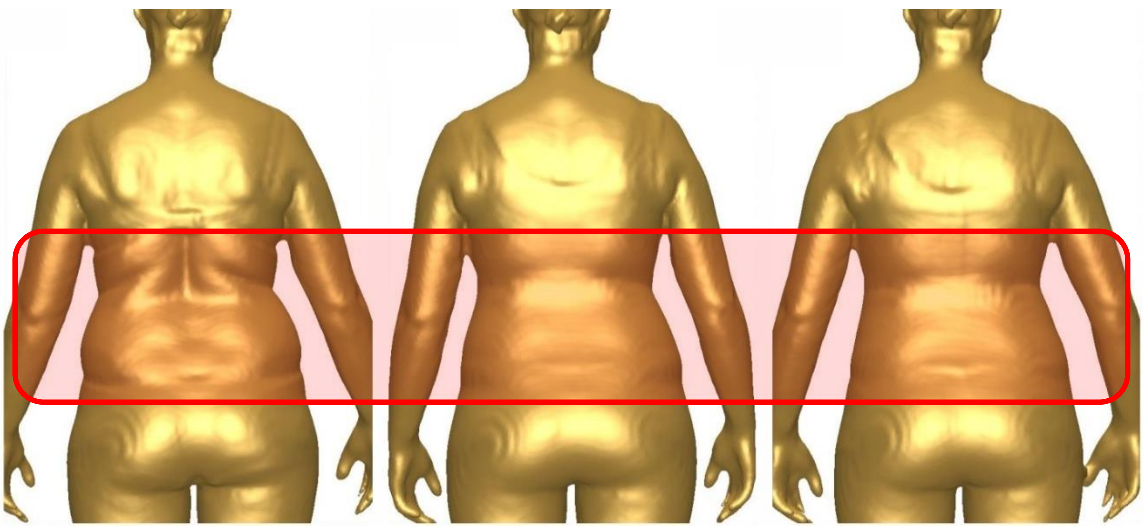
b. Example 2

Figure 35. Examples of body shape differences for medium size



No shapewear | Commercial shapewear | Prototype

a. Example 1



No shapewear | Commercial shapewear | Prototype

b. Example 2

Figure 36. Examples of body shape differences for large size

Fit Evaluation

A higher mean score of fit of the prototype was observed compared to the commercial shapewear (Table 25). When comparing the mean scores by groups, a higher mean score of fit in the prototype was observed for the small and large size groups with a lower mean score for the medium size group. Table 26 shows comparison of fit evaluation by groups.

Table 25

Comparison of Fit Evaluation

	C				P			
Rating	F	P (%)	M	SD	F	P (%)	M	SD
1(Not at all changed)	0	0	4.083	1.505	0	0	4.500	1.314
2	2	16.7			1	8.3		
3	3	25			2	16.7		
4	2	16.7			2	16.7		
5	2	16.7			3	25		
6	3	25			3	25		
7(Extremely changed)	0	0			0	0		
Total	12	100			12	100		

Note. F: Frequency, P (%): Percentage

Table 26

Comparison of Fit Evaluation by Groups

		C		P	
Size	n	M	SD	M	SD
S	4	3.500	1.732	5.250	.957
M	4	5.000	.816	4.000	1.154
L	4	3.750	1.707	4.250	1.707

An open-ended question asked participants to describe what they saw while wearing products that helped determine their level of satisfaction. Participants evaluated the fit of the prototype focusing on tightness and body shape changes while comfort and the body shape changes were the main evaluation criteria for the commercial shapewear. Three participants (25%) evaluated the commercial shapewear as not tight enough to change their body shape so that the commercial shapewear didn't make significant changes on their body shape (seven participants, 58.3%). While eight participants (66.7%) mentioned that the prototype provided visible changes to their body shape. However, more participants commented on comfort of the commercial shapewear garment. One person (8.3%) said the prototype was comfortable while four participants (33.3%) described the commercial shapewear as comfortable. One participant (8.3%) mentioned the effectiveness of the prototype in supporting her back by saying that the commercial shapewear provided less back support compared to the prototype. Table 27 presents descriptions of fit evaluation of each shapewear garment. The categories are based upon participants' fit evaluation of each shapewear garment. Note that the frequency of the items for the detailed answers in the parenthesis under the "Descriptions" in the table.

Table 27

Descriptions of Fit Evaluation

	C			P		
Theme	F	P (%)	Descriptions	F	P (%)	Descriptions
Tightness	3	25	Loose, not tight (3)	5	16.7	Tight (2) Not tight (3)
Comfort	4	33.3	Comfortable (4)	1	8.3	Comfortable (1)
Thinness(material)	1	8.3	Breathable, flexible (1)	1	8.3	Strict (1)
Body shape	8	66.7	Less changes (7), slimmed (1)	8	66.7	More changes, smoothed (8)
Wearability	2	16.7	Easy to wear (1) Hard to wear (1)	2	16.7	Easy to wear (1) Difficult to wear (1)
Back support	1	8.3	Less back support (1)	0	0	n/a

Note. F: Frequency, P (%): Percentage

A final question asked participants to describe other things they like or dislike about each shapewear garment. For the prototype, participants addressed that they like the body shape improvement exhibiting a slimmer and smoother body silhouette and back support making them stand straight. However, they mentioned the straps of the prototype were somewhat uncomfortable making the garment difficult to put on and take off. Some participants disliked the breast fit. Some example statements:

> "Fit felt right once you get it on. Definitely felt instantly slimmer with more confidence."

> "I like that the garment give my back some support. I feel like it forces me to stand straight (which I like). I dislike that the breast part doesn't cover the whole part of my bra."

> "I like how it made me appear and feel slimmer but it was tight and uncomfortable."

For the commercial shapewear, participants commented that they could wear the shapewear often because of the thin materials providing comfort while they disliked that the shapewear garment didn't provide visible body shape improvement. One participant mentioned that she did not like the minimal back support of the commercial shapewear garment. Some participants said they would prefer a two piece garment instead of the bodysuit type shapewear. Example statements were as follows:

> "Very thin, feel like something I would be able to wear under other clothing."

> "No change. I liked the different design (prototype) because it (commercial shapewear) provides less back support."

> "(I) would have preferred a two piece garment or just a separate piece for the bottom half."

To sum up, participants were satisfied with posture and body shape improvements with the prototype that provides tightness on the body while some participants mentioned the tightness of the garment caused some discomfort. On the other hand, participants were satisfied with the comfort of the commercial shapewear while some participants commented that it was less effective in smoothing the body shape because of the thin materials that were not tight on the body.

Since the commercial shapewear garment was the base garment of the prototype, there are no differences in thinness and tightness of the garment itself. Participants may have noticed differences in tightness between the two shapewear garments because the prototype added bands made that garment more difficult to don and doff. Likewise, the thickness of the added bands may have affected participants' perceptions of garment thickness. The construction of the prototype with the additional bands also likely affected participants' lowered skin comfort. Participants' qualitative evaluations indicate the need for further refinement of the prototype.

CHAPTER FIVE: CONCLUSIONS

This study presents an exploration into the development of a soft support structure added to a commercial shapewear product with the goal of designing a garment that comfortably and effectively modifies a woman's posture to more closely resemble an ideal balanced posture. The soft support structure was developed by experimenting with textile elastic bands positioned in a commercial shapewear garment to mimic structure and placement of anatomical postural features (muscles and spinal column) of a woman's back. The resulting support structure is called the "Posture Modification System using Soft materials structures" (PMSS).

Three research questions were posed: 1) Can the PMSS added to a commercially available shapewear be effective in modifying posture? 2) Do the PMSS materials combined with the shapewear product fabrics provide greater posture correction force than the shapewear product fabrics alone? and 3) Will the PMSS added to the shapewear product be acceptable to wear?

The first research question addressed the effectiveness of the PMSS added to shapewear in modifying total body posture by analyzing the body angles of participants wearing the garment. Participants were scanned in various positions, some while carrying an item. Posture alignment and balance were assessed from the scans. The results from the quantitative analysis of posture changes showed that there is sufficient evidence to conclude that wearing the prototype provides posture modification effects for θ_A, θ_B, and θ_C indicating balanced body alignment for most of the scan positions. The results were evident for participants in a standard anatomical position and in several item-carrying positions. Posture changes that more closely match an ideal were noted for shoulders more balanced on a plane parallel to the floor, aligned lateral center of gravity, and straighter spine.

The second question considered a characteristic of the band materials used for the PMSS compared to a characteristic of the shapewear fabric alone. Pounds of force were measured for the PMSS materials and extension of the shapewear fabric was assessed to determine a posture "correction force" of the PMSS. The additional exertion of pounds of force of the PMSS positioned at the back of the garment most likely results in a more erect and balanced posture compared to the overall fabric extension and compression of the shapewear without PMSS when worn on the body. The combination of several band elements mimicking body structures and the compression from the shapewear garment provides greater forces to the body in adjusting the spine from the posterior/anterior/lateral view and imbalanced shoulders.

A garment is not effective if it is not acceptable to the wearer. So, a third question addressed wearer acceptability (WA) of the shapewear with PMSS. An open-ended response questionnaire was used to assess WA. Qualitative analysis of participants' responses indicated that participants were more satisfied with their posture and body shape with the prototype combined with the PMSS than when wearing their own underwear or while wearing the shapewear without PMSS. Participants were also more satisfied with the fit of the prototype compared to the commercial shapewear. However, some participants indicated that the prototype was difficult to don and doff because the band structures were tight making the garment difficult to manipulate.

Results could lead to more inventive use of fabric structures in shapewear garments, essentially adding directional forces while stream-lining the shapes and placement of the textile elements. Experimentation with materials of differing extensibility and pounds of force could result in a more comfortable garment while maintaining the desired postural effects.

Beyond the answers for each research question, the larger question was posed: how does the garment work to affect posture change? The PMSS was developed by combining selected design elements in an attempt to affect overall body balance. In attempting to answer the question, why does the PMSS added to shapewear modify body posture?, these principles are proposed (see Figure 37):

1) T-shape bands: The horizontal band body straightening effects rely on the band anchoring to the armscye seams which encircle the entire arm thus providing support to the band beyond the back torso seam. The vertical band attaches to the center back neckline seam and to the center back waistline seam. The effect of this band is to exert a vertical force along the spine. It does not act independently but also relies on anchoring of the band to the circumference compression of the shapewear garment. Although the band does not extend to the crotch/inseam intersection, in effect it anchors at the crotch seam providing additional support and alignment. An upper torso garment (neckline to waistline) with the PMSS feature would not be effective in aligning posture as much as a garment with coverage from torso to the crotch.

2) X-shape bands: The theory in applying these design elements was to provide lateral alignment of the body. The bands attach at the upper sideseams near the lower armscye and to the lower sideseams just above the upper hip in the opposite direction. The apparent effect is to pull equally on the left and right side of the posterior torso to achieve lateral alignment.

3) Garment compression: The PMSS feature cannot function independently to modify posture, but must be anchored to a shapewear compression garment which encircles the body. By being incorporated into a compression garment, the bands can exert directional force to the body beyond overall compression.

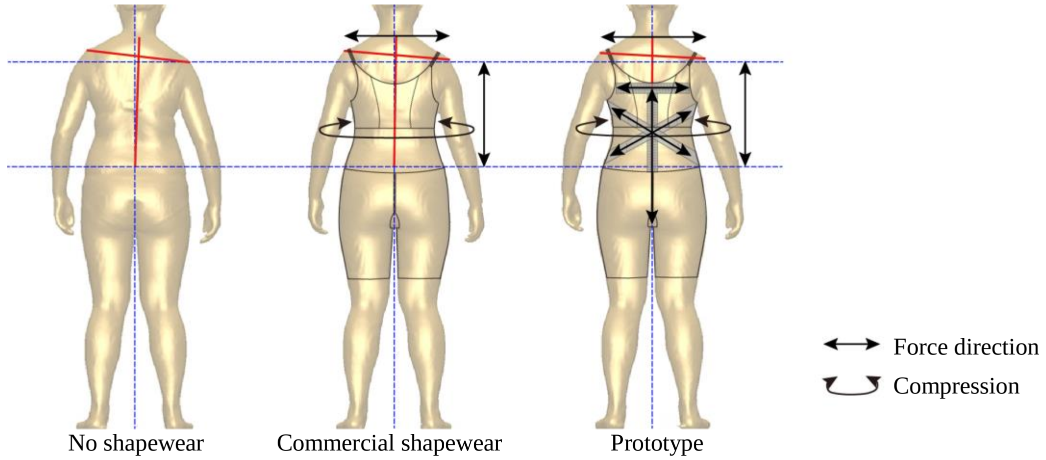


Figure 37. Principles of PMSS and compression shapewear working on the body

The principles stated above provide a plausible explanation of the physical effects of the PMSS on posture. However, the complex and interconnected factors of body posture and a garment worn on the body are acknowledged throughout the study. There may be some other factors affecting the posture changes observed in this study. The order the participants wore the garments could affect the degree of posture changes due to muscle training effects. Fatigue could affect posture as the participants were asked to wear several garments and stand in several poses throughout the study. Participating in a wear test could affect a participant's desire to appear in a more positive way possibly affecting posture. The very nature of being scanned in a body-revealing garment can affect how a person stands during the process. Further research to investigate more accurate and reliable mechanisms and factors affecting posture changes are indicated.

The PMSS is not intended as therapy for medical conditions or as a long-term solution to less than ideal posture, but as a possible addition to compression garments or shapewear for posture and body shape modification effects. The commercial success of shapewear products in the ready-to-wear lingerie category encourages further exploration in improving these types of products. Results of this study show the potential of developing the PMSS for use beyond the lingerie category. More aligned and balanced postures exhibited by participants wearing the shapewear plus the PMSS while carrying items indicate potential in developing soft-structured posture support garments for load-bearing situations in industrial and military settings.

The next steps are to examine variations and applications of soft-structural support garments based on the design concepts presented in this thesis. Variations to the initial design are disclosed in the US Non-Provisional Patent Application *No. 14/924,261, Posture Improvement Shapewear Garment and System* (Lyu, 2015). Beyond the product detailed in the patent, further research is indicated for use situations where balanced and aligned posture is important. In addition other types of directional force materials may be used instead of a textile band system. Sophisticated, detailed knit structuring using the inherent directional forces of elastomeric fibers and varying loop structures incorporated into a standard compression garment could replicate effects of the bands while providing a lighter-weight less bulky garment. Developments in smart materials and structures also open new possibilities for using active materials that will respond and adjust to an individual's posture needs and changes.

BIBLIOGRAPHY

Akel, I., Pekmezci, M., Hayran, M., Genc, Y., Kocak, O., Derman, O., ... & Yazici, M. (2008). Evaluation of shoulder balance in the normal adolescent population and its correlation with radiological parameters. *European Spine Journal, 17*(3), 348-354.

Ashdown, S. P., & Na, H. (2008). Comparison of 3-D body scan data to quantify upper-body postural variation in older and younger women. *Clothing and Textiles Research Journal*, *26*(4), 292-307.

Asher, M., Lai, S. M., Burton, D., & Manna, B. (2004). The influence of spine and trunk deformity on preoperative idiopathic scoliosis patients' health-related quality of life questionnaire responses. *The Spine Journal, 29*(8), 861-868.

Aspan, R., & Stark, S. (2006). *The lingerie handbook.* New York, NY: Workman Publishing Company.

Aubin, C. É., Labelle, H., Ruszkowski, A., Petit, Y., Gignac, D., Joncas, J., & Dansereau, J. (1999). Variability of strap tension in brace treatment for adolescent idiopathic scoliosis. *Spine*, *24*(4), 349-354.

Bazzarelli, M., Durdle, N., Lou, E., & Raso, J. (2001, May). A low power portable electromagnetic posture monitoring system [for scoliosis treatment]. *Proceedings of the 18th IEEE, Hungary: Vol 1.* (pp. 619-623).

Belli, J. F. C., Chaves, T. C., De Oliveira, A. S., & Grossi, D. B. (2009). Analysis of body posture in children with mild to moderate asthma. *European journal of pediatrics, 168*(10), 1207-1216.

Birbaumer, N., Flor, H., Cevey, B., Dworkin, B., & Miller, N. E. (1994). Behavioral treatment of scoliosis and kyphosis. *Journal of Psychosomatic Research, 38*(6), 623-628.

Black, C., & Cloud, R. (2008). Assessing functional clothing needs of bicycle patrol officers. *International Journal of Fashion Design, Technology and Education, 1,* 35–42.

Briedenhann, D. (2004). *Implementation of an off-season training programme to enhance throwing performance in high school athletes.* (Doctoral dissertation, Tshwane University of Technology). [Electronic version]. Retrieved March 20, 2008, from http://libserv5.tut.ac.za:7780/pls/eres/wpg_docload.download_file?p_filename=F 436930 584/briedenhann.pdf.

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

Chan, A. P., & Fan, J. (2002). Effect of clothing pressure on the tightness sensation of girdles. *International Journal of Clothing Science and Technology, 14*(2), 100-110.

Chapman, W. L., Bahill, A. T., & Wymore, A. W. (1992). *Engineering modeling and design.* Boca Raton, FL: CRC Press.

Chaudhuri, S. (2013). Hanes to Buy Maidenform for $575 Million. Deal Unites Two Makers of Intimate Apparel, a 'Natural Fit'. *The Wall Street Journal.* Retrieved April 26, 2016 from http://www.wsj.com/articles/SB10001424127887323610704578625452582620188.

Chen, C. M., LaBat, K., & Bye, E. (2010). Physical characteristics related to bra fit. *Ergonomics*, *53*(4), 514-524.

Chen, D., Liu, H., Zhang, Q., & Wang, H. (2013). Effects of mechanical properties of fabrics on clothing pressure. *Przegląd Elektrotechniczny, 89*(1b), 232-235.

Chen, Z. G. (2011). The Measurement and Analysis of Clothing Pressure. *Advanced Materials Research, 332,* 1176-1179.

Choi, S., & Ashdown, S. (2011). 3d body scan analysis of dimensional change in lower body measurements for active body positions. *Textile Research Journal 81*(1), 81–93.

Chow, D. H., Kwok, M. L., Cheng, J. C., Lao, M. L., Holmes, A. D., Au-Yang, A., ... & Wong, M. S. (2006). The effect of backpack weight on the standing posture and balance of schoolgirls with adolescent idiopathic scoliosis and normal controls. *Gait & Posture*, *24*(2), 173-181.

Chrisler, J. C. (2013). Womanhood is not as easy as it seems: Femininity requires both achievement and restraint. *Psychology of Men and Masculinity. 14*(2), 117-120.

Cobb, J. R. (1948). Outline for the study of scoliosis. In Instructional Course Lectures, *The American Academy of Orthopaedic Surgeons. 5,* 261-275.

Danielsson, A. J., Romberg, K., & Nachemson, A. L. (2006). Spinal range of motion, muscle endurance, and back pain and function at least 20 years after fusion or brace treatment for adolescent idiopathic scoliosis: a case-control study. *Spine, 31*(3), 275-283.

DeJonge, J. O. (1984). Forward: the design process. In S. M. Watkins (Ed.), *Clothing: The portable environment*. (pp. vii-xiii). Ames, IA : Iowa State University Press.

DeLong, M. R. (1998). *The way we look: Dress and aesthetics*. New York, NY: Fairchild.

De Rossi, D., Carpi, F., Lorussi, F., Mazzoldi, A., Paradiso, R., Scilingo, E. P., & Tognetti, A. (2003). Electroactive fabrics and wearable biomonitoring devices. *AUTEX Research Journal*, *3*(4), 180-185.

Dixon, J. R. (1966). *Design engineering: Inventiveness, analysis and decision making.* New York, NY: McGraw-Hill.

Dolan, L. A., & Weinstein, S. L. (2007). Surgical rates after observation and bracing for adolescent idiopathic scoliosis: an evidence-based review. *Spine, 32*(19), 91-100.

Douty, H. I. (1954). Objective figure analysis. *Journal of Home Economics, 46*(1), 24-26.

Douty, H. I. (1968a). Visual somatometry in health related research. *Journal of Alabama Academy of Science, 39*(1), 21-24.

Douty, H. I. (1968b). *Silhouette photography for the study of visual somatometry and body image.* National Textile and Clothing Meeting, Minneapolis, MN.

Douty, H. I. (1968c). *Visual somatotmetry-A basic research method for analysis of gross characteristics of the human organism.* Paper presented at the American Home Economics Association Convention, Research Station, Minneapolis, MN.

Dunne, L. E., Walsh, P., Hermann, S., Smyth, B., & Caulfield, B. (2008). Wearable monitoring of seated spinal posture. *IEEE Transactions on Biomedical Circuits and Systems*, *2*(2), 97-105.

Dworkin, B., Miller, N. E., Dworkin, S., Birbaumer, N., Brines, M. L., Jonas, S., ... & Graham, J. J. (1985). Behavioral method for the treatment of idiopathic scoliosis. *Proceedings of the National Academy of Sciences: Vol 82.* (pp. 2493-2497).

Edmison, J., Jones, M., Nakad, Z., & Martin, T. (2002). *Using piezoelectric materials for wearable electronic textiles. Proceedings of the 6th International Symposium on Wearable Computers, USA.*

Eisenstein, S. (1976). Measurements of the lumbar spinal canal in 2 racial groups. *Clinical Orthopaedics and Related Rresearch, 115,* 42-46.

Engh, L., Fall, M., Hennig, M., & Söderlund, A. (2003). Intra-and inter-rater reliability of goniometric method of measuring head posture. *Physiotherapy Theory and Practice, 19*(3), 175-182.

Entwistle, J. (2000). *The Fashioned Body: Fashion, Dress and Modern Social Theory.* Malden, MA: Polity press.

Fan, J., & Chan, A. P. (2005). Prediction of girdle's pressure on human body from the pressure measurement on a dummy. *International Journal of Clothing Science and Technology, 17*(1), 6-12.

Farringdon, J., Moore, A. J., Tilbury, N., Church, J., & Biemond, P. D. (1999, October). Wearable sensor badge and sensor jacket for context awareness. *The Third International Symposium on Wearable Computers, San Francisco, California,* 107-113.

Fedorak, C., Ashworth, N., Marshall, J., & Paull, H. (2003). Reliability of the visual assessment of cervical and lumbar lordosis: how good are we?. *Spine, 28*(16), 1857-1859.

Fisher, S.V. (1990). *Spinal orthoses.* In Kottke, F.J. & Lehmann, J.F. (4th ed.). Krusen's Handbook of Physical Medicine and Rehabilitation. Philadelphia, PA: W.B. Saunder Company, Harkcourt Brace Jovanovich, In. 593-601

Fortin, C., Feldman, D. E., Cheriet, F., & Labelle, H. (2010). Validity of a quantitative clinical measurement tool of trunk posture in idiopathic scoliosis. *Spine, 35*(19), E988-E994.

Francis, P. (1999). *Applied anatomy and kinesiology,* Supplemental materials. KB Books. 19-25.

Fraser, L. (2009). The inner corset: A brief history of fat in the United States. *The Fat Studies Reader*, 11-14.

Frontera W. R., Silver, J. K., & Rizzo, T.D. (2008). *Essentials of physical medicine and rehabilitation:Musculoskeletal disorders, pain, and rehabilitation.* Philadelphia, PA: Saunders.

Gatward, N. (2007). Anorexia nervosa: An evolutionary puzzle. *European Eating Disorders Review, 15*(1), 1-12.

Giele, H. P., Liddiard, K., Currie, K., & Wood, F. M. (1997). Direct measurement of cutaneous pressures generated by pressure garments. *Burns*, *23*(2), 137-141.

Gilbert, P., Price, J., & Allan, S. (1995). Social comparison, social attractiveness and evolution: How might they be related?. *New Ideas in Psychology*, *13*(2), 149-165.

Gilman, S. L. (2014). "Stand Up Straight": Notes Toward a History of Posture. *Journal of Medical Humanities*, *35*(1), 57-83.

Goh, S., Price, R. I., Leedman, P. J., & Singer, K. P. (1999). Rasterstereographic analysis of the thoracic sagittal curvature: a reliability study. *Journal of Musculoskeletal Research, 3*(2), 137-142.

Gordon, C. C., Churchill, T., Clauser, C. E., Bradtmiller, B., & McConville, J. T. (1989). *Anthropometric survey of US army personnel: methods and summary statistics 1988*. Retrieved from file:///C:/Users/Administrator/Downloads/ADA225094.pdf.

Gupta, D. (2011). Design and engineering of functional clothing. *Indian Journal of Fibre and Textile Research, 36*(4), 327.

Gupta, D., & Zakaria, N. (Eds.). (2014). *Anthropometry, apparel sizing and design.* Waltham, MA: Woodhead Publishing.

Gwosdow, A. R., Stevens, J. C., Berglund, L. G., & Stolwijk, J. A. J. (1986). Skin friction and fabric sensations in neutral and warm environments. *Textile Research Journal*, *56*(9), 574-580.

Harman, E., Hoon, K., Frykman, P., & Pandorf, C. (2000). *The effects of backpack weight on the biomechanics of load carriage* (No. USARIEM-T00-17). Retrieved from file:///C:/Users/Administrator/Downloads/ADA377886%20(1).pdf.

Harries, C. A., & Pegg, S. P. (1989). Measuring pressure under burns pressure garments using the oxford pressure monitor. *Burns*, *15*(3), 187-189.

Hart, D. L., & Rose, S. J. (1986). Reliability of a noninvasive method for measuring the lumbar curve*. *Journal of Orthopaedic & Sports Physical Therapy, 8*(4), 180-184.

Harumi, M., Miyuki, N., Hideo, M., & Kiyokazu, K. (2001). Effects of clothing pressure exerted on a trunk on heart rate, blood pressure, skin blood flow and respiratory function. *Journal of the Textile Machinery Society of Japan, 54*(2), 57-62.

Hickey, E. R., Rondeau, M. J., Corrente, J. R., Abysalh, J., & Seymour, C. J. (2000). Reliability of the cervical range of motion (CROM) device and plumb-line techniques in measuring resting head posture (RHP). *Journal of Manual & Manipulative Therapy, 8*(1), 10-17.

Horn, M. J., & Gurel, L. M. (1981). *The second skin* (3rd ed.). Boston. MA: Houghton Mifflin Company

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

Hutchinson, R., & Munden, D.L. (1978). The geometrical requirements of patterns for women's garments to achieve satisfactory fit: Part 1. *Clothing Research Journal, 6*(2), 68–88.

Hutton, G., Bayley, M., Broadhead, M., & Knox, A. (2002). Shape analysis for apparel applications and methods. *Proceedings of the Numerisation 3D Scanning, France.*

Ireland, R. D., Hoskisson, R. E., & Hitt, M. A. (2010). *Strategic Management: Concepts: Competitiveness and Globalization.* Stanford, CT: Cengage Learning.

Jackson, R. P., Kanemura, T., Kawakami, N., & Hales, C. (2000). Lumbopelvic lordosis and pelvic balance on repeated standing lateral radiographs of adult volunteers and untreated patients with constant low back pain. *The Spine Journal, 25*(5), 575-586.

Jones, N., & Guilbault, L. (2014, January 27). *Shapewear stands out.* Retrieved from http://www.magiconline.com/news/shapewear-stands-out.

Kendall, F. P., McCreary, E. K., Provance, P. G., Rodgers, M. M., & Romani, W. A. (2005). *Muscles: Testing and function with posture and pain* (5th ed.). Baltimore, MD: Lippincott Williams & Wilkins.

Kenins, P. (1994). Influence of fiber type and moisture on measured fabric-to-skin friction. *Textile Research Journal*, *64*(12), 722-728.

Knight, J. F., Bristow, H. W., Anastopoulou, S., Baber, C., Schwirtz, A., & Arvanitis, T. N. (2007). Uses of accelerometer data collected from a wearable system. *Personal and Ubiquitous Computing*, *11*(2), 117-132.

Koberg, D., & Bagnall, J. (1981). *The universal traveler: A soft-systems approach to creativity, problem solving and the process of reaching goals.* Lost Altos, CA: William Kaufmann.

Kouwenhoven, J. W. M., & Castelein, R. M. (2008). The pathogenesis of adolescent idiopathic scoliosis: review of the literature. *Spine, 33*(26), 2898-2908.

Kraemer, W. J., Bush, J. A., Triplett-McBride, N. T., Koziris, L. P., Mangino, L. C., Fry, A. C., ... & Gómez, A. L. (1998). Compression Garments: Influence on Muscle Fatigue. *The Journal of Strength & Conditioning Research, 12*(4), 211-215.

Kraemer, W. J., Bush, J. A., Wickham, R. B., Denegar, C. R., Gomez, A. L., Gotshalk, L. A., ... & Sebastianelli, W. J. (2001a). Continuous compression as an effective therapeutic intervention in treating eccentric-exercise-induced muscle soreness. *Journal of Sport Rehabilitation, 10*(1), 11-23.

Kraemer, W. J., Bush, J. A., Wickham, R. B., Denegar, C. R., Gómez, A. L., Gotshalk, L. A., ... & Sebastianelli, W. J. (2001b). Influence of compression therapy on symptoms following soft tissue injury from maximal eccentric exercise. *Journal of Orthopaedic & Sports Physical Therapy, 31*(6), 282-290.

Kraemer, W. J., Flanagan, S. D., Comstock, B. A., Fragala, M. S., Earp, J. E., Dunn-Lewis, C., ... & Powell, M. D. (2010). Effects of a whole body compression garment on markers of recovery after a heavy resistance workout in men and women. *The Journal of Strength & Conditioning Research, 24*(3), 804-814.

Kraemer, W. J., Volek, J. S., Bush, J. A., Gotshalk, L. A., Wagner, P. R., Gomez, A. L., ... & Selle, B. J. (2000). Influence of compression hosiery on physiological responses to standing fatigue in women. *Medicine and Science in Sports and Exercise, 32*(11), 1849-1858.

LaBat, K. L. L. (1987). *Consumer satisfaction/dissatisfaction with the fit of ready-to-wear clothing* (Doctoral dissertation, University of Minnesota).

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

LaBat, K. L., & Sokolowski, S. L. (1999). A three-stage design process applied to an industry-university textile product design project. *Clothing and Textiles Research Journal*, *17*(1), 11-20.

Lafond, D., Descarreaux, M., Normand, M. C., & Harrison, D. E. (2007). Postural development in school children: a cross-sectional study. *Chiropractic & Manual Therapies*, *15*(1), 1.

Lee, M. J. (2012). Theses: Basic Research on the Development of Skinny Jean Pants for Korean Women in Their 20s+. *Journal of Fashion Business*, *16*(6), 160-173.

Lee, S. W., & Mase, K. (2002). Activity and location recognition using wearable sensors. *IEEE Pervasive Computing*, *1*(3), 24-32.

Lee, Y. A., Hyun, K. J., & Tokura, H. (2000). The effects of skin pressure by clothing on circadian rhythms of core temperature and salivary melatonin. *Chronobiology International*, *17*(6), 783-793.

Leech, D. J. (1972*). Management of engineering design.* London, England: Wiley & Sons.

Leung, W. Y., Yuen, D. W., Ng, S. P., & Shi, S. Q. (2010). Pressure prediction model for compression garment design. *Journal of Burn Care & Research*, *31*(5), 716-727.

Lewis, J. S., & Valentine, R. E. (2007). The pectoralis minor length test: a study of the intra-rater reliability and diagnostic accuracy in subjects with and without shoulder symptoms. *BMC Musculoskeletal Disorders*, *8*(1), 64.

Lewis, W. P., & Samuel, A. E. (1989). *Fundamentals of engineering design.* New York, NY: Prentice Hall.

Li, J. X., & Hong, Y. (2004). Age difference in trunk kinematics during walking with different backpack weights in 6- to 12-year-old children. *Research in Sports Medicine*, *12*(2), 135-142.

Li, L., & Weiyuan, Z. (2007, August). Using 3D Body Scans for Shaping Effects Testing Developed by Foundation Garment. *8th International Conference on Electronic Measurement & Instruments, China*.

Li, Y. (2001). The science of clothing comfort. *Textile Progress*, *31*(1-2), 1-135.

Lissoni, A., Caimmi, M., Rossini, M., & Terenghi, L. (2001). Three-dimensional analysis of the sitting posture. *European Journal of Physical and Rehabilitation Medicine*, *37*(2), 101.

Liu, H., Chen, D., Wei, Q., & Pan, R. (2013). An investigation into the bust girth range of pressure comfort garment based on elastic sports vest. *Journal of the Textile Institute*, *104*(2), 223-230.

Loguidice, V., Mahoney, C. B., Haldeman, J., & Andersson, G. B. (2005). Clinical experience with a pneumatic vest-unloading the spine in the upright posture. *Journal of Musculoskeletal Research*, *9*(2), 65-69.

Lou, E., Lam, G. C., Hill, D. L., & Wong, M. S. (2012). Development of a smart garment to reduce kyphosis during daily living. *Medical & Biological Engineering & Computing*, *50*(11), 1147-1154.

Loukos, I., Zachariou, C., Nicolopoulos, C., Korres, D., & Efstathopoulos, N. (2011). Analysis of the corrective forces exerted by a dynamic derotation brace (DDB). *Prosthetics and Orthotics International*, *35*(4), 365-372.

Lusskin, R. , & Berger, N. (1975). *Prescription principles.* In: Atlas of orthotics: Biomechanical principles and application. American Academy of Orthopedic Surgeons. St Louis: Mosby Company. 370-372 .

Lyu, S. (2015). *U.S. Non-Provisional Patent Application No. 14/924,261*.Washington, DC: U.S. Patent and Trademark Office.

Macintyre, L., & Baird, M. (2006). Pressure garments for use in the treatment of hypertrophic scars—a review of the problems associated with their use. *Burns*, *32*(1), 10-15.

Mahaudens, P., Thonnard, J. L., & Detrembleur, C. (2005). Influence of structural pelvic disorders during standing and walking in adolescents with idiopathic scoliosis. *The Spine Journal, 5*(4), 427-433.

Mann, R., Yeong, E. K., Moore, M. L., & Engrav, L. H. (1997). A new tool to measure pressure under burn garments. *Journal of Burn Care & Research*, *18*(2), 159-163.

Mathie, M. J., Coster, A. C., Lovell, N. H., & Celler, B. G. (2004). Accelerometry: providing an integrated, practical method for long-term, ambulatory monitoring of human movement. *Physiological Measurement*, *25*(2), 1-20.

Mattmann, C., Amft, O., Harms, H., Troster, G., & Clemens, F. (2007, October). *Recognizing upper body postures using textile strain sensors.* 2007 11th IEEE International Symposium on Wearable Computers. Boston, MA.

McEvoy, M. P., & Grimmer, K. (2005). Reliability of upright posture measurements in primary school children. *BMC Musculoskeletal Disorders*, *6*(1), 35.

McRoberts, L. B. (2008). *The design and assessment of a soft structural prototype for postural alignment* (Doctoral dissertation. Florida State University).

McRoberts, L. B., Black, C. M., & Cloud, R. M. (2015). Evaluation of a Prototype Soft-Structured Thoracic Posture Support Garment. *Clothing and Textiles Research Journal, 34*(2), 143-158.

McRoberts, L. B., Cloud, R. M., & Black, C. M. (2013). Evaluation of the New York Posture Rating Chart for assessing changes in postural alignment in a garment study. *Clothing and Textiles Research Journal*, *31*(2), 81-96.

Medland, A. J. (1992). *The computer-based design process* (2nd ed.). London, England: Kogan Page.

Merkel, R. S. (1991). *Textile product serviceability*. Englewood Cliffs, NJ: Prentice Hall.

Middendorf, W. H. (1969). *Engineering design.* Boston, MA: Allyn and Bacon.

Million, R., Nilsen, K. H., Jayson, M. I., & Baker, R. D. (1981). Evaluation of low back pain and assessment of lumbar corsets with and without back supports. *Annals of the Rheumatic Diseases, 40*(5), 449-454.

Miyatsuji, A., Matsumoto, T., Mitarai, S., Kotabe, T., Takeshima, T., & Watanuki, S. (2002). Effects of clothing pressure caused by different types of brassieres on autonomic nervous system activity evaluated by heart rate variability power spectral analysis. *Journal of Physiological Anthropology and Applied Human Science, 21*(1), 67-74.

Morooka, H., Fukuda, R., Nakahashi, M., Morooka, H., & Sasaki, H. (2005). Clothing pressure and wear feeling at under-bust part on a push-up type brassiere. *Sen'i Gakkaishi, 61*(2), 53–58.

Nam, J. H., & Branson, D. H. (2012). Clothing textiles: Arm armor system performance study; net effect (perceptual response) analysis. *International Journal of Human Ecology, 13,* 117–128.

New York State Education Department (Division of Health, Physical Education and Recreation) (1958), *The New York Physical Fitness Test: A Manual for Teachers of PE.* New York, USA.

Ng-Yip, F. S. (1993). Medical clothing: a tutorial paper on pressure garments. *International Journal of Clothing Science and Technology, 5*(1), 17-24.

Norkin, C. C., & Levangie, P. M. (1992). *Joint Structure and Function: A Comprehensive Analysis* (2nd ed.) (p. 420). Philadelphia, PA: F.A. Davis.

Normand, M. C., Descarreaux, M., Harrison, D. D., Harrison, D. E., Perron, D. L., Ferrantelli, J. R., & Janik, T. J. (2007). Three dimensional evaluation of posture in standing with the PosturePrint: an intra-and inter-examiner reliability study. *Chiropractic & Manual Therapies, 15*(1), 15.

O'Brien, R., & Shelton, W. (1941). *Women's measurements for garments and pattern construction.* (Miscellaneous Publication No. 454) Washington, DC: U.S. Government Printing Office.

Perry, M., Smith, A., Straker, L., Coleman, J., & O'sullivan, P. (2008). Reliability of sagittal photographic spinal posture assessment in adolescents. *Advances in Physiotherapy*, *10*(2), 66-75.

Petrova, A., & Ashdown, S. (2008). Three-dimensional body scan data analysis. *Clothing and Textiles Research Journal, 26*(3), 227–252.

Pham, V. M., Houilliez, A., Schill, A., Carpentier, A., Herbaux, B., & Thevenon, A. (2008). Study of the pressures applied by a Chêneau brace for correction of adolescent idiopathic scoliosis. *Prosthetics and Orthotics International, 32*(3), 345-355.

Pithers, T. (2010). Shapewear for Men - "It's not a girdle, it's a guy-dle" retrieved August 20,2014, from http://styleforsuccess.com/blog/shapewear-for-men/.

Pownall, P. J., Moran, R. W., & Stewart, A. M. (2008). Consistency of standing and seated posture of asymptomatic male adults over a one-week interval: A digital camera analysis of multiple landmarks. *International Journal of Osteopathic Medicine*, *11*(2), 43-51.

Rasband, J. (2006). *Fabulous Fit.* New York, NY: Fairchild Publication.

Rhodes, M. (1996). Back in balance. *Women's Sports & Fitness*, *18,* 44-48.

Rubin, A. (2012). *Statistics for evidence-based practice and evaluation*. Belmont, CA: Cengage Learning.

Rutherford-Black, C., & Khan, S. (1995). Texas Tech police bicycle patrol: Encounter with a uniform. *Campus Law Enforcement Journal, 25*(1), 26-28.

Saladin, K. S., & McFarland, R. K. (2008). *Human anatomy* (2nd ed). New York, NY: McGraw-Hill.

Salleh, M. N., Acar, M., & Burns, N. D. (2011, April). *Pressure distribution model for pressure garments and its verification.* International Conference on Modeling, Simulation and Applied Optimization, Kuala Lumpur, Malaysia.

Silver, T., Fortenbaugh, D., & Williams, R. (2009). Effects of the bench shirt on sagittal bar path. *The Journal of Strength & Conditioning Research, 23*(4), 1125-1128.

Slater, K. (1985). *Human comfort.* Springfield, IL: Charles C. Thomas.

Smith, A., O'Sullivan, P., & Straker, L. (2008). Classification of sagittal thoraco-lumbo-pelvic alignment of the adolescent spine in standing and its relationship to low back pain. *Spine, 33*(19), 2101-2107.

Sone, Y., Kato, N., Kojima, Y., Takasu, N., & Tokura, H. (2000). Effects of skin pressure by clothing on digestion and orocecal transit time of food. *Journal of Physiological Anthropology and Applied Human Science, 19*(3), 157-163.

Sook Cho, Y., Komatsu, T., Takatera, M., Inui, S., Shimizu, Y., & Park, H. (2006). Posture and depth adjustable 3D body model for individual pattern making. *International Journal of Clothing Science and Technology, 18*(2), 96-107.

Sprigle, S., Flinn, N., Wootten, M., & McCorry, S. (2003). Development and testing of a pelvic goniometer designed to measure pelvic tilt and hip flexion. *Clinical Biomechanics, 18*(5), 462-465.

Sprigle, S., Wootten, M., Bresler, M., & Flinn, N. (2002). Development of a noninvasive measure of pelvic and hip angles in seated posture. *Archives of Physical Medicine and Rehabilitation, 83*(11), 1597-1602.

Steele, V. (2001). *The corset: A cultural history.* New Haven, CT: Yale University Press.

Straker, L., Burgess-Limerick, R., Pollock, C., Murray, K., Netto, K., Coleman, J., & Skoss, R. (2008). The impact of computer display height and desk design on 3D posture during information technology work by young adults. *Journal of Electromyography and Kinesiology, 18*(2), 336-349.

Sypeck, M. F., Gray, J. J., Etu, S. F., Ahrens, A. H., Mosimann, J. E., & Wiseman, C. V. (2006). Cultural representations of thinness in women, redux: Playboy magazine's depiction of beauty from 1979 to 1999. *Body Image, 3*(3), 229-235.

Tarafder, N., & Chatterjee, S.M. (1994). Techniques of measurement of fabric comfort. *Textile Trends India, 37*(5), 33-39.

Tate, S., & Shafer, M. (1982). *The complete book of fashion illustration.* New York, NY: Harper & Row.

Tognetti, A., Lorussi, F., Bartalesi, R., Quaglini, S., Tesconi, M., Zupone, G., & De Rossi, D. (2005). Wearable kinesthetic system for capturing and classifying upper limb gesture in post-stroke rehabilitation. *Journal of NeuroEngineering and Rehabilitation, 2*(1), 8.

Türker, K. S. (1993). Electromyography: some methodological problems and issues. *Physical Therapy, 73*(10), 698-710.

Yu, W., Fan, J. T., & Qian, X. M. (2004). A soft mannequin for the evaluation of pressure garments on human body. *Sen.i Gakkaishi, 60*(2), 57-64.

Van den Hout, J. A. A. M., Van Rhijn, L., Van den Munckhof, R., & Van Ooy, A. (2002). Interface corrective force measurements in Boston brace treatment. *European Spine Journal, 11*(4), 332-335.

Verbeek, M. (2008). *A guide to modern econometrics* (3rd ed.). West Sussex, England: John Wiley & Sons.

Vincent, J. F., Bogatyreva, O. A., Bogatyrev, N. R., Bowyer, A., & Pahl, A. K. (2006). Biomimetics: its practice and theory. *Journal of the Royal Society Interface*, *3*(9), 471-482.

Wang, Y. J., Mok, P. Y., Li, Y., & Kwok, L. (2010). *Analysis of lower limb measurements in running progress for high-performance slacks design.* In W. Karwowski, & G. Salvendy (Eds.), Advances in Human Factors, Ergonomics, and Safety in Manufacturing and Service Industries. (pp. 210-221). Florida, FL: CRC Press.

Watkins, S. M. (1988). Using the design process to teach functional apparel design. *Clothing and Textiles Research Journal*, *7*(1), 10-14.

Western, J. W., Rhodes, J., & Stevenson, K. (December 2002). Tips for avoiding neck pain. *Welding Journal, 81*(12), 36-39.

Wong, W. Y., & Wong, M. S. (2008) Smart garment for trunk posture monitoring: a preliminary study. *Scoliosis, 3*(7), 1748–1761.

Zhang, X., Yeung, K. W., & Li, Y. (2002). Numerical simulation of 3D dynamic garment pressure. *Textile Research Journal*, *72*(3), 245-252.

Appendix A. Posture Correctors Currently on the Market

1. **URgreat®.** Retrieved November 19, 2014, from http://www.ebay.com/itm/Therapy-Back-Posture-Corrector-Shoulder-Support-Brace-Straightener-Black-360-/281131015961.

The garment has a waist band which provides support for the abdominals and straightens the back and pulling belt which balances the vertebrae pushing them back in to their natural position, throws chest forward, pulls back into a straighter position and shoulder straps which draw shoulders back correcting 'desk slump' otherwise known as upper cross syndrome. Non-stretchable and elastic materials are used together.

2. **Mabis DMI®.** Retrieved November 19, 2014, from http://www.metromedicalonline.com/dmi632622.html#.VG10vouG-카.

The device claims that it is designed to restore posture and reduce back strain. It is made with reinforced, crisscross (X-shape) foam bands for back support. The fabric of this posture brace is cotton and Lycra® blend and the hook and loop (Velcro®) adjusts for a custom fit.

3. **Tonus elast®.** Retrieved November 19, 2014, from http://www.ebay.com/itm/Medical-Lower-Back-Posture-corrector-with-rigid-inserts/261600977631?_trksid=p2047675.c100009.m1982&_trkparms=aid%3D777000%26algo%3DABA.MBE%26ao%3D1%26asc%3D27538%26meid%3D7f75122849464214aaff0d4c2ba25320%26pid%3D100009%26prg%3D11353%26rk%3D1%26rkt%3D4%26.

It is a medical lower back posture corrector with stiff insets for prevention and elimination of fault in posture and spinal curvature. It is recommended for correction and acquiring skills in maintaining normal physiological posture. Composition of raw materials: 30% polyester, 25% polyurethane foam, 20% latex, 15% cotton, 10% nylon, and 10% Velcro® fastener.

4. **LHJM®.** Retrieved November 19, 2014, from http://www.weiku.com/products/10396066/Dorsal_Lumbar_Back_Brace.html.

Rigid aluminum uprights and pelvic bar limit spine flexion, extension, and lateral bending to provide intra-abdominal pressure against spinal instability.

5. **Soft FormÂ®.** Retrieved November 19, 2014, from http://www.amazon.com/Posture-Control-Brace-Support--Extra/dp/B00L4IPRTQ/ref=sr_1_4?s=hpc&ie=UTF8&qid=1416460840&sr=1-4&keywords=soft+form.

The device claims that it is designed to correct poor posture by gently pulling the shoulders back and holding them in the proper position. Elastic side panels provide support compression to stabilize the abdominal and lumbar regions for improved posture and alignment. Two bendable aluminum stays provide additional support and can be removed and shaped to contour the back. The X-shape band design in the back allows for adjustability.

6. **Neo-G®.** Retrieved November 19, 2014, from http://www.amazon.com/Medical-Grade-Dorsolumbar-Lower-Support/dp/B003XRNZQ8/ref=pd_sbs_hpc_4?ie=UTF8&refRID=0D6MT0Q7XASHY676SBA3

The device claims that it is designed to support and reduce an early thoracic kyphosis by encouraging correct alignment of the dorsal and lumbar spine. The firm yet flexible stays along with the anatomical design help provide added support to muscles, ligaments and tendons.

Appendix B. Academic Search

1. Laiyuenyi, H. (2011). *Final Year Project Development of Body Shaper for Improvement of Hunchback* (Bachelor thesis, Hong Kong Polytechnic University).

A shapewear prototype for upper torso support was developed in this study. The under-bust type body shaper claims thoracic region improvement and an underarm flesh control effect.

2. McRoberts, L. B. (2008). *The design and assessment of a soft structural prototype for postural alignment* (Doctoral dissertation, Florida State University).

This study developed and tested a soft structural posture support garment for thoracic region spine improvement. The prototype was created to be similar to a sports bra or fitted tank for upper torso support.

Appendix C. Patent Search

1. Balit, R. (1999). *U.S. Patent No. 5,996,120*. Washington, DC: U.S. Patent and Trademark Office.

This invention was disclosed as a swimsuit comprising an outer garment and an inner liner, wherein the inner liner is joined to the outer garment. It claims that the symmetrical T-shaped anchor portions on the hip region have a tendency to be pulled to each other, thus facilitating the lifting and shaping of buttock regions into a naturally looking form. The designs of this invention are substantially different to the PMSS design in this study and this patent invention focused on body bulges support smoothing rather than posture.

2. Jack, I. (1948). *U.S. Patent No. 2,443,316*. Washington, DC: U.S. Patent and Trademark Office.

This invention was designed to embrace the lower part of the body of the wearer, said girdle beginning at the waist line and extending downward to embrace the hips, abdomen and buttocks, an upper portion secured to and rising from the waist line of the girdle and extending upward over the back of the wearer. The biggest difference between this invention and the PMSS design is the absence of the front torso panel in this invention. Hence, it might be hard to support the overall torso effectively. Although it claims to provide some posture support elements, the support strap designs and the torso panel structure compared to the PMSS design in this study are quite a bit different.

3. Krawchuk, T. (2013). *U.S. Patent No. 8,549,763*. Washington, DC: U.S. Patent and Trademark Office.

This invention was designed for lower lift, upper lift and suspender support by being equipped with posture support bands in the foundation garment. This invention claims to prevent disorders associated with insufficient breast support and poor posture of the upper body. The posture support band designs are different with the PMSS design in this study; the support band width in this patent invention may be thinner and the design elements are much more complicated.

4. Ledyard, S. D. (2008). *U.S. Patent No. 7,395,557*. Washington, DC: U.S. Patent and Trademark Office.

A seamless women's upper body garment comprising a circumferential band below the bust line and dorsal and ventral vertical support panels was developed. The posture support elements including material selections and support element designs are differently structured by knitting compared to the PMSS design in this study.

5. Noel, K. (2013). *U.S. Patent No. 8,425,275*. Washington, DC: U.S. Patent and Trademark Office.

A bodysuit shapewear garment comprising a posture support element for upper body support was developed. This invention claims a body support for upper torso region by inserting firm-level support element to the inside back of the bodysuit, especially shoulder blades region. The posture support elements are differently designed and it claims different body support regions compared to the PMSS design in this study.

6. Sakamoto, A., Sudo, M. & Umemoto, M. (2010). *U.S. Patent Application 13/318,156*.

An upper body posture support garment equipped with a belt having a straining force stronger than that of the main body section was developed. This invention claims particularly the improvement of the spinal curvature and smooth body bulges of the lower abdomen region. The X-shape support system is similar to the PMSS design in this study but the placement of the bands and the overall support system design are different.

7. Sano, M. (1997). *U.S. Patent No. 5,699,559*. Washington, DC: U.S. Patent and Trademark Office.

A shape suit comprising a body formed by sewing together a front body and a back body with two stretchable bands was developed. This invention claims that these bands have a dual purpose in accordance with usage thereof; when the front body is provided with the stretchable bands in an X-shaped arrangement, the stretchable bands lift superfluous flesh on the waist region while the stretchable back bands lift superfluous flesh on opposite sides of the buttocks when the back body is provided with the stretchable bands in an X-shaped arrangement. Although, this invention has X-shape support bands, placement of the bands, material selection, and the band designs are different compared to the PMSS design in this study; in this patent invention, the support bands might be much wider and less stable on the back because of no stitches on the bands with the garment together.

8. Yoshihara, H. (1987). *U.S. Patent No. 4,698,847*. Washington, DC: U.S. Patent and Trademark Office.

A swimsuit having an inner liner of stretchable and resilient fabric was developed. This invention claims that the control panels are preferably located on the abdomen and both upper rear hip regions of the inner liner for encasing at least a portion of a person's torso, including the abdomen, hips and rear regions. Although the inventions are designed on the purpose of posture support, the support system is differently designed compared to the PMSS design in this study.

Appendix D. Market Search

1. **Leonisa®.** Retrieved November 19, 2014, from http://www.leonisa.com/en/.

The company has developed some posture support shapewear garments having X-shape bands over the shoulder or upper back region.

2. **Invisupport®.** Retrieved November 19, 2014, from https://www.cassandco.com/invisupport/.

This company has developed some shapewear garments with invisible support system with garment gauge changes on the back torso. The products claim eliminating bulges above the panty line and posture modification.

3. **Braologie®.** Retrieved November 19, 2014, from http://www.braologie.com/

The company has developed some posture lingerie including shapewear and bra. The products having X-shape bands on the back torso lining claim posture and body shape improvement.

4. **Instant figure ®.** Retrieved November 19, 2014, from http://m.instantfigure.com/Shapewear/posture-support-crop-top-curvy.

The company has developed an upper torso bra claims a posture support and enhance body line.

5. **Cortland®.** Retrieved November 19, 2014, from http://www.amazon.com/Cortland-Longline-Posture-Bra/dp/B003LY0BG0/ref=pd_sim_sbs_a_5?ie=UTF8&refRID=18TXE8GG6YB4TJAP757P.

The company has developed some posture lingerie having X-shape bands on the upper torso. The products claim to straighten the upper back, reduce shoulder strain, and help with back pain.

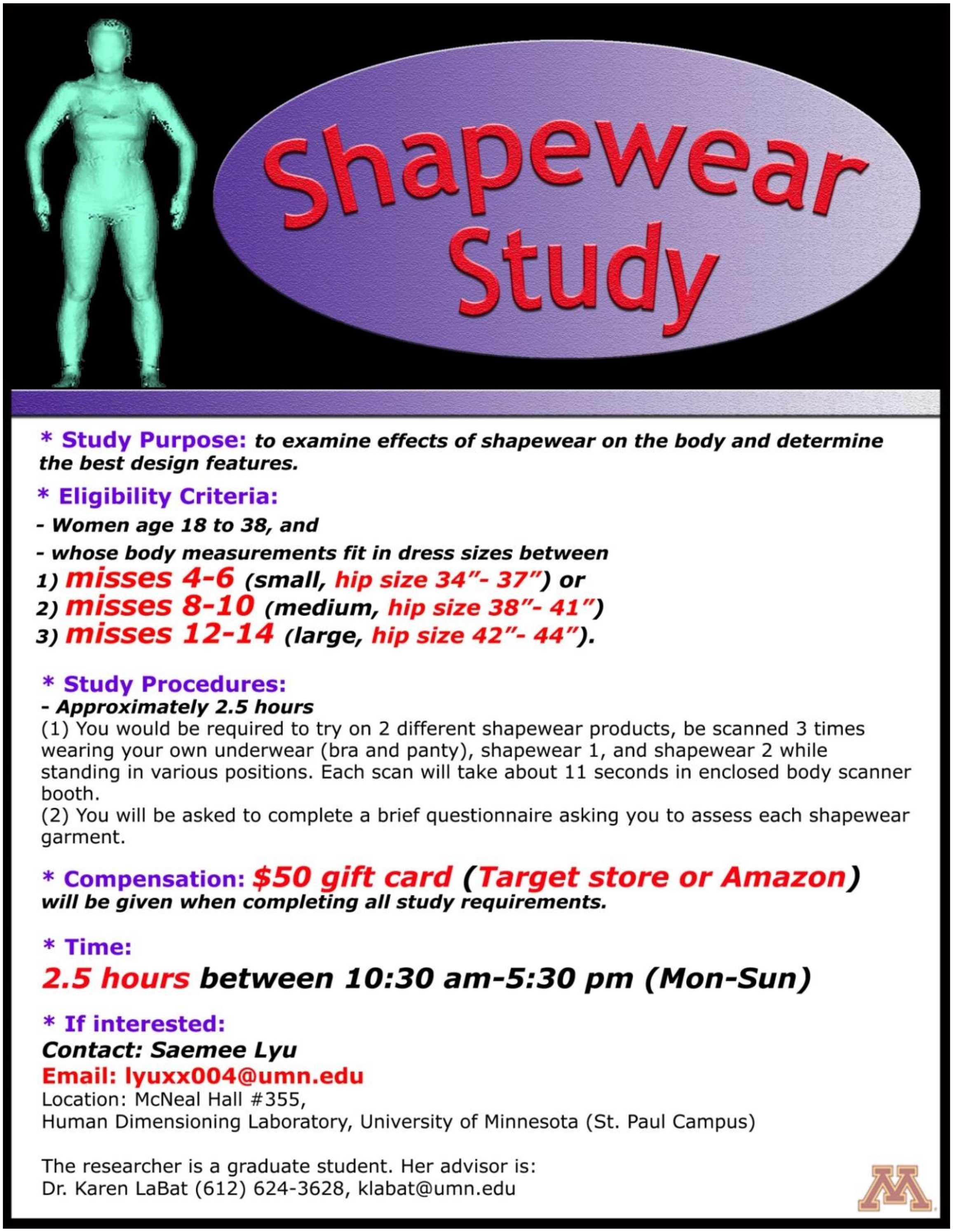
6. **Dare to flaunt®.** Retrieved November 19, 2014, from http://daretoflaunt.co.nz/index.php?route=product/product&path=61_89&product_id =1467.

The company has developed a tank type shapewear garment covering overall torso with X-shape bands on the back torso. The product claims that it pulls the shoulders down and supports back.

7. **Creation shapewear®.** Retrieved November 19, 2014, from http://www.creationshapewear.com/back_support_4018.htm.

The company has developed some types of posture modification shapewear garments having X-shape bands on the upper torso of the garment. The product claims maintaining proper back posture.

Appendix E. Recruiting Flyer



Appendix F. Recruiting Email

Seeking Participants for Shapewear Study

We are currently conducting a study of “shapewear”. The purpose of this study is to examine effects of shapewear on the body and determine the best design features.

We would appreciate your help by participating in this study. We're particularly interested in finding participants, 18 to 38 years old women with 1) Small, dress size 4 to 6 (hip size approximately 34” to 37”) or 2) Medium, dress size 8 to 10 (hip size approximately 38” to 41”) or 3) Large, dress size 12 to 14 (hip size approximately 42” to 44”).

If you are eligible to participate in this study, you would be required to try on 2 different shapewear products, be scanned 3 times wearing your own underwear (bra and panties), shapewear 1, and shapewear 2 while standing in various positions. The body scanner in the Human Dimensioning© Lab on St. Paul Campus of the University of Minnesota is used to capture a visual 3D image of a person and to quickly determine body measurements. The scanner captures topical measurements and the process takes 11 seconds. You will be able to see your image and may have a copy of your body measurements. After 3D scanning in each wearing condition, you will be asked to complete a brief questionnaire asking you to assess each shapewear garment. The full study will take approximately two and a half hours and you will be given a $50 gift card on completion of the study.

If you are interested in this study, please email me (lyuxx004@umn.edu) ☺ and if you know of anyone who fits the size categories, please feel free to forward this email to them.

Appendix G. Protocol

1. The flyer (Appendix E) was posted in the buildings at the University of Minnesota and faculty was asked to announce the study in class by handing out flyers to students or post the flyer on the class board electronically on the Moodle site.

2. Volunteers were sent an email (Appendix F) briefly describing the purpose, process and requirement of the study to make an appointment for the study.

3. If they were willing to participate and fit within the sample needs, they were asked to come to the Human Dimensioning© Lab at the University of Minnesota.

4. When volunteers arrived for the study at the Human Dimensioning© Lab, they heard the purpose of this study and the pre-scan procedure that they will be scanned one time in their own underwear to determine eligibility (body measurements).

5. The volunteers were instructed to remove street clothes, leaving on only their bra/panties and remove jewelry, accessories, and glasses and tie their hair back, etc. A robe was given to volunteers and they asked to put on a robe when the study procedure except for scanning procedure.

6. Volunteers were scanned one time in her own underwear in the standard anatomical position.

7. After scanning, they were asked to wait for 5 minutes by seating on a chair.

8. If volunteers met the sampling requirement (Appendix E and Appendix F), they were asked to read over the consent form and then sign the consent form: study consent

form (Appendix H). If volunteers didn't meet the sampling requirements, they heard their body measurements with the sampling criteria and were asked if they want to take a look at their scan images and 3D body measurements. After then, they were asked to get dressed and finish the test.

9. If they signed on the consent form, they were asked to complete a questionnaire with background information and experience wearing shapewear (Appendix L)

10. After the questionnaire was completed, the participants were weighed wearing their own underwear without the robe.

11. The participants were landmarked with a big earring back (1 cm for diameter and height respectively) on both shoulder points (acromion) and the center back neck point (cervicale) using a both-sided tape (Appendix I).

12. Waist and hip circumferences were measured on the participants' bodies using a tape measure.

13. The participants were given a brief overview of positions they were asked to perform (Appendix J) while viewing images of the positions (Appendix K).

14. The participant will be guided to the scan booth and told to place their feet in foot position device.

15. The participant will be given a brief overview of scanning procedures:

    A. Each scan will last approximately 11 seconds so stand still, look forward, and breathe normally. You will need to hold the position without moving until you hear “Please Relax”.

B. Hands should always be slightly away from the body.

C. The lights will be out while the scan is taking place.

16. After the preparation, participants were scanned. Once the scan is checked for accuracy, the subject may be rescanned if necessary. The protocol was repeated on each participant in each wearing condition.

17. After each position was successfully scanned in no shapewear condition, the robe was provided for the participants and they asked to return to the main room and take a 5-misute break. During the break, captured scan views in no shapewear were made for questionnaires (anterior, posterior, lateral-right side, horizontal view at the top).

18. After 5 minutes, participants put on one of the shapewear products. It was randomly assigned (WOC shapewear without the PMSS/ISG shapewear with the PMSS).

19. Before scanning, some garment dimensions were measured on the participant’s body using a tape measure and the tape measuring procedures were repeated for each garment:

    A. Garment torso lengths at location of the PMSS soft materials (thoracic and lumbar regions, respectively)

    B. Garment torso diagonal lengths where the PMSS soft-materials placed diagonally from underarm to opposite side seam at upper hip level

    C. Waist circumference

20. After measuring, participants were scanned and the scanning procedures were

repeated for each garment.

21. After all scanning procedures were completed for each shapewear product, the participants were told to put the robe on and go over to the table in the main room.

22. In the main room, they were told to take a 10-minute break and get dressed during the break. The captured scan views in each shapewear were made during the break.

23. After the break, the participants were asked to complete a shapewear product evaluation questionnaire related to the shapewear product they tried on and were scanned in (questionnaire indicates the name of the shapewear garment as WOC or ISG). They were asked to provide their opinions about their scan as seen on the computer screen by comparing the scans in no shapewear versus the scans in the first shapewear they tried on (Appendix M).

24. After finished, they were asked to complete the second questionnaire by comparing the scans in no shapewear versus the scans in the second shapewear they tried on (Appendix M).

25. At completion of the process, participants were asked to choose a store of the $50 gift card (Target store or Amazon) and given the gift card. If the participant wanted to be given a Target store gift card, they were given a $50 gift card in person. While a $50 gift card was sent via email to participants who wanted to be given an Amazon gift card on the day of the test.

26. The participants were thanked for their participation.

Appendix H. Study Consent Form

You are invited to participate in a research study of shapewear products (compression type underwear garment). You were selected as a possible participant because you fit within our sample needs. We are expecting to demonstrate the effects of shapewear on the body and are seeking your input to improve shapewear designs. We ask that you read this form and ask any questions you may have before agreeing to be in the study.

Background Information

The purpose of this study is to examine effects of shapewear on body shape and to determine the best design features.

Procedures

If you agree to be in this study, you would be required to try on 2 different shapewear products, be scanned 3 times wearing: 1) your own underwear (bra and panties) only, 2) shapewear WOC, and 3) shapewear ISG in various positions. You will be asked to repeat the positions carrying a backpack, a shoulder/cross bag, and hand carrying for the carrying an item position (approximately 10% of your body weight). You will be asked to complete three questionnaires, one with basic demographic data and two assessing the shapewear products. The study will take approximately 2 hours and half or less of your time.

Risks and Benefits of Participating in the Study

The study poses minimal risks. The non-hazardous scanner uses a red-light laser that captures a 3 dimensional view of the human body and each scan will take approximately 11 seconds and 3D data will be kept confidential. Questions in the questionnaire will ask for your opinion, along with your concerns and desires. You may refuse to answer any question that may make you uncomfortable.

Compensation

A $50 gift card

Confidentiality

Research records will be kept in a secure, safe location and only researchers will have access to those materials. We will not share confidential information about you. 3D scan data and questionnaire answers will be kept confidential on the College of Design secure G drive. Final reports and presentations will not include any information that would identify a participant. Written permission will be secured.

Voluntary Nature of the Study

All participation in this study is voluntary. If you decide to participate in the study, you are welcome to refuse to answer any question or withdraw your participation at any time without affecting the aforementioned relationships.

Contacts and Questions

Any questions or comments you may have about this study may be directed to Saemee Lyu (lyuxx004@umn.edu, 612-624-9825) or Dr. Karen LaBat (klabat@umn.edu, 612-624-3628). Any questions you may have now or later are welcomed. If you have any questions or concerns about the study that you would like to discuss with someone other than Saemee Lyu or Dr. Karen LaBat, you are encouraged to contact the Research Subjects' Advocate Line, D528 Mayo, 420 Delaware Street SE, Minneapolis, MN 55455, or (612) 625-1650.

Participant

signature____Date________________

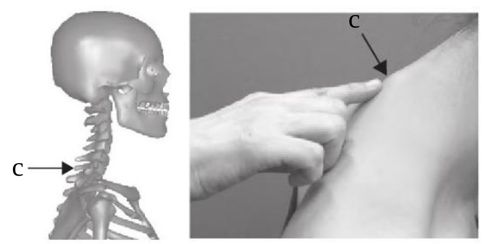
Investigator

signature_______________________________________Date________________

Appendix I. Landmarks for 3D Scan

The cervicale and the shoulder points referring to the designator with lower case letters in each figure:

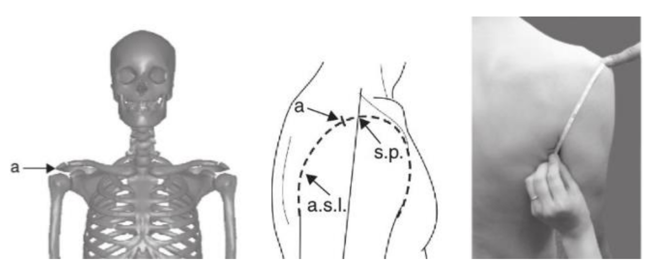
1. **Cervicale:** "The cervicale ("c" in the pictures**)** is the tip of the spinous process of the seventh cervical vertebra (A) and the tip of the spinous process of the seventh cervical vertebra is visible and easily palpated when the subject bends the head forward (B)" (Gupta & Zakaria, 2014).



(A) (B)

7^{th} cervical vertebra (Gupta & Zakaria, 2014)

2. **Shoulder point:** "The shoulder point ("s.p." in the pictures) is the crossing point of the armscye line (a.s.1.) and a line that bisects the antero-posterior diameter of the upper part of the upper arm (B). The armscye line (a.s.1.) is defined using a string which is placed under the arm of the subject abducting her arm approximately 30° referring to the acromiale which is the most lateral point a of the lateral edge of the acromial process of the scapula (C)." (Gupta & Zakaria, 2014)



(A) (B) (C)

Shoulder point (Gupta & Zakaria, 2014)

Appendix J. Position Directions

1. **Position 1 (P1):** Stand straight, with your feet shoulder width apart, elbows slightly bent and hands approximately 6” from your body.

2. **Position 2 (P2):** Carry the backpack, stand straight, with your feet shoulder width apart, elbows slightly bent and hands approximately 6” from your body.

3. **Position 3R (P3R):** Put the handbag strap (long length) on your right shoulder, stand straight, with your feet shoulder width apart, left elbow slightly bent and left hand approximately 6” from your body and right hand put on the handbag naturally.

4. **Position 3L (P3L):** Put the handbag strap (long length) on your left shoulder, stand straight, with your feet shoulder width apart, right elbow slightly bent and right hand approximately 6” from your body and the left hand put on the handbag naturally.

5. **Position 4R (P4R):** Put the handbag strap (long length) on your left shoulder to place the weight on your right hip, stand straight, with your feet shoulder width apart, left elbow slightly bent and left hand approximately 6” from your body and right hand put on the handbag naturally.

6. **Position 4L (P4L):** Put the handbag strap (long length) on your right shoulder to place the weight on your left hip, stand straight, with your feet shoulder width apart, right elbow slightly bent and right hand approximately 6” from your body and the left hand put on the handbag naturally.

7. **Position 5R (P5R):** Carry the handbag (short handles) with your right hand, stand straight, with your feet shoulder width apart, left elbow slightly bent and left hand

approximately 6” from your body.

8. **Position 5L (P5L):** Carry the handbag (short handles) with your left hand, stand straight, with your feet shoulder width apart, right elbow slightly bent and right hand approximately 6” from your body.

Appendix K. Participant 3D Scan Positions


Position 1


Position 2


Position 3R


Position 3L


Position 4R


Position 4L


Position 5R


Position 5L

Appendix L. Shapewear Study Questionnaire: Background Information

Today's date: ________________________

Name: ____________________________ Participant #: _________________________

Date of birth: ____

Email address: ____

Home address: ____

Phone: ____

Occupation: ____

Please describe your response or place an X in the box at the location that describes the best response.

1. Have you ever worn a shapewear garment?

   *Shapewear is defined as a foundation garment functionally designed to help wearers achieve a desired body shape which is slim and curvy or balanced posture for aesthetic purposes by providing clothing pressure (Pithers, 2010).

   ☐NO ☐YES

2. If NO, why not?

____

____

____

3. If YES, why?

____

____

____

4. If YES:

A. What types? (Check all that you have worn or currently wear)
*Figures have been retrieved from
http://www.spanx.com/shop/spanx/shapewear/cat-38-catid-tn_spx_sw

☐Mid-Thigh ☐High-Waist /Cincher ☐Camisole ☐Slip /Tank ☐Bodysuit

☐Others (describe any other product you've worn that you consider a product that changes your body shape.)

____

B. How often do you currently wear shapewear?

☐Everyday ☐Several times a week ☐For special occasions only

C. If your goal is to change your body shape when wearing a shapewear garment—which body areas or parts of the body do you want to change? Be as specific as possible.

____

____

____

D. How do you want these areas to change? (e.g. smaller/larger/slimmer/balanced, etc.) Describe each area you want to change.

____

____

____

Appendix M. Shapewear Product Evaluation Questionnaire (Product ISG/WOC)

Name: __________________________ Participant #: __________________________

For purposes of this study I ask you to focus on the shapewear you tried on and were scanned in. The shapewear would typically be worn under other clothing so you may consider that in your evaluation.

Please provide your opinions about your scan as seen on the computer screen. Circle the one number that best describes your opinion.

1 Body Shape

1.1 Did the shapewear change your body shape?

Not at all ... Extremely changed

1 --------------- 2 --------------- 3 --------------- 4 --------------- 5 ---------------- 6 --------------- 7

1.2 If you think the shapewear changed your body shape, explain how (What differences do you notice compared to your body shape in your underwear?).

____

____

____

2 Posture

2.1 Did the shapewear change your posture?

Not at all ... Extremely changed

1 --------------- 2 --------------- 3 --------------- 4 --------------- 5 ---------------- 6 --------------- 7

2.2 If you think the shapewear changed your posture, explain how (What differences do you notice compared to your posture in your underwear?).

____

____

____

3 Fit

3.1 How satisfied are you with the “fit” of the shapewear?

Extremely dissatisfied — Extremely satisfied

1 --------------- 2 --------------- 3 --------------- 4 --------------- 5 ---------------- 6 --------------- 7

3.2 Describe what you see in this shapewear product that determined your level of satisfaction: In other words, how did you determine good fit or poor fit.

____

____

____

3.3 Please describe other things you like or dislike about this garment if you have.

____

____

____