LABORATORY ASSESSMENT OF

RANGE OF MOTION AND PRESSURE

ASSOCIATED WITH FEMALE SOLDIERS

WEARING A BALLISTIC VEST

By

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CHAPTER I

INTRODUCTION

Background of Study

The ballistic vest is designed to protect wearers from serious injuries in combat environments (Horsfall, Champion, & Watson, 2005). Used with other personal protective equipment including the helmet, the ballistic vest has been widely utilized for individual protection against fragmentation as well as handgun and rifle projectiles. In the current conflicts in Iraq and Afghanistan, U.S. military personnel have used ballistic vests to protect themselves from injuries from everything from high-velocity bullets to bomb fragments (Michael, 2006).

The ballistic vest is categorized into two classes, soft and hard ballistic vests (Chen & Chaudhry, 2005), based on the materials contained inside the vest. The soft ballistic vest is generally composed of 20 to 35 fabric layers of synthetic ballistic-resistant fibers, such as Kevlar®, Dyneema®, Spectra®, Twaron®, or other newly invented materials. The number of layers is dependent on the material and the desired level of protection. In contrast, the hard ballistic vest consists of rigid ceramic plates or other fiber-composite plates, which are designed to be inserted into the internal pockets of the vests. The type of vest used depends on the wearer's need and the situation. For instance, military personnel tend to wear both soft and hard armor ballistic vests since they require high levels of protection in combat environments, while law enforcement personnel usually wear only soft ballistic vests (Westrick, 2001).

The importance of the ballistic vest has been documented in previous studies (Macaulay, 2008; Michael, 2006; National Institute of Justice, 2008; Westrick, 2001). According to Westrick (2001) and Macaulay (2008), the death rate of police officers from ballistic attacks has decreased during the past three decades because of the vests. The Federal Bureau of Investigation (FBI) stated that, if a police officer wears the ballistic vest, his/her risk of death is 14 times less than that of an officer who does not wear it (Westrick, 2001). Moreover, according to the National Institute of Justice (2008), since 1973, the lives of more than 2,500 military personnel have been saved by wearing ballistic vests.

Despite the increases in using the ballistic vest for numerous dangerous applications, ballistic vests for military personnel are primarily designed for males because of the heretofore infrequent presence of female military personnel in combat areas (Tung, 2008). Over time, however, female soldiers have become increasingly involved in dangerous and physically demanding military areas (Todd, Paquette, & Bensel, 1997; Zehner, Ervin, Robinette, & Daziens, 1987). The percentage of female soldiers in the U.S. Armed Forces has increased steadily over the past three decades (Ricciardi, 2007). According to a report by Office of Army Demographics (2005), about 18 % of active duty military personnel are females. Moreover, because of the nature of recent attacks and the lack of a combat front, most soldiers are required to wear the ballistic vests in most situations, even while training.

According to Hamilton (2007), reflecting the increased use of ballistic vests by females, PT Armor, a vest manufacturer, developed a female version of the ballistic vests that was more suitable to the female body shape. PT Armor began the process of manufacturing these vests by asking female police officers to identify how the existing vests were uncomfortable and ill-fitted. Most of the female police officers reported discomfort in the bust area, so the female version of the ballistic vest was created using a streamlined stitching design that creates a bulge in the bust area.

However, female military personnel still wear the unisex-designed ballistic vest, called the Interceptor™ vest (Brantley, 2000; Tung, 2008) for training and some military operations. Female soldiers have complained that the Interceptor™ vest fits poorly in the chest, neckline, and armhole areas (Tung, 2008)—all important places that could potentially influence wearer's performance and safety (Fowler, 2003).

This study focuses on females wearing the Interceptor™ vest while completing specific movements. Range of motion and pressure-contact area in the front torso region were examined by bust size. To this end, the most current U.S. army anthropometric database (Gordon, Churchill, Clauser, Bradtmiller, McConville, Tebbetts, & Walker, 1989) was used to build criteria for recruitment, classification and grouping of subjects. A focus group interview was held with five female soldiers in fall 2009 in order to identify types of clothing worn while wearing the ballistic vests and movements difficult or uncomfortable to perform while wearing the vests.

Purpose

The overall purpose of this research is to explore to what extent restrictions in performance and pressure exerted on the front torso are found for females wearing ballistic vests by measuring range of motion and pressure-contact area. Restriction in performance and range of motion for women wearing the Interceptor™ ballistic vest is determined using four specific movements; 1) trunk flexion, 2) hip flexion with kneeling, 3) shoulder flexion, and 4) shoulder horizontal adduction. To explore pressure exerted on the front torso, pressure-contact area for the bust area is determined for the four movements. Finally, both the range of motion and the pressure-contact area are compared between groups based on bust size.

Objectives

This study has multiple objectives and was conducted in three phases.

Phase I

1. Develop criteria for acceptance of subjects by examining a secondary military data source.
2. Develop bust size grouping categories to compare subjects.

Phase II

1. Determine test garments for the laboratory wear test.
2. Explore areas of perceived discomfort experienced by female soldiers when wearing ballistic vests.
3. Determine specific movements to be used in the laboratory wear test that reflect female soldiers' activities while wearing the ballistic vest.

Phase III

1. Develop protocols to obtain range of motion data and pressure-contact area data for the bust area during the four movements.
2. Determine if range of motion is influenced by bust size and/or wearing the ballistic vest for the four specified movements.
3. Investigate pressure placed on the bust area by use of the ballistic vest with hard plates and determine if differences exist by bust size for the selected movements.

Hypotheses

H^0_1: There are no significant differences in range of motion by garment treatment for shoulder flexion movement.

H^0_2: There are no significant differences in range of motion by garment treatment for shoulder horizontal adduction movement.

H^0_3: There are no significant differences in range of motion by garment treatment for trunk flexion movement.

H^0_4: There are no significant differences in range of motion by garment treatment for hip flexion with kneeling movement.

H^0_5: There are no significant differences in range of motion for shoulder flexion while females wear the Interceptor™ vest based on differences in the subjects' bust sizes.

H^0_6: There are no significant differences in range of motion for shoulder horizontal adduction while females wear the Interceptor™ vest based on differences in the subjects' bust sizes.

H^0_7: There are no significant differences in range of motion for trunk flexion while females wear the Interceptor™ vest based on differences in the subjects' bust sizes.

H^0_8: There are no significant differences in range of motion for hip flexion with kneeling while females wear the Interceptor™ vest based on differences in the subjects' bust sizes.

H^0_9: There are no significant differences in pressure-contact area during shoulder flexion by bust size.

H^0_{10}: There are no significant differences in pressure-contact area during shoulder horizontal adduction by bust size.

H^0_{11}: There are no significant differences in pressure-contact area during trunk flexion by bust size.

H^0_{12}: There are no significant differences in pressure-contact area during hip flexion with kneeling by bust size.

Significance of the Study

In previous studies, the importance of properly fitted protective clothing related to wearer performance has been determined for garments such as a firefighter's ensemble and chemical-protective gloves (Bradley, 1969[a]; Bradley, 1969[b]; Chen, Cochran, & Bishu, 1989; Huck, 1988; Tremblay, 1989). However, studies that focus on performance of female military personnel while wearing ballistic vests have been limited (Tung, 2008; Zehner, Ervin, Robinette, & Daziens, 1987). Therefore, this research examines female soldiers' range of motion performance while wearing the Interceptor ballistic vest.

Second, no research was found that focused on range of motion associated with wearing a ballistic vest with consideration given to differences in female bust size. By evaluating range of motion and extent of pressure on the bust area during the four defined movements, group differences by bust size are explored. If differences are found by bust size, the results of the present study could potentially contribute to improving the design of ballistic vests for female military personnel.

Third, this research includes methodological significance since 1) it employs a 3-D body scanner to measure under-bust and bust circumferences in order to group the subjects by bust size, 2) it uses motion-capture technology to evaluate females' range of motion while wearing the Interceptor^{TM} vest, and 3) it utilizes a Tekscan pressure sensor system to explore pressure on the bust area during movement.

Limitations

1. Although multiple types of ballistic vests are available, only the Interceptor^{TM} vest is tested in this study because it has been used by the U.S. military in Afghanistan and Iraq and is currently used during military training.
2. This study focuses only on females who have bust circumferences from 32.3 inches to 41.7 inches, based on the distribution of the subjects' body measurements.
3. In this study, only pressure-contact area in the bust area is measured.
4. Recruit of the samples was limited to volunteers living in a small midwestern university city and surrounding areas.

Definitions of Terms

Anthropometric database: "dimensional measurements of human body parts, which are key to any garment sizing system" (Le Pechoux & Ghosh, 2002).

Bra: "a shaped undergarment worn by women to mold and support the breasts. Usually consists of two cups held in place with straps over the shoulders and elastic in center back" (Calasibetta, 1998, p. 61).

Bust circumference: "the maximum horizontal circumference of the chest at the fullest part of the breast" (Gordon, Churchill, Clauser, Bradtmiller, McConville, Tebbetts, & Walker, 1989, p. 138).

Comfort: "a mental state of ease of well-being, a state of balance of equilibrium that exists between a person and his or her environment" (Sontag, 1985, p. 10).

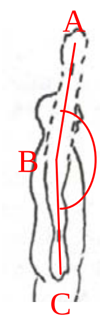
Ease: "the difference between garment measurement and body measurement" (Daanen & Reffeltrath, 2007, p. 203).

Good Fit: "A well-fitted garment feels comfortable, is becoming, is consistent with present fashion, and adjusts naturally to the activities of the wearer – in general, it hangs or sets without wrinkles, sagging, or poking out." (Erwin, 1949, p. 335). Five interrelated factors: ease, line, grain, set, and balance, contribute to good fit (Erwin, 1949, p. 335 - 338).

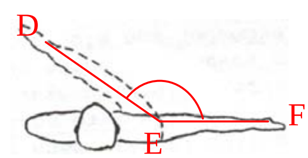
Mobility: "the ease with which an articulation, or a series of articulations, is allowed to move before being restricted by the surrounding structures" (Kreighbaum & Barthels, 1996, p. 64).

Range of motion: "the total amount of angular displacement through which two adjacent segments may move" (Kreighbaum & Barthels, 1996, p. 64). For this study, range of motion was operationally defined for the following four movements as follows.

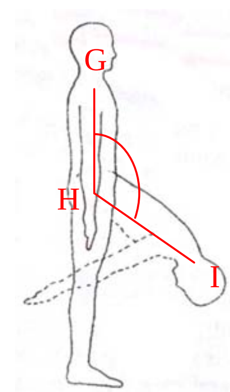
Shoulder Flexion = ∠ ABC



Shoulder Horizontal Adduction = ∠ DEF



Trunk Flexion = ∠ GHI



Hip Flexion with Keeling = ∠ JKL

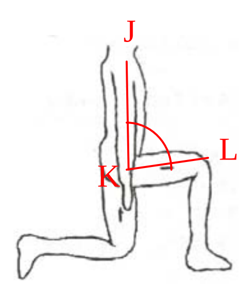


Figure 1. Operational Definition of ROM for Selected Four Movements.

Sizing system: "a table of numbers which presents the value of each of the body dimension used to classify the bodies encountered in the population for each size group in the system" (Petrova, 2007, p. 57).

Under-bust circumference: "the horizontal circumference of the chest at the level of the inferior juncture of the lowest breast with the rib cage" (Gordon, Churchill, Clauser, Bradtmiller, McConville, Tebbetts, & Walker, 1989, p. 142).

CHAPTER II

REVIEW OF LITERATURE

This chapter contains five main sections; (1) definition of fit, (2) ballistic vest, (3) breast (bust), (4) military sizing system, and (5) anthropometric database. The section on definition of fit includes good garment fit, the relationship between fit and garment ease, the influence of fit on wearer's performance, and methods to evaluate human performance associated with fit issue. The general heading of ballistic vest covers materials of the modern ballistic vest, the importance of fit, standard for ballistic resistance protection level, and the current status of the female version of the ballistic vest. Next, in the breast section, the basic breast structure, breast pain during the activities, and the general bra sizing system are explained. Finally, the sizing system used by the military, the anthropometric database it employs, and the new technology apparent in the anthropometric database are described in this chapter as well.

Definition of Fit

Numerous researchers have defined a fit of garments. However, garment fit is a complicated concept to define because of the various factors such as fashion, style, culture, individual characteristics, wearer's movement, ease, line, grain, balance, and so on, that influence fit. For instance, Efrat (1982) and Yu (2004[a]) showed that the concept of good fit change over time because fit is influenced by fashion, style, culture, industrial norm, and individual perception of fit. Cain (1950) and Chamber (1969) explained that fit is an important factor to consider relative to how well a human body moves when wearing a garment. In addition, fit has been described as a combination of ease, line, grain and balance (Erwin, 1949).

Fit and Ease

The primary factor related to the good fit of a garment is the “ease” value (Chamber, 1969; Laing & Sleivert, 2002), which is the difference between the body dimensions and garment dimensions. In other words, ease is described as an additional value that is often incorporated into garment measurements to allow a wearer to move in the garment for a variety of body positions (Petrova, 2007).

Several previous researchers examined garment fit by evaluating the ease value of the garment (Petrova & Ashdown, 2008; Rosenblad-Wallin, 1987). Ashdown and Watkins (1992) developed the effective ease values of a protective coverall to maximize the wearer’s performance. Each of the subjects in this study, all of whom were experienced in the building trades, wore one of three protective coveralls that had previously been slashed in one of three directions (vertical, horizontal, or diagonal) and a work glove. While performing selected tasks, the subjects were videotaped to record the full range of stresses that the coveralls were subjected to during movement. The location and direction of the stresses were used to analyze the amount of additional ease to be added at several sites within the garment. Based on this analysis, a new design for the protective coverall (Model B) was developed. Next, researchers compared the performance in terms of movement under actual working conditions of Model B with that of the original protective coverall (Model A). For this process, the Model A and Model B coveralls worn by 17 asbestos removal workers were lab and field tested. Wearer of Model A generated more tears in that garment composed to wearer of Model B. The tears in Model A garments were also longer than those in Model B garments. Overall, they found that subjects when wearing the Model B coverall, which was newly suggested, showed significantly better performance than subjects who wore the original coverall in terms of fit, movement, and general performance.

Keeble, Prevatt, and Mellian (1992) researched the fit of three different manufactured protective coveralls by comparing body and garment measurements. The testing garments provided by three different manufacturers were divided into seven size categories; extra small, small, medium, large, extra large, double extra large, and triple extra large. A total of 166 subjects participated in the study. Seven comparative measurements of the subjects' bodies and with three garments were obtained: 1) chest circumference; 2) leg inseam length; 3) shoulder length; 4) back torso length; 5) biceps circumference; 6) thigh circumference; and 7) front torso length. Based on data of these measurements, the researchers calculated the ease values regarding the different sizes and styles of protective coveralls. The researchers concluded that significant different ease values were revealed between sizes but not between styles, and no significant interactions existed between sizes and styles. Additionally, the study found that there was greater fit satisfaction among subjects who wore the middle sizes of the garments than subjects in the extremely small or large sizes garments.

Huck, Maganga, and Kim's study (1997) provided another example of using the ease value to design a better fitting protective overall. The researchers made a horizontal slit in an overall from side seam to side seam at waist level in the center back. The subjects wore the slitted overall and performed a crouching position with arms extended in front of the body. The researchers measured the vertical gap formed by the slit at the center back. The height of the slit was considered as an appropriate ease value for the protective overall and it was used for designing two testing garments. Garment 1 was designed without any ease value; garment 2 was created by adding the ease value on the vertical trunk circumference as extending the length of the center back; finally, garment 3 was made by adding the ease values on both front and back patterns. The subjects performed movements: 1) trunk flexion; 2) shoulder adduction; 3) shoulder flexion; and 4) knee flexion, while wearing all three test garments and filled out the wearer's acceptability instrument to measure the range of motion. The researchers found that subjects preferred garments 2 and 3, which had the added ease value, to garment 1 with no ease value. Garment 2, with added ease value only on the center back, was selected as the desirable design to maximize the wearer's movements.

Furthermore, Rosenblad-Wallin (1987) examined a new sizing system for military mittens, which applied the effective ease values of the mittens. In this research, the comprehensive anthropometric database for military personnel was used and two groups of hand measurements were chosen for 313 young male soldiers and 385 refresher training soldiers. Hand circumference and hand length were selected as the key dimensions for the size distribution of the mitten. For hand circumference, eight ease values of mittens per 1 cm were applied on the length of mitten from 18.5 cm to 26.4 cm. Six ease values of mittens per 1 cm were also developed for the width of the mitten from 15.5 cm to 21.4 cm. Each subject was given these two mittens ease values based on their respective hand measurements. According to the ease values' distribution of key dimensions, two sizes of mittens, medium and large, were manufactured. A group of 160 young soldiers aged between 18 and 20 wore appropriately sized mittens developed by the new sizing system, which were tested in wear trials. Afterward, the subjects completed a 16-items questionnaire. The results indicated that 81 % of the participants believed the fit was good, 3 % responded that the mittens were too small, and 16 % felt that the mittens were too large. Finally, the researcher concluded that the tested sizes of the new size system were well accepted by the group of young soldiers.

Kim, Suh, Suk, Park, and Lim (2001) compared the ease values of one jacket style in two sizes produced by seven different ready-to-wear jackets to improve the fit satisfaction for women's ready-to-wear jackets. Two sizes of jackets, B85 and B88, were provided by seven different companies, and four female subjects participated in the study. Two of the subjects wore the B85 size jackets while the others wore B88 size jackets, according to their bust girth. Each subject was scanned eight times, once while wearing minimum clothing and seven times wearing the seven different jackets. To quantify the ease of the jacket on the wearer, the gap between the body and garment was measured at six body areas: shoulder, armscye, bust, waist, abdomen, and hip. Ultimately, the researchers identified four valuable results to provide effective ease values for women's ready-to-wear jackets: 1) The ease values of each jacket were similar to each other but some differences were noted in the armscye (B85) and the waist (B88). 2) There were significant differences in ease values between size group B85 and B88 except for the abdomen. 3) The greatest number of ease values existed in the back and front in the armscye, waist, and abdomen, the front and back of the bust, and at the front of the hip.

4) When grading the jacket pattern for all seven jackets in size B88, the abdomen and armscye needed to be increased as did the bust, waist, and hip.

Fit and Human Performance

Garment fit should be seen as a principle factor that affects human performance (Laing & Sleivert, 2002). To allow the worker's free movement and comfort while wearing the garment, appropriate fit should be provided (Huck, Maganga, & Kim, 1997) since poor fit degrades the wearer's performance. A poorly fitted garment can restrict movement and protection (Keeble, Prevatt, & Mellian, 1992). Both loose fit and tight fit hinder the wearer's movement (Laing & Sleivert, 2002). A loose fit can cause an accident because the extra fabric can be jammed into machinery while performing a movement. Conversely, a tight fitting garment can prove uncomfortable and potentially reduce protection.

To evaluate wearers' performance related to garment fit, physical, physiological, and psychological factors can be measured (Laing & Sleivert, 2002; Nam, 2009). Activity completion time, movement time, activity performance quality, manual dexterity, range of motion, and pressure executed on the body can be used as physical factors to assess wearers' performance (Nam, 2009; Tremblay & Weihrer, 1996). Physiological characteristics, such as heart rate, energy expenditure, ventilation rate, skin moisture, sweat rate, skin temperature, core temperature, fatigue, and blood pressure also can be measured to determine wearers' physiological response to wearing garments in specified environments (An, Park, Cao, Peksoz, & Branson, 2009; Peksoz, 2005). Finally, psychological factors can be used in such assessments such as perceived comfort, perceived pressure, and perceived restriction (Laing & Sleivert, 2002; Nam, 2009).

Physical Factors

An example of a physical factor that has been studied for evaluation of wearer's performance is Tremblay and Weihrer's study (1996). They tested wearers' performance while wearing different chemical protective gloves by measuring manual dexterity. The five different sizes of gloves used in the assessment were extra small, small, medium, large, and extra large. Liners also were provided according to size to be worn inside the chemical protective gloves. Twenty-four subjects participated in this research. Four manual dexterity testing methods were employed: the Minnesota Rate of Manipulation Turning Test, the O'Connor Fine Finger Dexterity Test, the Cord Manipulation and Cylinder Stringing Test, and the Magazine Loading Test. Each subject selected a smaller fitted size, a best fitted size, and a looser fitted size in both glove and liner. Then, all subjects were trained in several practical trials to become acquainted with each dexterity evaluation. After training for the practical trials, six tests of each dexterity assessment were performed by each subject under the following hand wear conditions: unlined best fitting size, unlined smaller size, unlined larger size, lined best fitting size, lined smaller size, and lined larger size. No significant differences were noted between the unlined smaller fitting and the unlined best fitting hand wear condition in performance times. However, the performance times for the best fitting unlined glove increased more significantly than the performance times for the larger fitting unlined glove. Furthermore, no significant performance time differences were noted between the unlined hand wear and lined hand wear conditions except during the O'Connor test.

In addition, in Tremblay's (1989) study, dexterity was also measured to evaluate the functional fit and comfort of agricultural workers' protective gloves. The researcher used four different gloves available commercially. They represented various combinations of polymer types and material thicknesses. Thirty-eight male subjects, whose have measurements corresponded to 95 percent of hand circumference and 99 percent of length of the middle finger of the agricultural population's measurements, participated in the research. To conduct a dynamic fit of the gloves, the subjects underwent two performance tests, the Minnesota Rate of Manipulation Turning Test and the Cralk Screw Test, while wearing no gloves and four types of gloves. The researcher found that there were significant differences among the four gloves in the decrement of performance. In terms of the ratio of performance, the researcher also recognized that the thinner glove was the best.

In Huck's study (1988), range of motion was used to test the fit of three different firefighter's outfits. Testing outfits were designed by using different fabrication, layering, and coat length. Nine subjects wore each type of protective outfit and performed eight joint movements that represented the type of physical activity of a firefighter: 1) shoulder flexion/extension; 2) shoulder adduction/abduction; 3) shoulder rotation; 4) elbow flexion/extension; 5) hip flexion/extension; 6) trunk lateral flexion; 7) knee flexion/extension; and 8) hip adduction. Range of motion at each joint movement was calculated by using a Flexometer. The researcher concluded that the ensemble that provided the least restriction of range of motion would provide the most effective performances of their duties.

In Nam's study (2009), the researcher measured the pressure value under the arm armor system as one method to compare the performance effects while wearing three different arm armor systems. The researcher attached two localized pressure sensors to the inner side of the upper and lower arm armor. Subjects wore each arm armor system with attached pressure sensors inside of the arm armor and performed five shoulder movements; flexion, extension, abduction, horizontal flexion, and horizontal extension. The pressure results showed that there were no significant differences among the three different arm armor systems and among five different movements in both locations. There was also no pressure interaction effect of the arm armor systems by the movements in both locations. However, greater pressure in the lower arm area was found.

Physiological Factors

Nielsen, Gavhed, and Nilsson (1989) measured skin temperature, core temperature, heart rate, sweating start time, and subjective thermal evaluation to determine how a tight fitting undergarment and a loose fitting shirt affected the cooling of human skin. In this assessment, two types of test garments were provided: a tight fitting undergarment and a loose fitting shirt. Ten male subjects performed the standardized packing work while wearing each test garment under three environmental conditions. The results indicated that a tight fitting undergarment produced higher skin temperatures at torso and upper arm than a loose fitting shirt. The evaporation rate and mean skin temperatures associated with a tight fitting undergarment also were higher than for a loose fitting shirt. Furthermore, sweating began earlier while wearing a tight fitting undergarment than a loose fitting shirt. However, no significant differences were observed in core temperature, heart rate, or subjective thermal evaluation. The researchers concluded that a tight fitting undergarment allows less cooling of the skin than a loose fitting shirt.

Bygrave, Legg, Myers, and Llewellyn (2004) also measured physiological factors to determine how lung function was affected by the fit of a backpack. One backpack in three sizes, small, medium, and large, were prepared. Twelve healthy male subjects participated in the study and each selected one best fitting backpack among the three sizes of the backpack according to their body size. Each subject adjusted the length of the shoulder straps, hip belt, and chest strap to achieve a "comfort fit" on their body. The comfort fit length for each subject was measured and recorded. Next, "loose pack fit" was acquired by loosing 3 cm from comfort fit on shoulder straps and ship belt. "Tight pack fit" also was obtained by tightening 3 cm from the comfort fit. The researchers recorded four physiological factors in measuring lung functions: forced vital capacity, forced expiratory volume, peak expiratory flow, and forced expiratory flow. All of these indicators were recorded under three conditions: no pack, loose pack, and tight pack. The researchers concluded that lung function was significantly affected by loose pack fit and tight pack fit. Lower forced vital capacity, forced expiratory volume, and forced expiratory flow were observed on lung function while the subject wore a tight pack fit as compared to a loose pack fit.

Psychological Factors

The wearer's perceived fit evaluation, which is one of the representative psychological categories to evaluate the wearer's performance related to the fit of garment, was shown in Griffey and Ashdown study (2006). In this study, five customized gore skirts, developed based on 3-D body scanned data, were used to evaluate subjects' perceived fit. Subjects wore the customized skirt prototype and tried to move and sit to assess the fit of the skirt under actual conditions. Then, the subjects were given a questionnaire comprised of three constructs in fit evaluation that applied to the waist, hip, and overall. The researchers indicated that three of the five subjects stated that the prototype skirt fit was perfect at the waist, hip, and overall. The other two subjects said that they thought the skirts were tight at the waist but were otherwise perfect good. Therefore, the customized style patterns derived from the 3-D body scan data were accomplished successfully.

In Nam's study (2004), two types of perceived fit evaluation were completed, one by wearers and the second by experts, in order to evaluate different types of cooling vests. In her study, the eight subjects assumed three active positions – standing, bending, and twisting – while wearing three garment treatments: without vest, prototype I, and prototype II. After the subjects were scanned in positions, the subjects completed a wearer's perceived fit evaluation ballot for each vest. The experts completed their fit evaluation assessment by comparing the scanned images of the three garment treatments on each subject. The researcher concluded that the prototype II provided better fit in the bending and twisting positions.

In Ashdown, Loker, Schoenfelder, and Lyman-Clarke's study (2004), experts' fit evaluations were used to assess the fit of pants. All 245 participants were scanned twice, once in minimal clothing and once in the best fitting pants as selected by the researchers. The scanned images were merged, aligned, and cleaned to provide smoothed 3-D visualization. Three experts evaluated the garment fit based on size while observing the nude and pants images of the 3-D scanned data. The experts assessed several critical fit locations, such as waist, waist location, abdomen, hip, crotch length, and thigh circumference as acceptable, marginal, or unacceptable. The researchers stated that the waist placement front, hip front, thigh front, and thigh back were fitted well, but that the waist front and waist back, crotch, and overall back frequently were misfitted.

Ballistic Vest

A ballistic vest is an important item to absorb the impact of a bullet or sharp weapon on the torso (Ashcroft, Daniels, & Hart, 2001; Tung, 2008). Several previous studies have shown the importance of using ballistic vests to save lives and achieve greater safety in dangerous battle areas. Statistically, ballistic vests have helped to preserve the lives of more than 2,800 law enforcement officers since the 1970s (Ashcroft, Daniels, & Hart, 2001; National Institute of Justice, 2004).

Modern Ballistic Vest

The modern ballistic vest affords improved protection, fit, and comfort over previous versions of the ballistic vest. Furthermore, when combined with other accessory items, such as a helmet, shoulder armor, and leg armor, the modern protective ensemble provides greater protection against hand grenade blasts (Ashcroft, Daniels, & Hart, 2001).

The ballistic vest can be categorized as being either soft or hard. A soft ballistic vest consists of multiple layers of manmade lightweight fibrous polymeric materials that exhibit typically composed of ballistic resistance (Chen & Chaudhry, 2005) while the hard ballistic vest includes rigid plates, composites that can be inserted into pockets in the soft ballistic vest to increase the protection level. Thus, the hard ballistic vest includes both soft ballistic materials and some type of rigid plates.

As presented in Table 1, there are many lightweight fibrous polymeric materials available currently for use in soft ballistic vests. The first lightweight ballistic vest material was Kevlar, which was developed in the 1970s by DuPont (Body Armor – Technological Issues, 2006). With the advent of Kevlar, the performance of the modern ballistic vest was improved substantially because of the combination of material properties that allowed for high strength with low weight, high chemical resistance, and high cut resistance. Kevlar also is flame resistant, cannot be melted, softened, or floated, and its fiber is not affected by dipping in water (Ashcroft, Daniels, & Hart, 2001).

Table 1. Fiber Compositions and Properties of Soft Ballistic Resistant Fabrics
(Source: Ashcroft, Daniels, & Hart, 2001; Chen & Chaudhry, 2005; Tung, 2008)

Name	Manufacturer	Fiber Composition	Properties
Kevlar	DuPont	Aramid	First material used in modern body armor High strength Lightweight High chemical / cut / flame resistance Unaffected in water
Spectra	Honeywell	Unidirectional polyethylene	High strength Water penetration resistance High chemical / cut resistance Lightweight
GoldFlex	Honeywell	Unidirectional aramid	Lightweight Thin Good protection against blunt trauma
Twaron	Twaron Products	Para-aramid	High energy absorption Quicker impact dispersal
Dyneema	DSM	Unidirectional polyethylene	Very lightweight High energy absorption Water resistant
Zylon	Toyobo	p-phenylene-2-6-benzobisoxazole	High thermal properties Better tensile strength Lightweight

Spectra, manufactured by Honeywell, is an ultra-high strength polyethylene fiber. It is resistant to water penetration, has extremely high chemical resistance, and has high cut resistance properties. Notably, Spectra Shield composites patented by Honeywell were made by sealing the fiber and resin layers between two thin sheets of polyethylene film, which gave the product its noteworthy properties, including strength, light weight, flexibility, and ballistic protection (Ashcroft, Daniels, & Hart, 2001). In its advancement of the Shield technology process, Honeywell produced another Shield composite called GoldFlex, which uses an aramid fiber instead of the Spectra fiber (Ashcroft, Daniels, & Hart, 2001).

Another manufacturer, Twaron Products, developed the Twaron fiber for use in ballistic vests. Ashcroft, Daniels, and Hart (2001) stated that “Twaron used 1,000 or more finely spun single filaments that act as an energy sponge, absorbing a bullet’s impact and quickly dissipating its energy through engaged and adjacent fibers.”(p. 21)

Dyneema, which is produced by DSM, originally was available only in the Netherlands (Ashcroft, Daniels, & Hart, 2001), but is now available in the United States. It also is lightweight, floats on water, and demonstrates high energy absorption characteristics (Tung, 2008).

Toyobo, a Japanese company, developed Zylon which is a Polyphehylenebenzobisoxazole (PBO) material. PBO provides high thermal properties but is suspected to offer almost twice the tensile strength of conventional para-aramid fibers (Ashcroft, Daniels, & Hart, 2001). Thus, the Toyobo Company asserts that Zylon allows the construction of comfortable protective garments because of its excellent heat and mechanical properties (Ashcroft, Daniels, & Hart, 2001). However, this fiber has been shown to have its protection degraded in combined high heat and humidity (Armor Holdings: Products Division, 2003).

Ceramic composites and other fiber composites typically are used to produce hard rigid plates. Ceramic composites, consisting of a ceramic aluminum oxide with a fiberglass laminate (Carothers, 1988), first were provided in the early 1960s to reduce weight while increasing ballistic protection. According to Carothers (1988), the first hard ballistic vest served as protection against small arms, and it utilized ceramic plates within a ballistic nylon carrier. It was used by aircraft crewmen as protection against small caliber projectiles and low velocity shrapnel.

Other types of hard plates are made from fiber composites. Multiple layers of ballistic fibers are formed according to the requirements of bullet resistance. Several layers of material are heated, bonded, or pressed together to make a single, thick, hard plate (Ferguson, 1978).

National Institute of Justice (NIJ) Standard

The primary role of the ballistic vest is to protect the wearer against impacts from bullets or sharp knives. To facilitate the accurate assessment of ballistic vests, the National Institute of Justice (NIJ) established levels of protection for ballistic vests (National Institute of Justice, 2008). This standard provides different classes depending on threat and ballistic performance. It also specifies the procedure to be used for torso tests of ballistic vests, considering only projectiles fired by guns. Other types of projectiles, such as hand grenade fragments or blast fragments, are not covered in this standard. Currently, all of the ballistic garments commercially available in the United States have NIJ certification.

According to the National Institute of Justice Standard 0101.06 (National Institute of Justice, 2008, pp. 3~4), personal armor is classified according to seven levels, as shown in Table 2. The classification of an armor panel that provides two or more levels of NIJ ballistic protection at different locations on the ballistic panel shall be that of the minimum ballistic protection provided at any location on the panel.

Table 2. NIJ Standard for Body Armor Ballistic Performance
(Source: National Institute of Justice, 2008, p.3~4)

Armor Level	Ballistic Performance
Type I (.22 LR; .380 ACP)	This armor would protect against 2.6 g (40 gr) .22 Long Rifle Lead Round Nose (LR LRN) bullets at a velocity of 329 m/s (1080 ft/s ± 30 ft/s) and 6.2 g (95 gr) .380 ACP Full Metal Jacketed Round Nose (FMJ RN) bullets at a velocity of 322 m/s (1055 ft/s ± 30 ft/s). It is no longer part of the standard.
Type IIA (9 mm; .40 S&W)	New armor protects against 8 g (124 gr) 9x19mm Parabellum Full Metal Jacketed Round Nose (FMJ RN) bullets at a velocity of 373 m/s ± 9.1 m/s (1225 ft/s ± 30 ft/s) and 11.7 g (180 gr) .40 S&W Full Metal Jacketed (FMJ) bullets at a velocity of 352 m/s ± 9.1 m/s (1155 ft/s ± 30 ft/s). Conditioned armor protects against 8 g (124 gr) 9 mm FMJ RN bullets at a velocity of 355 m/s ± 9.1 m/s (1165 ft/s ± 30 ft/s) and 11.7 g (180 gr) .40 S&W FMJ bullets at a velocity of 325 m/s ± 9.1 m/s (1065 ft/s ± 30 ft/s). It also provides protection against the threats mentioned in Type I.
Type II (9 mm; .357 Magnum)	New armor protects against 8 g (124 gr) 9 mm FMJ RN bullets at a velocity of 398 m/s ± 9.1 m/s (1305 ft/s ± 30 ft/s) and 10.2 g (158 gr) .357 Magnum Jacketed Soft Point bullets at a velocity of 436 m/s ± 9.1 m/s (1430 ft/s ± 30 ft/s). Conditioned armor protects against 8 g (124 gr) 9 mm FMJ RN bullets at a velocity of 379 m/s ±9.1 m/s (1245 ft/s ± 30 ft/s) and 10.2 g (158 gr) .357 Magnum Jacketed Soft Point bullets at a velocity of 408 m/s ±9.1 m/s (1340 ft/s ± 30 ft/s). It also provides protection against the threats mentioned in Types I and IIA.
Type IIIA (.357 Sig; .44 Magnum)	New armor protects against 8.1 g (125 gr) .357 SIG FMJ Flat Nose (FN) bullets at a velocity of 448 m/s ± 9.1 m/s (1470 ft/s ± 30 ft/s) and 15.6 g (240 gr) .44 Magnum Semi Jacketed Hollow Point (SJHP) bullets at a velocity of 436 m/s (1430 ft/s ± 30 ft/s). Conditioned armor protects against 8.1 g (125 gr) .357 SIG FMJ Flat Nose (FN) bullets at a velocity of 430 m/s ± 9.1 m/s (1410 ft/s ± 30 ft/s) and 15.6 g (240 gr) .44 Magnum Semi Jacketed Hollow Point (SJHP) bullets at a velocity of 408 m/s ± 9.1 m/s (1340 ft/s ± 30 ft/s). It also provides protection against most handgun threats, as well as the threats mentioned in Types

	I, IIA, and II.
Type III (Rifles)	Conditioned armor protects against 9.6 g (148 gr) 7.62x51mm NATO M80 ball bullets at a velocity of 847 m/s ± 9.1 m/s (2780 ft/s ± 30 ft/s). It also provides protection against the threats mentioned in Types I, IIA, II, and IIIA.
Type IV (Armor Piercing Rifle)	Conditioned armor protects against 10.8 g (166 gr) .30-06 Springfield M2 armor piercing (AP) bullets at a velocity of 878 m/s ± 9.1 m/s (2880 ft/s ± 30 ft/s). It also provides at least single hit protection against the threats mentioned in Types I, IIA, II, IIIA, and III.
Special Type	A purchaser having a special requirement for a level of protection other than one of the above standard types and threat levels should specify the exact test round(s) and reference measurement velocities to be used and indicate that this standard shall govern all other aspects.

Styles of Ballistic Vest

The ballistic vest is categorized into three different styles: concealable, semirigid, and rigid ballistic vests (Ashcroft, Daniels, & Hart, 2001; Tung, 2008), according to the protection level afforded. The concealable ballistic vest is the most widely used style of body armor. It is worn underneath the normal uniform shirt of law enforcement officers as a protective garment. It can provide Levels I, II-A, II, or III-A protection. It provides more effective performance in terms of comfort, weight, and mobility than the other styles (National Institute of Justice, 2008; National Law Enforcement and Corrections Technology Center, 2006). The semirigid ballistic vest is designed for Levels III and IV. Individuals usually wear this vest outside their shirt. It also is used regularly by soldiers in battle. The wearer cannot hide the vest because of its thickness as it is composed of plastic, steel, or ceramic articulated plates (Ashcroft, Daniels, & Hart, 2001; National Institute of Justice, 2008). Finally, the rigid ballistic vest is utilized in situations that need Level IV and above protection, such as military intensive combat situations. It is the most restrictive in terms of mobility because it is made using a molded ballistic material tailored to protect certain parts of the body (National Institute of Justice, 2008).

Fit of the Ballistic Vest

In recent years, complaints related to the fit of ballistic vests often have been reported (Barker, 2007; Tung, 2008). Even though the ballistic vest is a required item that saves the lives of thousands of police officers, Ashcroft, Daniels, and Hart (2001) reported that 40 percent of police still do not wear a ballistic vest because of discomfort. Furthermore, Shanley, Slaten, and Shanley (1993) noted that the ballistic vest should be fitted very well on the wearer to allow maximum performance and mobility. It is understandable how uncomfortable wearers must feel while wearing the ballistic vest and how it reduces their performance (Barker, 2007; Fowler, 2003; Tung, 2008).

Few researchers have focused their studies on improving the ballistic vest. Brantley (2000) evaluated the fit of the ballistic vest of active duty male Marines. The Interceptor was used for this study since at least 90 percent of Marines used it as their current ballistic protective vest. For this research, 251 male Marines volunteered to participate in the study. In order to determine vest size, chest circumference was measured by using a tape measure on the surface of the skin, since this is a key dimension for sizing of the Interceptor ballistic vest. Each subject then received the appropriate size Interceptor vest and performed basic movements, such as reaching overhead with their arms, crossing both arms over the chest, bending at the waist, and kneeling on one knee. As the subjects performed these movements, the researcher asked each Marine to rate their perception of the overall fit as acceptable or unacceptable. Each subject performed these movements a second time while wearing the most frequently used size of the

Interceptor. Based on this fit evaluation, the researcher made the following recommendations for improving the Interceptor's fit among the Marines: 1) for the medium size Interceptor, reduce the waist circumference by one inch and the front length by one-half inch; 2) for the large size, chest circumference by one-half inch, waist circumference by one inch, and front and back length by one-half inch; and 3) for the extra-large size, reduce of the Interceptor body armor required a reduction of chest circumference by one-half inch, waist circumference by one inch, and front and back length by three-quarters of an inch.

Barker (2007) studied how physical and psychological factors influenced the comfort of police who wore the ballistic vest. Ninety-one police officers participated in the study to determine their satisfaction levels while wearing the ballistic vest. The subjects filled out a 56-item questionnaire about their experiences and perceived comfort when wearing the ballistic vest. The researcher documented that significant correlations existed between the comfort and fit of the ballistic vest and between the comfort and vest properties. This study also presented that the comfort of the ballistic vest was judged according to the wearer' comfort adjustment, which was applied or changed as physical and psychological dimensions occur. Finally, the researcher provided the physical and psychological dimension in three attributes: first, physical dimension was identified as 1) person attributes – posture, mobility, activity, and exposed surface area; 2) clothing attributes – fit, design, shape, fabric, components, and so on; and 3) environmental attributes – air temperature and humidity. The psychological dimension included 1) person attributes – attitudes, awareness, and behaviors; 2) clothing attributes – aesthetics, style, and design; and 3) environment attributes – geographic location and situation of wearer.

Fowler (2003) evaluated two types of ballistic vests for male police officers by measuring range of motion, movement analysis, and wearer acceptability. Two different ballistic vests of similar design differed by fabrication; one was made of a woven mat material composed of synthetic fibers such as aramid or high performance polyethylene (HPPE), and the other was made of ArmorFelt (a needle punched nonwoven material) which consisted of both aramid and HPPE fibers. For the range of motion test, ten male subjects wore both ballistic vests while performing shoulder abduction, shoulder adduction, shoulder hyperextension, shoulder flexion, trunk hyperextension, and truck flexion. All angles were measured using a goniometer. Next, the subjects performed movement protocols that included kneeling, duck squats, body bends, torso twists, and so on, and subjects assessed their perception of ease to complete each movement using a 5-point Likert-type scale with descriptors "easy to do" and "hard to do." Finally, wearer acceptability data was collected from all subjects through use of a ballot. The researcher concluded that there were no significant differences between the two ballistic vests in function, comfort, fit, and overall satisfaction. However, the ArmorFelt vest was cooler, more comfortable, more flexible, easier to move in, and more acceptable to wear than the other vest.

Female Ballistic Vest

The rate of female participation has increased in the active duty military and in law enforcement (Todd, Paquette, & Bensel, 1997; Tung, 2008; Zehner, Ervin, Robinette, & Daziens, 1987). Notably, almost one in five (18 percent) of the Army's active duty soldiers is female (The Office of Army Demographics, 2005) and female police officers represent more than 15 percent of the law enforcement population.

However, most females wear ballistic vest designed for males, and several problems result from this practice. Hamilton (2007) notes that the male ballistic vest will be quite bulky and heavy for females. When a female wears a male ballistic vest, she usually adjusts it to fit her bust and waist. The side coverage of the ballistic vest might be reduced in order to adequately cover the bust. In terms of physical characteristics, females are significantly different from males in the bust area. Ashcroft, Daniels, and Hart (2001) indicated that the ballistic vest developed for male wearers causes female wearers to breathe with greater difficulty because of the pressure applied by the front plate to the bust area due to the straighter design of its hard plates. This property could contribute to lower performance by female.

In Tung's study (2008), several reasons why the male ballistic vest does not provide a suitable fit for wear by females were documented based on outcomes derived from different body shapes. The researcher used standard body measurements issued by the American Society for Testing and Materials (ASTM) to compare body measurements for both genders (Table 3).

Table 3. Comparison between Male's and Female's Torso Measurements with the Same Chest Measurement (Source: Tung, 2008, p. 34)

	Male	Female	Difference
Chest/Bust	36	36	
Waist	30	28	2
Armscye	17	15 ¾	1 ¼
Cervical Height	59	56 ½	2 ½
Waist Height	42	40 ¼	1 ¾
Torso Length	17	16 ¼	¾
Armscye Depth	5 1/16	7 5/8	- 2 9/16

Note. Unit = Inch

During this research, Tung employed male and female subjects with the same chest size —36 inches—a key dimension used to determined appropriate sized vests. Then, the subjects tried on identical vest sizes. Although both subjects wore the same ballistic vest, the female officer faced several problems. First, they reported having less mobility than the males because of the bulky extra fabric in the waist area because of their smaller waist circumference (two inches less). Second, due to the female having arms that were one-and-a-quarter inches shorter than their male counterparts, the armhole of the ballistic vest presented a more dangerous issue to females. The next problem was associated with torso length. The length of a female's torso is about three-quarters of an inch smaller than a male's. This difference in torso length likely influences fit, especially when sitting down while wearing the ballistic vest. Moreover, the excessive torso length of the ballistic vest certainly would push into the abdomen area or upward toward the female's neck (Tung, 2008). Finally, the smaller armhole depth of male ballistic vest may reduce the mobility of the arms and increase the discomfort experienced by female wearers of male vests because of the pressure around the bust and arm areas.

In view of the increased presence of female soldiers and police officers, there is a need for a female version of the ballistic vest (Moss, 2006). Therefore, Tung (2008) designed a female ballistic vest for female soldiers by analyzing the problems with current ballistic vests that female soldiers use. The researcher first developed a questionnaire to collect complaints of female wearers. The survey included 12 open-ended questions related to vest fit and activities performed while wearing the vest. Throughout the questionnaire, the researcher identified several issues: 1) fit satisfaction was reduced at the neckline, chest, waist, bottom edge of the vest, armholes, and vest length when wearing the hard plate; 2) shooting and head rotation were seen as movements that were essential for the wearers to perform; 3) the most significant design elements to be considered are fit of the female body, arm mobility, and that the vest is compatible with the load bearing vest. Based on this feedback, the researcher suggested a female ballistic vest that was adjustable 1) to allow wearers to adjust the armhole size using a four-inch adjustable armhole design; 2) to give wearers extra security at the waist area and help fasten down the front plate pocket using the 10-inch side fastening system; 3) to include several one inch by one-and-one-quarter inch loops; 4) to introduce a cancellable front plate pocket; and 5) to permit new sizes of front and back hard plates.

Furthermore, SAVVY developed a concealable ballistic vest for women in law enforcement (Wolf, 2008). They suggested three shaping technologies for developing the female vest: thermal-forming, radial offset pleating, and advanced draping. Through these shaping technologies, all of the varied sizes and shapes needed to fit women can be taken into consideration to obtain a better fit for female officers and soldiers. The ceramic plates used for vests for females also were introduced in order to cover the curved bust area with a comfortable fit (Moss, 2006).

However, some females with small bust sizes still prefer to wear the male vest. Thus, SAVVY and other companies that produce the female ballistic vest are concentrating on developing a more efficient female ballistic vest to provide the most comfortable fit to wearer (Hamilton, 2007).

Breast (Bust)

Adult females have breasts on the chest wall, which must be considered when companies design clothes for females to achieve well fitting garments (Zheng, 2006). Gain (1950) stated that clothing poorly fit in the bust area can restrict the wearer's movement as well as cause discomfort. Therefore, consideration of breast size is important in order to develop comfortable clothes for females. Breast structure, previous researches on breast pain, and bra sizing systems follow.

Breast Structure

The basic structure of the breast consists of two major parts: the epithelial component and the structural component (Valdes, n.d.) (Figure 2). The epithelial component includes lobes, bulbs, and ducts and can produce milk. The lobes are located in the center portion of the breast. Milk is produced from bulbs and carried to the nipple through ducts (Read, 1993).The second component is the system to support the structure of the breast. It is composed of fatty tissue with muscle only beneath the breast. To support the weight of the breast on the chest wall, the ligaments connect to the muscle behind and underneath the breast (Gehlsen & Stoner, 1987).

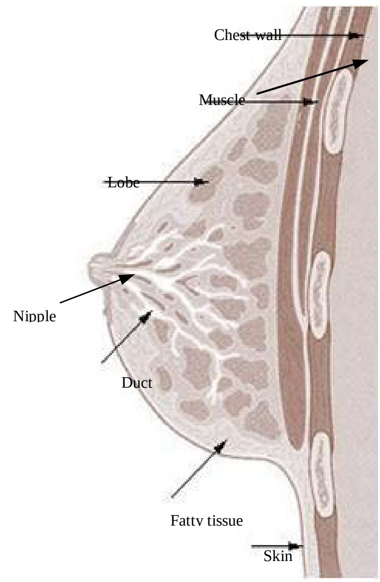


Figure 2. Structure of the Breast (Source: Valdes, n.d.)

Breast Pain

As mentioned above, the breast lacks a supportive structure (Bowles, Steele, & Munro, 2008). Therefore, it is common to have some pain in the breast during exercise (Lorentzen & Lawson, 1987). Many researchers have sought ways to reduce breast pain in terms of bra fit (Bowles, Steele, & Munro, 2008; Mason, Page, & Fallon, 1999) during physical activity.

Bowles, Steele, and Munro (2008) studied bra wearing and purchasing habits of Australian young females for physical activity. The researchers conducted a mail survey and collected 267 questionnaires. The questionnaire, which was developed by bra industry representatives, contained questions about bra purchasing habits, fitting history of bras, occurrence of breast pain, types of physical activity, types of bras worn during physical activity, experiences of wearing sports bras, and the reasons why the respondents did or did not wear sports bras during physical activities. The researchers found that most Australian young females do not wear encapsulating sports bras during physical activities even though the encapsulating sports bras have been shown to reduce breast movement, pain, and discomfort during physical activities. Finally, this study indicated that underwear marketers should educate their female consumers about the importance of wearing a well-fitted and supportive bra during physical activities to reduce negative outcomes of not wearing a bra or wearing an unfitted bra.

In Mason, Page, and Fallon's research (1999), movement of breast tissue was measured and compared when wearing four different breast supports such as a sports bra, a fashion bra, a crop top, and no bra. Three healthy, young, and active Australian subjects participated in this study. To analyze breast movement, the researchers marked the following five points on the subjects' breasts: 1) medial, 2) lateral, 3) superior, 4) inferior to the nipple, and 5) the notch of the sternum. After marking all points, the subjects performed four activities such as walking, aerobics march, jogging, and running in four conditions: 1) no bra, 2) sports bra, 3) fashion bra, and 4) crop top. The subjects' movements were videotaped, and the subjects completed a comfort scale form to assess their perceived breast pain. Through the breast movement analysis and comfort responses, the researchers concluded that the sports bra provided superior support and reduced breast pain, and that females should wear a fitted sports bra during exercise to minimize breast pain.

Bra Sizing System

The first attempt to develop a bra sizing system was in 1926 (Morris, Mee, & Salt, 2002). To categorize various breast shapes, the survey was performed by Berlei Underwear Company in Australia from 1926 to 1928. In this survey, the female's chest, bust, and under-bust circumferences were used as important factors for development of a bra sizing system. In 1935, Warners introduced four different cup sizes which were called alphabetically and indicated the volume of breast (Zheng, 2006): A for youthful cup, B for average cup, C for large cup, and D for heavy cup (Bressler, Newman, & Proctor, 1998). Based on the alphabetical cup size system, the modern bra cup sizing system, which is composed of the band and cup sizes, was established (Figure 3) (Zheng, 2006).

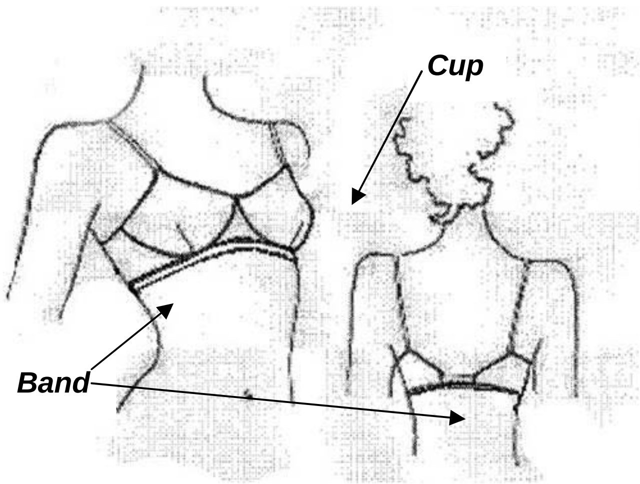


Figure 3. Bra Construction (Source: Haggar, 2004)

The band size is a circumference of the wearer's under-bust circumference while the cup size is an indication of the circumference of the wearer's fullest part of the breast (Chen, 2007; McGhee & Steele, 2006; Zheng,Yu, & Fan, 2007) (Figure 3). In the modern bra cup sizing system, the band size represents the number (e.g., 32, 34, and 36) and a cup size is expressed in a letter (e.g., A, B, and C). To determine cup size, the under-bust circumference and the full bust circumference are measured. The number of inches is added to the under-bust measurement and subtracted from the full bust circumference. The cup size is assigned according to the difference.

However, there is a lack of a standard method to determine for a well fitting bra for each female (Greenbaum, Heslop, & Morris, 2003; Kanhai & Hage, 1999; Pechter, 1998; Wise, 1956). Thus, underwear companies use different methods that lead to consumers' confusion.

In order to investigate the current bra sizing system, McGhee and Steele (2006) researched how respiration and measurement affect the bra sizes of the wearers. Sixteen Australian females with large breasts, were selected as participants in this study. The bust and under-bust circumferences of each subject were measured three times at two respiratory conditions, inspiration and expiration. The self-reported bra sizes were compared with the bra sizes calculated by using the Australia standard method. The cup size was also calculated by using the breast hemi-circumference method and compared to the cup size calculated using the standard method. The results of this study showed that both respiration condition and measurement method significantly affected bra sizes. According to the respiration condition, the bust and under-bust circumference were significantly different. Thus, the researcher concluded that the bra size calculated using Australia standard method was significantly different from the subject's reported bra size. However, the cup size calculated using the breast hemi-circumference method did not differ significantly from the subject's self reported cup size.

Here, another researcher who improved the current bra sizing system is Wright (2002). In this study, the researcher analyzed the common bra size calculation method and found many problematic issues in it. Thus, the researcher proposed an alternative to bra size calculation method in order to provide better fitted bras to all female wearers. The alternative method is: 1) measure the under-bust circumference; 2) calculate band size by adding four inches if the under-bust circumference is an even number, or five inches if it is an odd number; 3) measure the bust circumference and round it up to the next integer; 4) measure the difference between the band size and the bust measurement; and 5) convert the difference to a letter to determine the cup size.

Military Sizing System

The military sizing system is developed differently depending on the specific type of clothing involved (Table 4). Soldiers primarily use two kinds of garments, uniform and protective clothing. Uniforms are usually worn almost every moment for training, ceremonies, combat, and etc. Alternatively, protective clothing, such as the ballistic vest, is worn for training and missions (Todd, 2007). The uniforms have many sizes while protective clothing have fewer sizes, 12 sizes, 2 sizes, and 3 sizes (Table 4).

Table 4. Sizes and Cost per Unit for Uniform and Protective Clothing (Feb 2006)
(Source: Todd, 2007, p. 279)

Types	Items	Sizes	Cost per Unit
Uniform	CWU-27/P flyer's coverall	28 (Man) / 48 (Woman)	US $ 103.30
	ACU coat	38	US $ 36.95
Protective Clothing	CWU-62B/P man's anti-exposure suit	12 (Man) / 9 (Woman)	US $ 489.85
	PRU-60A/P soft armor	2	US $ 594.65
	Coveralls, firemen's, aluminized, proximity	3	US $ 466.35

There are some of the reasons why protective clothing is offered in fewer sizes. The main factor of fewer sizes of protective clothing than uniform is because the protective clothing provides adjustable fit mechanisms (Todd, 2007). Even though there are only two or three sizes, diversity of torso shapes and sizes can be fitted. Another critical factor that causes protective clothing to be available in fewer sizes is the high cost per unit (Todd, 2007). It is extremely expensive to supply the multiple sizes for covering the various body shapes of wearers (Tung, 2008).

Moreover, the army current wear field uniforms were designed and sized for male wearers (Gordon, 1986). However, as more females joined the military, for female soldier, the other military clothing as well as the uniform are need to be designed and also created the female sizing system. For instance, Gordon (1986) derived a single sizing system for the battle dress uniform (BDU) that is considered both men and women. To do so, the appropriate anthropometric databases of both male and female soldiers were selected. To facilitate a comparison of the male anthropometric database and the female anthropometric database, the dimensions selected for the shirt were shoulder circumference and stature while for the trouser; hip circumference and crotch height were chosen as key dimensions for both garments. Based on these dimensions, all anthropometric databases were arranged into a 20-size system for the shirt and a 20-size system for the trouser to address adequately both females and males. Three master patterns were developed to create the 20 integrated sizing systems; Small X-short, Medium Regular, and X-Large Long. After constructing each master pattern for both shirt and trouser, computerized pattern grading was applied to each pattern to produce the full range of sizes in both the shirt and trouser sizing systems. The grading increments for the adjacent sizes were obtained by subtracting the garment design values of the smaller or shorter sizes from the larger or longer sizes for every critical dimension specified. As a result of this study, the researcher suggested new integrated sizing systems for the shirts and trousers that comprise the battle dress uniform for both genders.

Anthropometric Database

Generally, an anthropometric database is a critical issue in designing proper sizes of clothing since it contains extensive body size and shape information (Donelson & Gordon, 1996). Moreover, it contains body measurements for use in establishing a garment sizing system (Le Pechoux & Ghosh, 2002). Thus, the anthropometric database is quite necessary for designing an appropriate sizing system in view of the target population. Table 5 shows several of the anthropometric sources of data that were available in the past.

Table 5. Anthropometric Data Sources
(Source : Le Pechoux & Ghosh, 2002, p. 12)

Source	Year	Basis of data
U.S. Dept. of Agriculture	1941	National survey civilian population
U.S. Dept. of Commerce 'PS 42-70'	1971	1941 database
National Center for Health Statistics HES	1962	National survey civilian population
Swedish Ball-Bearing Co.	1969	Foreign survey Industrial female workers
National Center for Health Statistics HANES	1974	National survey civilian population
Tokyo Women's University	1974	Foreign survey civilian population
NASA Reference publication #1024	1978	61 surveys national and international civilian and military populations
U.S. army NATICK ANSUR	1988	National survey army personnel
Federal Aviation Administration	1983	HANES national local survey
U.S. navy NCTRF	1990	National survey navy personnel
ASTM 55+	1993	1941 database PS-42-70 national
ASTM Misses 2-20	1994	1941 database PS-42-70 U.S. army & 1988 U.S. navy 1990

The anthropometric data sources given in Table 5 were developed traditionally. First, the measurers were trained to acquire correct measurements from the population. They learned the process needed to record anthropometric measurements consistently.

The measurers used calipers (Figure 4) and measuring tapes as tools for measuring the subjects' bodies.

Source: Lafayette anthropometers. (n.d.). *Model 01290 large anthropometer*. Retrieved July 08, 2009, from http://www.nexgenergo.com/medical/images/lafayettea1.jpG (left)

Figure 4. Calipers

In Yu's study (2004[b]), the traditional, manual method of measuring can result in numerous errors. The situation that can affect traditional anthropometric measurements the most is human error. Even though a measurer is trained, the accuracy of the measurements taken can vary based on the measurer's judgment when deciding the landmarks on the body. Further, when the measurer determines the landmarks on a subject's body, errors can result based on the position of the tools and the pressure of the tape. Yu (2004[b]) also presented another error associated with the traditional measurement method derives from the length of time required to obtain the many measurements. If traditional measuring methods are used for anthropometric measurement, completing the anthropometric database may take at least a year; moreover, it may involve a significant budget and tremendous effort.

Anthropometric Database for the Military

The anthropometric database for the military has been used for a long time because it is essential in the design of ceremonial and battle uniforms, protective garments, and personal equipment (Anthropometry of U.S. military personnel, 1991). Table 6 introduces many different kinds of military anthropometric databases available in the U.S.

Table 6. U.S. Military Anthropometric Databases
(Source: Anthropometry of U.S. military personnel, 1991)

Year	Population	Gender	Sample size
1946	U.S. Women's Army Corps	Women	7,563
1950	U.S. Air Force Flying Personnel	Men	4,000
1959	U.S. Army Aviators	Men	500
1964	U.S. Navy Aviators	Men	1,529
1965	U.S. Air Force Ground Personnel	Men	3,869
1966	U.S. Army Ground Personnel	Men	6,682
1966	U.S. Marines	Men	2,008
1966	U.S. Navy Recruits	Men	4,095
1967	U.S. Air Force Flying Personnel	Men	2,420
1968	U.S. Air Force Women	Women	1,905
1970	U.S. Army Aviators	Men	1,482
1977	U.S. Army Women	Women	1,331
1988	U.S. Army Men and Women	Men / Women	1,774 / 2,208

As shown in Table 6, there is a lack of data in the female anthropometric database. Most of the military clothing and accessories were designed for males because in the past, most soldiers were male. As female soldiers were gradually introduced, a downsizing system was used (Gordon, 1986). However, simply downsizing male clothing for women does not result in well fitted female soldiers because of differences in body proportions (Gordon, 1986). A typical item that was unfitted for female soldiers is the battle dress uniform (BDU). Even though a female soldier can find an appropriate shirt based on her chest circumference, the shirt likely will not fit properly over her hip area. Moreover, if a female soldier chooses a larger BDU shirt to cover her hip area, the shoulder part of the shirt may be very loose on her shoulders and fit poorly through the bust area.

The first U.S. Army anthropometric database for both females and males was based on a 1988 anthropometric study of U.S. Army personnel. Body measurements were taken from comparably measured males and females to serve the Army's current and future design and engineering needs. This anthropometric database included 2,208 females and 1,774 males, and 132 body dimensions were taken to obtain data using traditional measuring instruments and methods (Gordon, Churchill, Clauser, Bradtmiller, McConville, Tebbetts, & Walker, 1989).

Recently, researchers at the U.S. Army's Natick Research Department and Engineering Center and the Armstrong Laboratory (AL) operated by the U.S. Air Force (USAF) have used 3-D body scanners to update the anthropometric database (Paquette, 1996). The USAF's AL reported that the whole body surface of 53 subjects was scanned to acquire body measurements. This effort represented a pilot study intended to create protocols and methods needed by the military for using 3-D body scanner technology for the future survey.

Three-Dimension Scanner for Anthropometric Database

Currently, the new technologies of three-dimension (3-D) body scanning and automated measurement have been used to reduce the number of errors associated with the traditional anthropometric method (Le Pechoux & Ghosh, 2002; Yu, 2004[b]). This trend began during the mid-1980s and included head, face, and other body segments. However, since the development of the laser-based whole body scanner, the 3-D body scanner has become an efficient tool for use in the development of an anthropometric database and which is not restricted to body segments.

Many studies have focused on the introduction of the 3-D body scanner and on the benefits it offers (Jones, Lie, Brooke-Well, & West, 1995; Kang & Kim, 2000; Paquette, 1996). First, using the 3-D body scanner to generate data for an anthropometric database reduces the amount of time needed (Paquette, 1996). For instance, during the 1988 anthropometric survey of U.S. Army personnel, researchers spent four hours per subject to complete all body measurements (Gordon, Churchill, Clauser, Bradtmiller, McConville, Tebbetts, & Walker, 1989). By using the 3-D body scanning method, however, researchers spent just 10 seconds to capture data on a subject's entire body (Precise body measurement, n.d.). Subsequently, data on any part of the body can be obtained by analyzing the scanned images using the computer software (Precise body measurement, n.d.). The second advantage of using the 3-D body scanner is the accuracy of the measurements that it provides (Le Pechoux & Ghosh, 2002; Paquette, 1996). As discussed previously, most errors result from measurers' subjective decisions, such as the amount of pressure used to secure of the measuring tape. These can be prevented by using the 3-D body scanner. When the subject stands in the right position for the scanning process, the scanner uses eight cameras and four lasers at the corners of a scanning chamber to capture approximately 300,000 data points per scan. No pressure is applied during the application of this new method since the measure does not touch the subject. The natural aspects of subjects' body surfaces are captured via this 3-D body scanning process. Finally, the information obtained regarding the human figure was using computer software.

CHAPTER III

METHODOLOGY

This chapter presents methods used for all three phases of this research. Phase I discusses the process used to identify appropriate subjects for this study to represent the female soldier population. Phase II reviews methods used to conduct a focus group interview with female soldiers and presents results on information about ballistic vests and other clothing worn by female soldiers, in order to specify test garments and test movements that are used to simulate female soldiers' routine performance during duty. Phase III describes methods used to conduct the range of motion and pressure laboratory experiments. The Phase III study design, equipment, and procedures are also presented.

Phase I: Determination of Sample

Gender, age, vest size, and bust size are the criteria used to identify potential subjects for this research.

Distribution of Female Soldier Population

In this study, since the target population is female soldiers, the most recent U.S. Army anthropometric database conducted from 1987 to 1988 (Gordon, 1986), was selected for examination of female soldier measurement data. The database includes information on 3,982 soldiers, specifically 2,208 females and 1,774 males. Each subject in the database was measured for 132 specific body dimensions from the head to the feet using traditional measuring instruments, methods and millimeter units. Female soldiers ranged from 18 to 50 years old, while male soldiers ranged from 17 to 51 years old. Among the 2,208 female soldiers, 9.7% were either under 19 or over 35 years of age, and the remaining 90.3% (1,996) were between 19 and 35 years of age. Therefore for this study, the desired age range for subjects was specified as 19 to 35 years of age. The measurement data for the 1,996 female soldiers, aged to 19 and 35 years of age, was examined to specify desired sizes for the study.

Figure 5. The Interceptor™ Ballistic Vest

The primary test garment for this study is the Interceptor™ ballistic vest (Figure 5). Five sizes of Interceptor™ vests (Brantley, 2000) are designed to accommodate at least 90% of males and females, with a slightly different range of chest circumference based on gender as shown in Table 7.

Table 7. Five Sizes of Interceptor™ Ballistic Vest (Modified from Brantley, 2000)

Sizes	Chest Circumferences (inches)	
	Male	Female
XSmall	Under 33.00’’	
Small	33.00’’ - 36.99’’	33.00’’ - 37.99’’
Medium	37.00’’ - 40.99’’	38.00’’ - 41.99’’
Large	41.00’’ - 44.99’’	Over 42.00’’
XLarge	Over 45.00’’	NA

Since chest circumference is the key dimension used to determine appropriate size for the Interceptor™ vest as presented in Table 7, chest circumference data for the 1,996 female soldiers were examined; 348 females had a chest circumference less than 33 inches, 1,387 females had chest circumferences between 33 and 37.99 inches, and 248 females had chest circumferences between 38 and 41.99 inches. Thus, the largest number of female soldiers (1,387) would wear the size small Interceptor™ vest. Therefore, the size small Interceptor™ vest was specified for this study. Summarizing, then, this study includes only female subjects aged 19 to 35 years with chest circumferences between 33 and 37.99 inches.

Classification of Subjects According to Bust Size

The literature review section presents important issues related to the bust when females perform physical activity, as well as issues related to breast pain and size (Gehlsen & Stoner, 1987; Lorentzen & Lawson, 1987). Thus, classification of subjects by bust size is needed for this study.

Use of Under-Bust Circumference and Bust Circumference

In order to classify the population of female soldiers according to bust size, two body measurements, under-bust circumference and full bust circumference, were used since these two measurements are necessary to calculate bust size. Figure 6 presents a visual plot of the under-bust circumferences plotted against bust circumferences of the 1,387 female subjects in the U.S. Army database who met the requirements of this study, that is, they were between 19 and 35 years of age with a chest circumference between 33 and 37.99 inches.

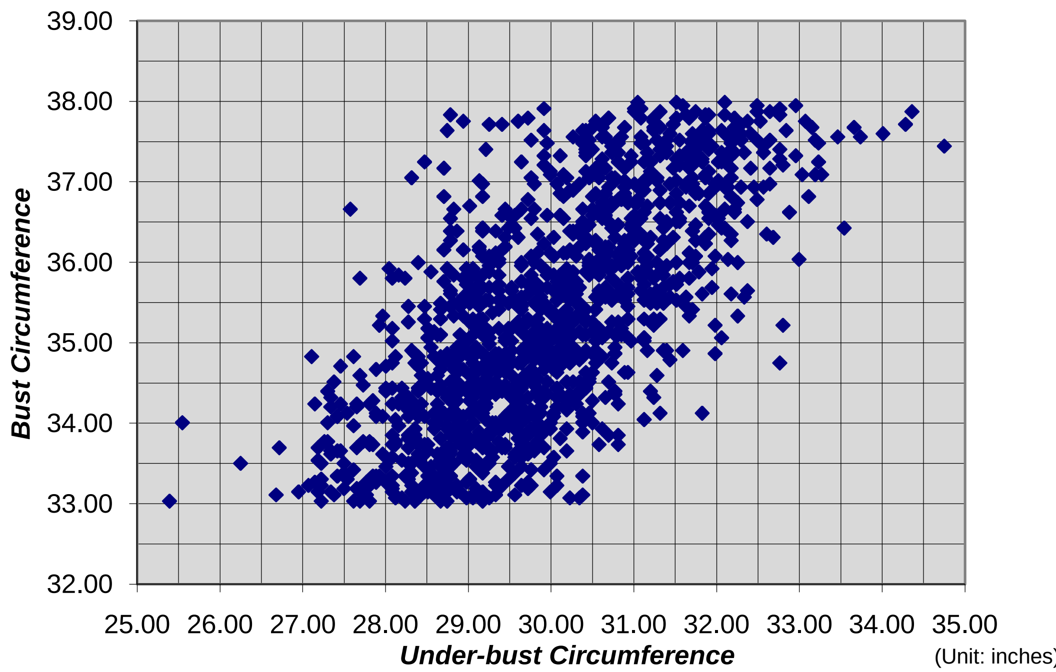


Figure 6. Plot of Female Soldiers for Under-Bust and Bust Circumferences

Grouping Based on Bust Sizes

To determine bust size, under-bust circumference and full bust circumference are required. Generally, bra band size is determined based on under-bust circumference. The difference in values between the band size and the bust circumference is calculated, and cup size of the bra is assigned according to this difference. To identify appropriate cup sizes, a small scale investigation of current bust cup sizing systems was conducted. The following Chapter III sections present the current sizing systems of six selected bra manufacturers.

<u>Five Existing Methods of Determining Bust Size</u>

Due to a lack of a standard method for determining bra sizing, many manufacturers use their own bra-sizing systems. To illustrate this, six systems from six companies were explored. Five popular bra manufacturers whose bras are found at Wal-Mart were specified including: Curvation, Hanes, Smart & Sexy, Secret Treasure, and Jing. Wacoal, a sixth bra manufacturer, which is known for high quality expensive bras, was also selected.

According to the manufacturers' websites, Hanes and Smart & Sexy use the same calculation method to develop their bra sizes, and the other four manufacturers employ four other calculation methods. Table 8 describes the five different sizing systems.

Table 8. Five Different Methods to Determine Bra Size According to Specified Manufacturers' Websites (Modified from the websites of six different bra manufacturers)

<table>
<tr><th>Methods</th><th>Steps</th></tr>
<tr><td>Curvation (Method 1)</td><td>1. Measure the under-bust circumference and the fullest part of the bust circumference.
2. Add 5 inches to the under-bust circumference. This is the band measurement.
3. Subtract the fullest part of the bust circumference measurement from the band measurement.
4. The cup size is determined according to the difference chart.
<table>
<tr><td>Difference</td><td>1”</td><td>2”</td><td>3”</td><td>4”</td><td>5”</td></tr>
<tr><td>Cup size</td><td>A</td><td>B</td><td>C</td><td>D</td><td>DD</td></tr>
</table></td></tr>
</table>

<table>
<tr>
<td>Hanes
and
Smart & Sexy
(Method 2)</td>
<td>1. Measure the under-bust circumference and the fullest part of the bust circumference.
2. If the under-bust circumference is an even number, add 4 inches and if under-bust circumference is an odd number, add 5 inches. This is the band measurement.
3. Subtract the fullest part of the bust circumference from the band measurement.
5. The cup size is determined according to the difference chart.
<table>
<tr><td>Difference</td><td>1”</td><td>2”</td><td>3”</td><td>4”</td><td>5”</td></tr>
<tr><td>Cup size</td><td>A</td><td>B</td><td>C</td><td>D</td><td>DD</td></tr>
</table>
</td>
</tr>
<tr>
<td>Secret
Treasures
(Method 3)</td>
<td>1. Measure the under-bust circumference and the fullest part of the bust circumference.
2. If the under-bust circumference is an even number, round up to an odd number to get the band measurement. If the under-bust circumference is an odd number, use number as the band measurement.
3. Subtract the fullest part of the bust circumference from the band measurement.
4. The cup size is determined according to the difference chart.
<table>
<tr><td>Difference</td><td>1”</td><td>2”</td><td>3”</td><td>4”</td><td>5”</td></tr>
<tr><td>Cup size</td><td>A</td><td>B</td><td>C</td><td>D</td><td>DD</td></tr>
</table>
</td>
</tr>
<tr>
<td>Jing
(Method 4)</td>
<td>1. Measure the under-bust circumference and the fullest part of the bust circumference.
2. If the under-bust circumference is an odd number, add 1 inch to get the band measurement. If under-bust circumference is an even number, use number as the band measurement.
3. Subtract the fullest part of the bust circumference from the band measurement.
4. The cup size is determined according to the difference chart.
<table>
<tr><td>Difference</td><td>1”</td><td>2”</td><td>3”</td><td>4”</td><td>5”</td></tr>
<tr><td>Cup size</td><td>A</td><td>B</td><td>C</td><td>D</td><td>DD</td></tr>
</table>
</td>
</tr>
<tr>
<td>Wacoal
(Method 5)</td>
<td>1. Measure the under-bust circumference and the fullest part of the bust circumference.
2. If the under-bust circumference and the fullest part of the bust circumference are not integer numbers, round to the nearest integer number.
3. If the under-bust circumference is an even number, add 2 inches and if the under-bust circumference is an odd number, add 3 inches. This is the band measurement.
4. Subtract the fullest part of the bust circumference from the band measurement.
5. The cup size is determined according to the difference chart.
<table>
<tr><td>Difference</td><td>0-0.5”</td><td>0.5-1”</td><td>2”</td><td>3”</td><td>4”</td><td>5”</td></tr>
<tr><td>Cup size</td><td>2A</td><td>A</td><td>B</td><td>C</td><td>D</td><td>DD</td></tr>
</table>
</td>
</tr>
</table>

The specification of bra cup and band size is complicated. The descriptions of the five methods from the manufacturers' websites do not provide enough information to explain all details of the necessary calculation. One piece of missing information is how to convert fractions to integer numbers if the bust and/or under-bust measurements are not integers. It is an important step for acquiring an accurate bra size because all band sizes (e.g. 32, 34, or 36) and the difference charts (e.g. 1", 2", or 3") between bust and band measurements are composed of integer numbers. Among the six manufacturers, only Wacoal explains how to derive integers from the measurements. For example, if a female has an under-bust measurement of 34.25 inches, how should band size be calculated? Is it 34, or 35? The typical practice in math is to round up if the fraction is equal to .5 or higher, and to round down if the fraction is less than .5. However, the websites do not specify this rule leading to potential consumer confusion. Thus, a consumer might round up to 35 or down to 34.

Furthermore, except for Wacoal, most manufacturers do not state an order for recording and adding a number. Let's imagine that a female has an under-bust measurement of 34.25 inches, and she wants to buy a bra manufactured by Hanes. She must round to the nearest integer number first (34") and then add 4 inches making her band size 38 (34" + 4").

Finally, cup sizes are provided only from A to DD. Methods 1, 2, 3, and 4 do not provide a bust cup size if the difference between bust circumference and under-bust circumference is under 1 inch, and Method 5 does not present a cup size for differences of less than ½ inch.

Therefore for this study, when applying these five methods to the selected data from the U.S. army female anthropometric database, rules for handling those details were controlled to avoid inconsistent results and confusion in the calculation of band and cup size, in order to create bra cup comparisons. The process was as follows: 1) convert the under-bust and bust circumferences to integers before further calculation by rounding up when the fraction is .5 or more, or by rounding down if the fraction is less than .5, 2) in the event of a difference less than 1 inch, additional sizes (2A, 3A, 4A, and 5A) were created, and 3) in the event of a difference greater than 5 inches, additional sizes (F, G, H, and I) were added.

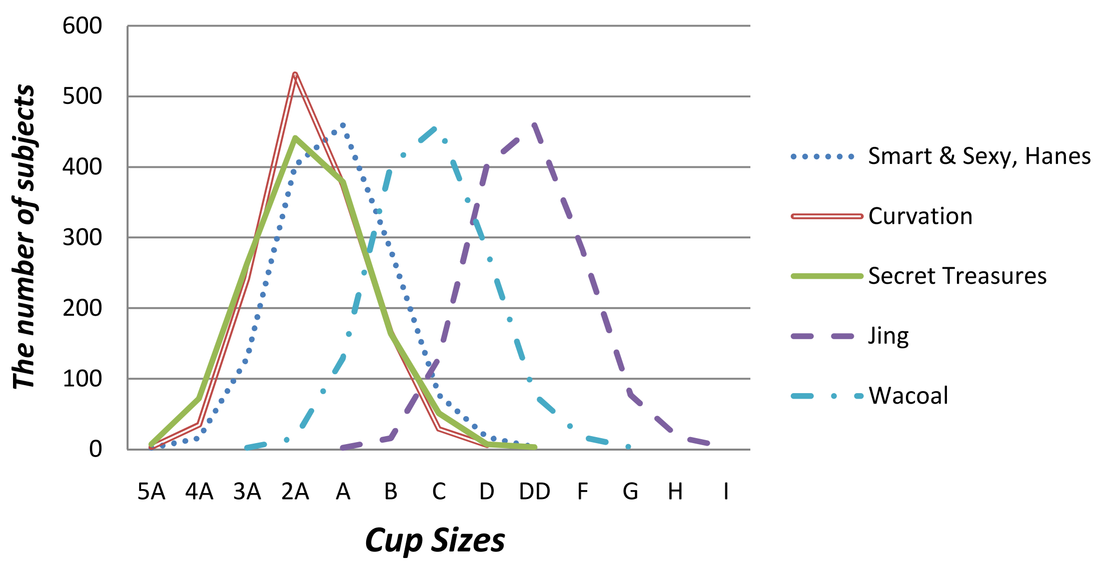
<u>Cup Sizes of Female Soldiers by Using Five Methods</u>

Measurement data from the 1,387 female soldiers were used to calculate soldiers' cup sizes using the five manufacturers' methods and the rules specified on page 52 to eliminate ambiguity in manufacturer methods. As Table 9 and Figure 7 demonstrate, all five manufacturers' methods provided different cup sizes for the same 1,387 female soldiers; Curvation (5A – D), Smart & Sexy and Hanes (5A – DD), Secret Treasures (5A – DD), Jing (A – I), and Wacoal (3A – G), and the clarifications specified for this research (pages 52 and 53). It should be noted that the distribution of female soldiers by cup size is the same for Hanes, Smart & Sexy, Jing, and Wacoal except for the assignment of cup size. For example, two subjects were assigned 5A bra cup by Hanes and Smart & Sexy while according to Jing and Wacoal, the same two subjects were assigned A and 3A bra cup sizes accordingly.

Table 9. Cup Sizes of Female Soldiers Derived by Using Five Selected Manufacturer Methods*

Bust cup sizes	Curvation	Hanes, Smart & Sexy	Secret Treasures	Jing	Wacoal
5A	3	2	7		
4A	35	16	72		
3A	242	129	263		2
2A	531	402	441		16
A	375	459	379	2	129
B	166	282	164	16	402
C	29	77	51	129	459
D	6	17	7	402	282
DD		3	3	459	77
F				282	17
G				77	3
H				17	
I				3	
Total	1,387	1,387	1,387	1,387	1,387

*Based on measurement data from the 1,387 female soldiers of the U.S. Army anthropometric database, conducted from 1987 to 1988.



*Based on measurement data from 1,387 female soldiers in the U.S. Army anthropometric database, conducted from 1987 to 1988.

Figure 7. Range of Cup Sizes of 1,387 Female Soldiers by Using Five Different Bra Manufacturer Methods*

The first three methods provided a similar range of cup sizes, but the Jing and Wacoal methods assigned very different cup sizes. The great variety in appropriate cup size was apparent. Clearly, this small investigation demonstrates that asking subjects for self-reported bra cup and band size is not a viable method for grouping subjects for this study. Thus, using measurement data from 3D body scans were chosen to assist in grouping subjects by bust size.

Grouping of Female Soldiers by Using Only the Under-Bust and Bust Circumferences

In order to determine the female soldiers' bust size group, first only the under-bust and bust circumferences was taken and plotted in Figure 8 with three groups identified based on specified differences between under-bust and bust circumferences as shown in Table 10. These three groups contain 1,188 female soldiers. The remaining 199 (14.3%) soldiers did not fit into any of the three groups. Table 11 presents the number of female soldiers in each of the three groups. Group 2 contained 502 (36.2%) soldiers who had differences between under-bust and bust circumference measurements from 5 to 5.99 inches, group 1 included 404 (29.1%) soldiers who had differences from 4 to 4.99 inches, and group 3 contained 282 (20.3%) soldiers who differences from 6 to 6.99 inches.

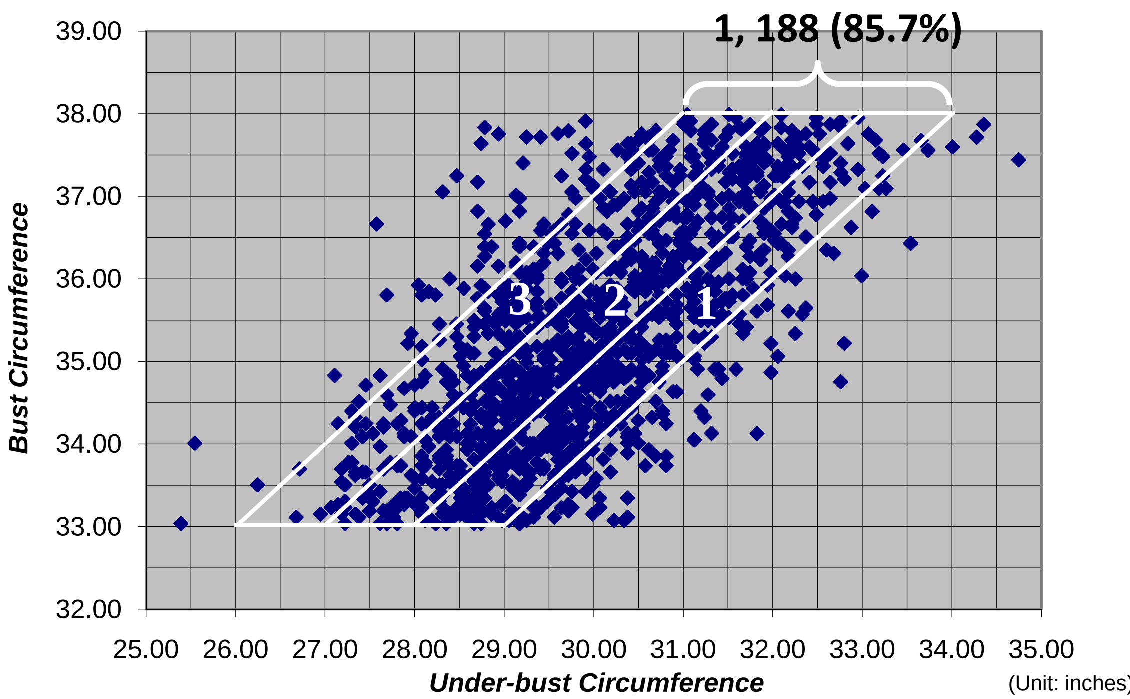


Figure 8. Three Groups in the Plot of 1,387 Female Soldiers

Table 10. Definition of Three Groups by Differences between the Under-Bust and Bust Circumferences

Groups	Difference between bust circumference and rib cage
1	4.00” – 4.99”
2	5.00” – 5.99”
3	6.00” – 6.99”

Table 11. Three-Group Distribution of 1,387 Female Soldiers

Groups	Frequency (N)	Percent (%)
1	404	29.1
2	502	36.2
3	282	20.3
Total of 3 groups	**1,188**	**85.7**
Outliers	**199**	**14.3**
Total	1,387	100.0

Therefore, for this study, subjects were sought to fit into one of the three identified groups based on the difference between their under-bust and bust circumference measurements.

Phase II: Focus Group Interview

A focus group interview was conducted to explore general information about female soldiers' problems while wearing the ballistic vest, overall experience in wearing the vest, the actual clothing system typically worn (e.g., clothing layers and type of bra), and perceived discomfort in movement while wearing the vest.

Recruiting Participants

Before recruiting the participants for the focus group, the procedure was approved by the Oklahoma State University (OSU) Institutional Review Board (IRB) (Appendix A). To recruit female soldiers to participate in the focus group interview, the researcher contacted an officer of the Oklahoma National Guard and explained the purpose of this study. With the officer's approval and assistance, a script was sent (Appendix B) to solicit female soldiers' participation.

Data Collection

Five female soldiers volunteered to participate in the focus group interview. The focus group interview was held at the Venture I Conference Room in the Oklahoma Technology & Research Park on November 7, 2009.

Each participant was asked to sign a consent form (Appendix C) prior to participation. The researcher and an Oklahoma State University faculty member led this focus group interview by asking eight questions (Appendix D), related to clothing worn as well as the ballistic vest, areas of discomfort, and typical movements completed while wearing the vests. The focus group interview which lasted about 90 minutes, was audio-recorded, and transcribed. The researcher also made notes during the interview concerning general impressions of the group and non-verbal observations.

Summary of Data

The five female soldiers who participated in the focus group interview had each been in the Guard for between one and eight years. Three had been deployed and two had not. Their primary job descriptions included: water verifier, cook, filler, vehicle maintainer, and truck driver. All had experience in wearing the Interceptor^{TM} vest. Only one soldier, who had been deployed to Kuwait, had worn the newer style vest and one had experience in wearing the Flack vest used prior to and immediately after the September 11th attack. They also reported the size of the ballistic vests that they wore: two wore size small and three wore size medium.

The first topic participants discussed in the focus group interview was overall experiences in wearing the Interceptor^{TM} vest. Most of the participants asserted that the Interceptor^{TM} vest was too tight over the bust. Some commented on the hard plates pressing on the bust area. The hard plate, which is primarily rectangular in shape with cut-off corners, covers most or all of the bust area and causes considerable perceived compression on the bust according to participants. For instance, one participant said that, after performing active movements, such as running while wearing the Interceptor™ vest, she had problems breathing which she attributed to compression over her bust and the limited space between the breasts and the vest. Participants also noted that they were sometimes issued a larger vest size than their chest measurements would indicate because smaller size vests were unavailable. Finally, the participants were asked about their level of satisfaction in wearing the Interceptor™ vest on a scale from 1 (very dissatisfied) to 5 (very satisfied). Two participants who had a large bust ranked their satisfaction level at 1, another two participants ranked their satisfaction level at 2, and one participant who was thin chose 3 to express her satisfaction level. No participants ranked their satisfaction level at 4 or 5.

One participant had experience wearing the new Army style vest and reported that it was more comfortable than the Interceptor™ vest. However, she also reported that a problem with the new style vest was the complicated design, which made it difficult to properly locate and assemble all components of the vest. Other than this problem, she was pleased with the new-style vest and ranked her satisfaction with the new-style vest at 4.

Next, the entire clothing system was described in order to clarify what clothing female soldiers typically wore under their ballistic vests. First, participants explained what kinds of bras they wore while wearing the ballistic vests. All five participants said that they preferred to wear sports bras instead of regular bras. Two reported wearing the Army-issued sports bra, and the other three said that they were unaware that an Army-issued sports bra was available. However, all participants agreed that they wore sport bras, whether Army-issued or not, when they were involved in physical activities because sports bras avoided tight bands and sweating and maintained better room over the bust area for easier breathing. Only one participant, who had a larger bust than the others, mentioned that she sometimes wore both a regular bra and a sports bra at the same time to reduce bust movement.

Subjects reported that other clothing worn over the bra consisted of a T-shirt and a blouse (the jacket of the Battle Dress Uniform (BDU)) or, in colder weather, instead of short T-shirt, a long-sleeved T-shirt under the BDU jacket. The ballistic vest was worn over the blouse in warmer weather and, in cool weather, a jacket was worn over the blouse, with the vest over the jacket. Respondents reported that they usually did not wear the front neck protection piece. All reported that they inserted the front and back hard plates into the pockets of the ballistic vest because of strict rules that they do so for all conditions, even for training.

The final topic discussed in the focus group interview was female soldiers' typical movements practiced while wearing ballistic vests. The first noted problematic movement was getting into a truck. While wearing the ballistic vest, the female soldiers reported that it was difficult to perform this movement because the heavy and bulky vest restricted their shoulder movement and made it difficult to move their arms straight up to grab hold of the handle to pull the body up into the truck. Moreover, the first step of the truck is about 1 m (39.39 inches) from the ground, which is quite high even for a male. The soldiers usually had to place one foot on the truck, reach overhead, grip the handle, and push off with the other foot to get into the truck. One participant also stated that she could not raise her arms all the way up when she loaded something into the truck because of restricted shoulder movement due to the ballistic vest.

The second movement that participants discussed was the shooting position. The female soldiers reported that while holding a rifle in a standing shooting position, the rifle butt should be located in a specific place near the shoulder. This position, however, was reported as difficult for some who found that the thickness of the vest was problematic. The soldiers also reported discomfort in the armhole area when raising the rifle. In doing so, the shoulder should be lifted up and forward, resulting in pressure on the side armhole area and restricting shoulder flexion. The participants also reported having problems with the kneeling shooting position. When some assumed that pose, the ballistic vest was lifted up because the length of the vest touched the thigh and pushed the vest upward toward the chin.

Third, participants indicated that it is difficult to bend at the torso while wearing ballistic vests. One of the participants said that if she picked up something she had dropped on the floor, it was difficult to bend the trunk while wearing the vest. Thus, she usually chose to squat to pick up the object, rather than bending.

All participants claimed that crawling and the prone position were uncomfortable because of restrictions caused by the ballistic vest. When crawling, soldiers are down on the ground. They reported that it was difficult to move their whole body, as they must do when crawling, while wearing the vest.

The results from the focus group highlighted the need for research, specifically obtaining quantifiable data related to movement and pressure. Second, the participants' discussion about the clothing system led the researcher to specify the following as test garments for this study: <u>A sports bra, T-shirt, BDU blouse/jacket, and Interceptor™ vest</u>

in order to simulate the same conditions experienced by female soldiers. Front and back hard plates were inserted into the vest. The collar and front neck piece were not worn.

The focus group data were also used to specify four basic movements that were difficult for female soldiers to perform during normal operations while wearing the vest. Shoulder flexion, shoulder horizontal abduction, trunk flexion, and hip flexion with kneeling (Table 12) were specified as the test movements addressed in this study.

Table 12. Four Specified Test Movements for This Study

Movements	Front views	Side views
Shoulder Flexion		
Shoulder Horizontal Adduction		
Trunk Flexion		
Hip Flexion with Kneeling		

Shoulder flexion reflected the shoulder movement required to hold the handle when getting into a truck and loading something onto a truck. Secondly, shoulder horizontal adduction was selected as a component movement when soldiers assume a shooting position and when they move their arm across their chest and vest. Truck flexion movement was adopted to simulate the bending torso movement while wearing the ballistic vest. The final movement was hip flexion with kneeling, which simulated the soldier's kneeling shooting position.

Phase III: Laboratory Wear Test

In Phase III, range of motion and pressure-contact area over the bust area were measured while selected volunteer subjects performed four specified movements completed in designated garments in a controlled two-part laboratory experiment. Range of motion test was conducted in the first part of the laboratory test and pressure-contact area was determined in the second part of the laboratory test. This section of Chapter III discusses sampling plan, alternative methods of grouping subjects, independent variables, dependent variables, study designs, equipment, test garments, test procedures, data collection, data extraction, and statistical analyses for both parts of the experiment.

Sampling Plan

Potential participants in this study were originally planned to consist of female volunteers, ages 19 to 35 years, with a bust circumference ranging from 33 inches to 37.99 inches. The goal was to recruit 30 subjects in total, ten subjects in each of three bust size groups based on analysis of measurement data conducted during Phase I of this study. However, a sufficient number of subjects could not be found for all three groups.

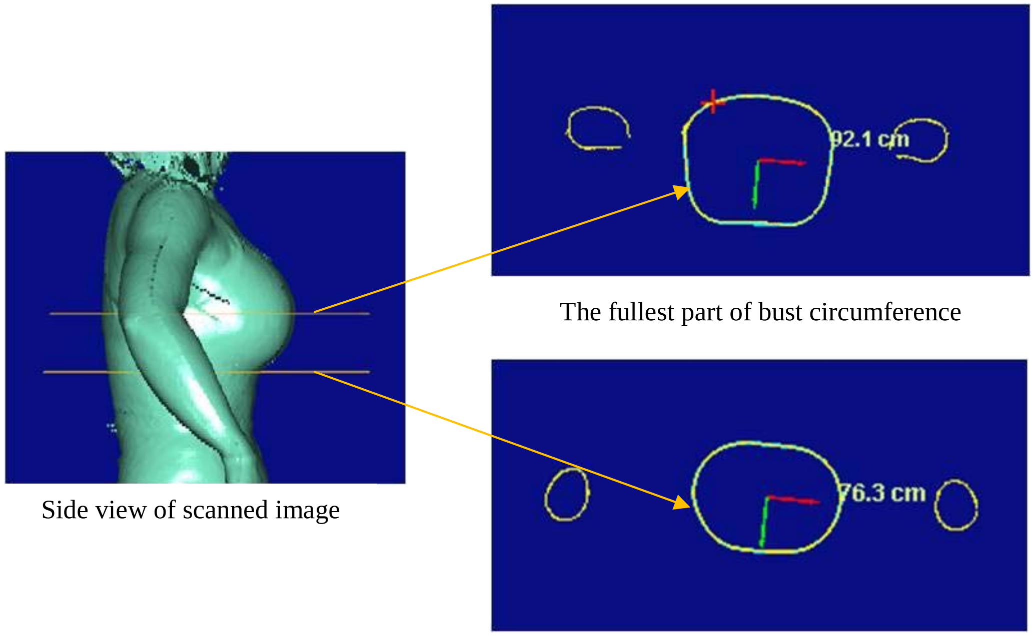
Acceptance of subjects began in early March, 2010. A total of 38 females responded to posting of the first flyer (Appendix E). The volunteers were scanned to measure their under-bust and bust circumferences as their measurements were used to determine if they satisfied the criteria to participate in the study. Of the 38 potential subjects, 16 satisfied the criteria and were subsequently involved in the laboratory experiments. None of the 16 subjects fit into the third group.

The flyer (Appendix E) previously approved by the IRB was amended to recruit subjects who wore large bra cup sizes; the age range was extended to include 18 year-olds; and specific cup sizes (32 C, D, or above) were added. The amended flyers (Appendix F) were once again posted throughout the Oklahoma State University campus. Ten additional volunteer subjects were recruited to participate after posting the amended flyers. Although six of the ten had bust circumferences that exceeded 37.99 inches, they were accepted for participation in the study. The second round of subject recruitment was accomplished from May 15 to June 4, 2010.

Alternative Methods for Grouping Subjects

Method A

To categorize subjects into groups based on bust size, method A proposed to divide the three groups based on the difference between bust circumference and under-bust circumference as previously discussed and specified in Table 10 (page 56). The scanned images were used to measure both circumferences. The scanned images were rotated to the side view to create two planes at the level of the fullest part of the bust and under-bust using the AnthroScan software. These two circumference measurements were calculated automatically (Figure 9).



Side view of scanned image

The fullest part of bust circumference

The under-bust circumference

Figure 9. Process to Measure Bust and Under-bust Circumferences (Method A)

The circumference measurements were converted from *cm units* to *inches*; the differences between these two measurements were subsequently calculated for each subject. Based on the differences, each subject was assigned to one of the three groups defined by method A. The smallest group, those with a difference between under-bust and bust circumferences ranging from 4.00 to 4.99 inches, had 11 subjects; the medium group, those with a difference between from 5.00 to 5.99 inches, had 14 subjects; and the large group, those with a 6.00 to 6.99 inches difference, had one subject. Thus, method A did not appear to be an appropriate grouping method for use with the 26 subjects because only one subject was in group three.

Method B

Method B was an alternative grouping method based on the thickness of the right side of the breast from a vertical plane created at the right side of the under-bust area and parallel to the front of the body. To create the vertical plane at the under-bust level, an under-bust point directly below the bust point was determined as shown in Figure 10. The AnthroScan program created a plane through the under-bust point and parallel to the body as shown Figure 10. The thickness of the right breast from the vertical plane was determined as the distance from the plane to the bust point as shown in Figure 11.

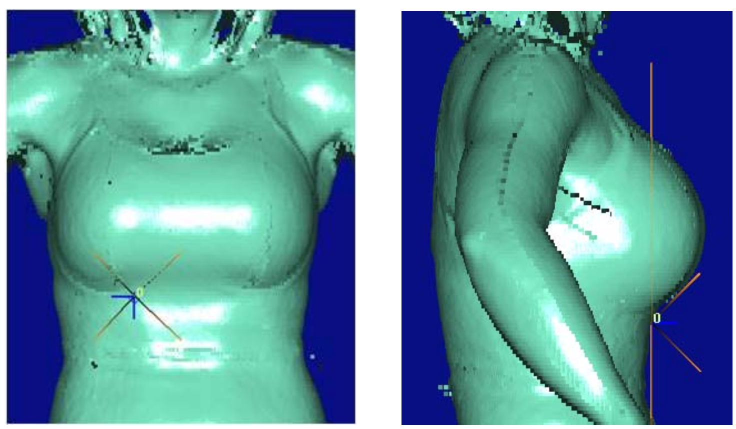


Figure 10. Under-Bust Point (left) and Vertical Plane (right)

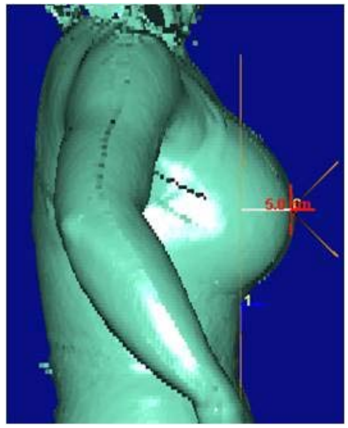


Figure 11. Process to Measure the Thickness of the Right Breast
from a Created Vertical Plane (Method B)

Using the right breast thickness, all 26 subjects were categorized into three groups. The small group, which ranged from 0.5 to 2.0 cm, had 14 subjects; the medium group, which ranged from 2.1 to 3.5 cm, had nine subjects; and the large group, which ranged from 3.6 to 5.0 cm, had three subjects. Although method B provided more subjects in the large group, number of subjects per group was still unbalanced.

Method C

Grouping method C used an inclined plane instead of a vertical plane to measure the right breast thickness. First, four points were created in the scanned image as follows: 1) right breast under-bust point, 2) left breast under-bust point, 3) giugula, and 4) right breast point. The same right bust point created in method B was used in method C. The inclined plane was created based on three points: the right breast under-bust point, the left breast under-bust point, and the giugula. Using the inclined plane, thickness of the right breast was determined. All of these processes are shown in Figure 12.

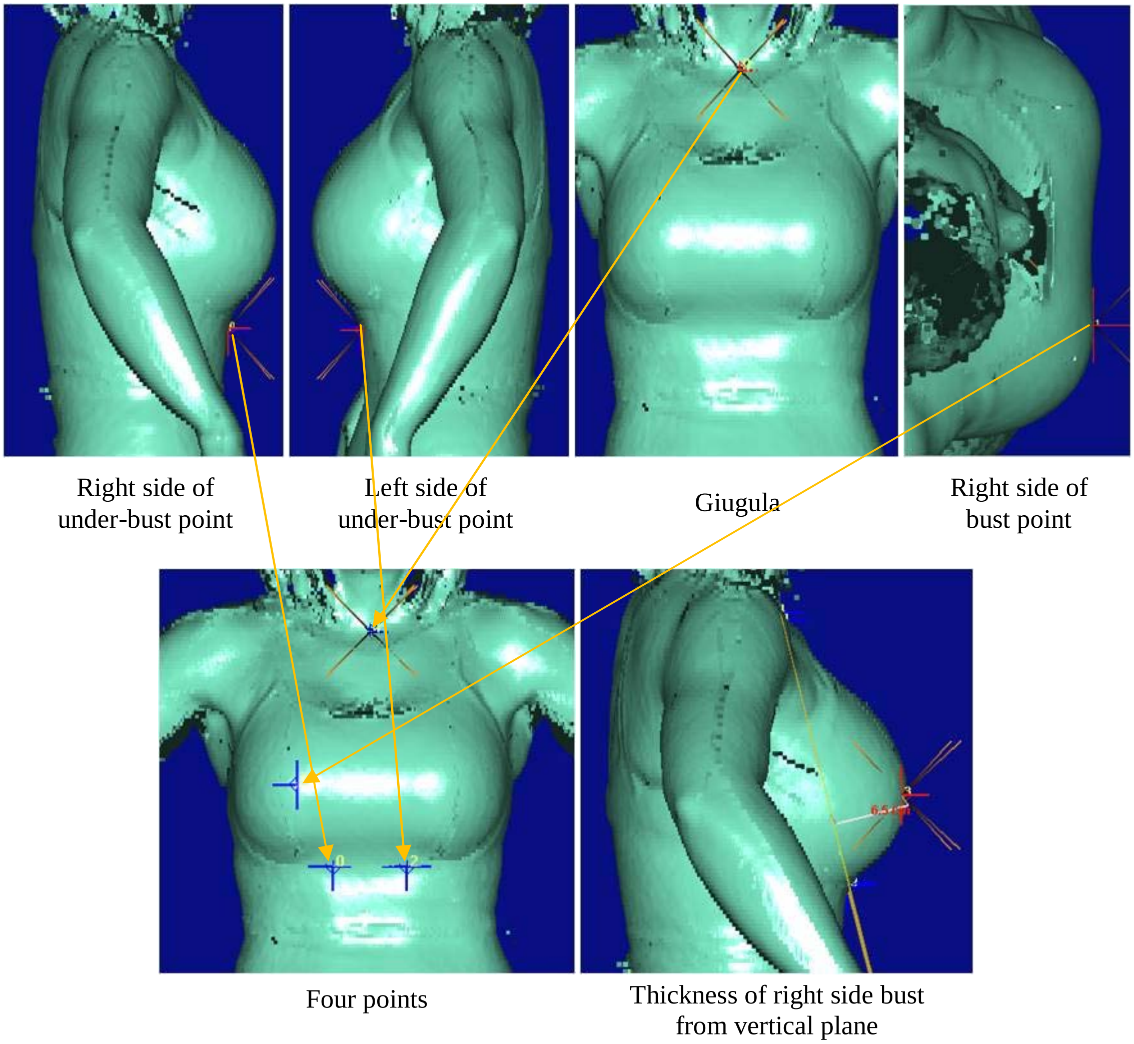


Figure 12. Process to Measure the Thickness of the Right Breast from the Inclined Plane (Method C)

Figure 13 shows the distribution of the 26 subjects using for method C. The small group includes eight subjects with bust thickness from 2.0 to 3.5 cm, the medium group includes 11 subjects with bust thickness from 3.6 to 5.0 cm, and the large group includes seven subjects with bust thickness from 5.1 to 6.5 cm.

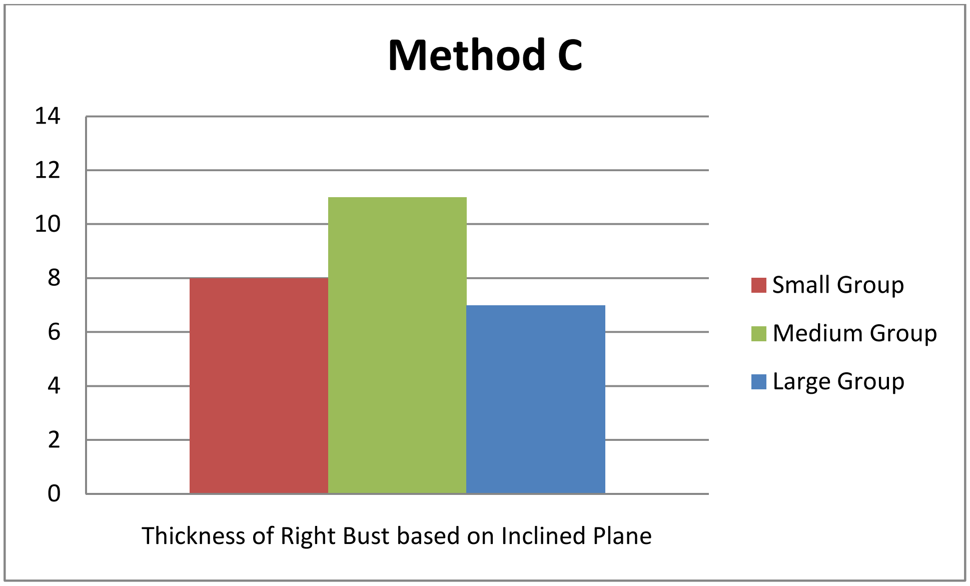


Figure 13. Distribution of 26 Subjects in Method C

After examining all three alternative methods for grouping subjects, method C was selected for grouping the 26 subjects for this study. One of the other two methods could have been used if only two groups were formed. Method C not only provides 7 subjects in group three. But, that method conceptually is meaningful when considering distribution of breast tissue over the front torso.

Independent Variables

The first independent variable, bust size, had three levels for both parts of the laboratory experiment. The first level indicates the group with bust thickness ranging from 2.0 to 3.5 cm. The second level represents the group of subjects whose bust thickness ranged from 3.6 to 5.0 cm. The third level is the group of subjects with a 5.1 to 6.5 cm bust thickness. The second independent variable for the first part for the laboratory experiment was garment treatment at two levels, with and without the Interceptor™ vest.

Dependent Variables

Dependent variables were range of motion and pressure-contact area over the bust area during completion of the specified movements. Range of motion was tested in the first part of the experiment and pressure-contact area was determined in the second part of the experiment.

Study Design

Two experiments using two different designs were performed to investigate the two dependent variables separately. First, to determine range of motion, a randomized complete block factorial design was employed, incorporating two factors: bust size and garment. The subjects performed four movements.

The second design, which determined pressure-contact area over the bust area, was also a randomized complete block design but with one factor (i.e., bust size). For the statistical analysis, the experiment was blocked based on subjects. Each subject performed the same four movements in three trials, repeating five cycles in each trial.

Equipment

Three pieces of equipment were used to acquire data for this study: 1) the VITUS XXL Three-Dimension (3-D) body scanner, which was used to obtain subjects' measurements accurately; 2) the BTS Smart – D Motion Capture System, which was employed to measure subjects' range of motion while the subjects performed the four selected movements; and 3) the Tekscan BPMS, which was used to measure pressure-contact area over the bust while the subjects performed the four selected movements.

VITUS XXL Three-Dimension (3-D) Body Scanner

The VITUS XXL 3-D full body scanner by Human Solutions was used to determine potential subjects' under-bust and bust measurements. This full body scanner captures the complicated curvature of the human body (http://www.human-solutions.com). The scanning is a quick (12 seconds) and accurate method of taking body measurements. Four laser lights are located on columns at the corners of the booth and scan from the top of the subject's head to the feet. During the scanning process, eight cameras capture the reflected light from the body's surface and the computer system translates the captured light into 3D data vertically on a screen as an image. Finally, two parallel planes on the under-bust and bust levels were created based on the scanned images, and these two circumferences were measured using AnthroScan measurement tools.

BTS Smart – D Motion Capture System

The BTS Smart – D Motion Capture System was used to measure subjects' range of motion. Eight infrared cameras capture the laser light reflected from the body's surface, and the computer system translates the captured light into 3D data as an image on the screen.

To operate the BTS Smart – D Motion Capture System, three software programs were used: 1) BTS Smart – Capture, 2) BTS Smart – Tracker, and 3) BTS Smart – Analyzer. BTS Smart – Capture is used to calibrate the system and acquire the subject's movements. The data captured by BTS Smart – Capture are then reconstructed into 3-D motion-captured data using BTS Smart – Tracker. Finally, BTS Smart – Analyzer transfers the 3-D motion-captured data into biomechanical data, such as distances, angles, speeds, acceleration (linear and angular), forces, moments, and powers. In this study, only the maximum angles of range of motion were measured during the movements. The angles measured for each movement are presented in Figure 1 (please see p. 9).

Tekscan BPMS

Pressure-contact area was measured using the Tekscan BPMS, which is a digital pressure-sensing device developed by Tekscan Inc. The current study used sensor number 5350 (Figure 14), which is 42.5 × 39.5 cm in dimension. During the data collection procedure, the sensor is inserted into an evolution sensor handle to gather data from the sensor (Figures 14). Data from the sensor are sent to a computer and analyzed using the BPMS Research 6.20 Tekscan software. Force, contact area, and pressure can be calculated from the obtained data.

Figure 14. Tekscan BPMS Sensor (# 5350) and Evaluation Sensor Handle

Test Garments

To test range of motion and pressure-contact area over the bust area, three garment conditions were prepared: 1) garment A (the sports bra + a sleeveless shirt + long knit pants), 2) garment B (the sports bra + a sleeveless shirt + long knit pants + the Interceptor™ vest with hard plates), and 3) garment C (the sports bra + T-shirt + battle dress uniforms [BDU] + the Interceptor™ vest with hard plates). Garments A and B were used to measure range of motion while garment C was used to test for pressure-contact area.

Garment A consisted of a sports bra, long knit pants, and a sleeveless 100% cotton shirt (Figure 15). Subjects wearing Garment A performed the four movements in order to measure their range of motion with no clothing restrictions. To measure range of motion of subjects' joints, markers were attached as close as possible to the skin; thus, seminude clothes were chosen as they tended to cling to the subjects' skin and allow for capture of more precise range of motion data.

Garment B consisted of an Interceptor™ ballistic vest (Figure 15) over Garment A. Front and back hard plates in size small were inserted into the pockets of the Interceptor™ vest. The front and back hard plates, which are commercially available, have a trapezoidal shape with a slight curve to cover the human body (Figure 16).

Finally, Garment C consisted of the Interceptor™ ballistic vest over the BDU (Figure 15). The same front and back hard plates (Figure 16) were inserted into the vest. This garment condition was used to measure pressure-contact area over the inside of the ballistic vest. Wearing the T-shirt and BDU was used to simulate clothing normally worn by female soldiers in combat areas.

Figure 15. Garment A (left), Garment B (middle), and Garment C (right)

Figure 16. Front View (left) and Back View (right) of Small Size Hard Plate

Test Procedures

Approval to carry out all test procedures was acquired from the Oklahoma State University Institutional Review Board (OSU IRB) (Appendix G) before human subject data collection began. A initial flyer (Appendix E) advertising for subjects included the three criteria for participation: 1) female, 2) ages 18 to 35 years old, and 3) bust circumference from 33 to 37.99 inches. As already described, a second flyer (Appendix F) was created and posted to assist in recruiting subject with a large difference in bust and under-bust circumferences. The flyers were posted around the Oklahoma State University campus, and interested subjects were directed to the Institute for Protective Apparel Research and Technology (IPART) laboratory located in the Venture I building in the Oklahoma Technology and Research Park. Once a female subject arrived in the lab, she was informed about the purpose of the research as well as all test procedures. If the subject was still interested in participating in the study, she was provided with the consent form (Appendix H) and asked to read and sign the form.

After signing the consent form, each potential subject was given and asked to don a sleep bra, a sleeveless shirt, and long knit pants in order to determine body measurements over each subject’s own underwear. Potential subjects entered the scanning box and positioned their feet on the marked floor (Figure 17). After positioning their feet appropriately, subjects were asked to spread their arms slightly so the scanner did not miss any portion of their body surfaces, as shown in Figure 12. Before scanning began, the subjects were asked to assume the scanning position three times in order to become accustomed to the testing position.

Figure 17. The Scanning Position

After practicing the position, the subjects stood in the center of the scanner platform while maintaining the same position and were scanned to capture their full body surfaces. After scanning was completed, the researcher used the measurement tool in the AnthroScan software to determine subjects' under-bust and bust circumferences. Based on these measurements, the subjects were categorized into one of three groups as previously described. If the subjects' measurements were outside the parameters of the three groups, they were not permitted to participate in this study. Selected subjects participated in the two part laboratory wear test for this study.

Range of Motion (ROM)

To define range of motion for each movement, the researcher developed measurement protocols for all four selected movements. The protocols developed to extract the angle from the captured motion data are presented in Appendix I. Next, to determine the range of motion, the BTS Smart – D Motion Capture System was calibrated according to the procedure described in Appendix J. The test procedures for gathering the range of motion data are explained below.

1. Each subject wore garment A (a sports bra + a sleeveless shirt + a pair of long knit pants).
2. After changing into the test clothes, the subject performed the four specific movements following the researcher's explanations and visual presentations of the movements posted on the lab wall to help subjects understand the procedures. Subjects practiced each movement three times to become accustomed to the procedures.
3. The researcher attached the markers (Figure 18) to the following joints to capture subject's motion during all four movements: 1) right acromion, 2) giugula, 3) left acromion, 4) right asis, 5) sacrum, 6) left asis, 7) right elbow, 8) right wrist, 9) right trochanter, and 10) right femoral condyle (Figure 19). All markers were attached at the beginning of the test; unnecessary markers for each movement were removed during the data extraction process.

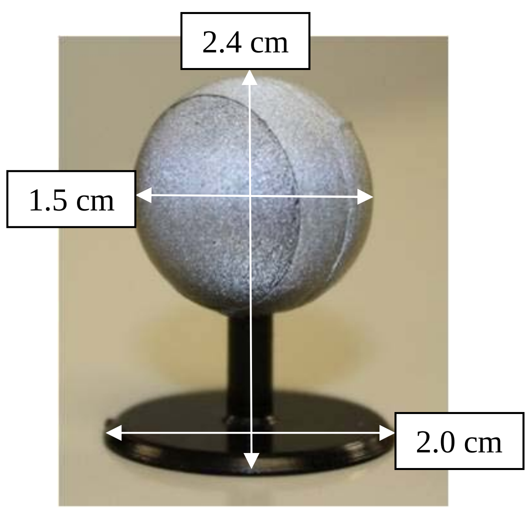


Figure 18. Marker of BTS Smart Motion Capture System

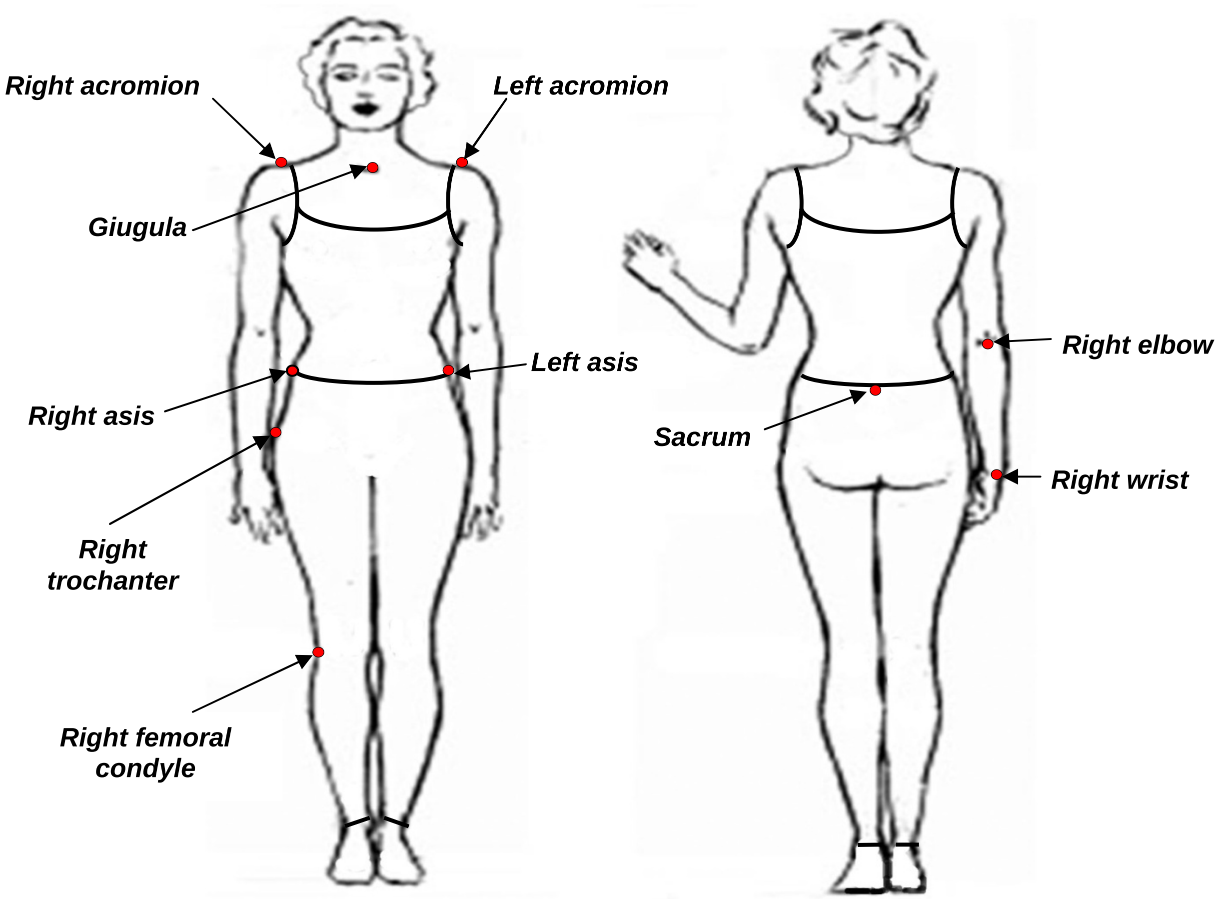


Figure 19. The Locations of the Markers

4. After attaching all markers, the subject stood in the designated space volume for capturing measurement data and performed all four movements, shoulder flexion, shoulder horizontal adduction, trunk flexion, and hip flexion with kneeling, while wearing garment A. Three sets of data were obtained for each movement, and each set was collected for 30 seconds. During the movement itself, the subject moved the body segments that were part of the movement as much as possible without moving other body parts.

5. The subject donned the Interceptor™ vest with inserted front and back hard plates over garment A (i.e., garment B). The subject performed all four movements while the range of motion was captured. This was repeated three times for each movement.
6. Upon completion of the range of motion test for all four movements, the subject moved to the next test procedure to obtain the pressure-contact data.

Pressure Data

The researcher calibrated the Tekscan BPMS before starting the pressure test. For the pressure test, the selected 5350 Tekscan sensor was sufficiently large enough to cover the entire bust area (Figure 20).

Figure 20. Sensor (# 5350) Attached to the Inner Side of the Left Front Interceptor™ Vest

The sensor was attached to the inner side of the left front Interceptor™ vest (Figure 20) as the Interceptor™ vest has a front opening with a Velcro closure. After preparing the calibration and placing the sensor on the ballistic vest, the pressure data were collected. The procedures for measuring the pressure data were as follows:

1. Subject donned garment C (the sports bra + T-shirt + BDU + the Interceptor™ vest with hard plates), and the pressure sensor was inserted between the BDU and ballistic vest.
2. The researcher inserted the sensor into an evolution sensor handle to transfer the data to the computer. Using this procedure, all pressure data on the bust area inside the ballistic vest were recorded and saved into the computer (Figure 21).

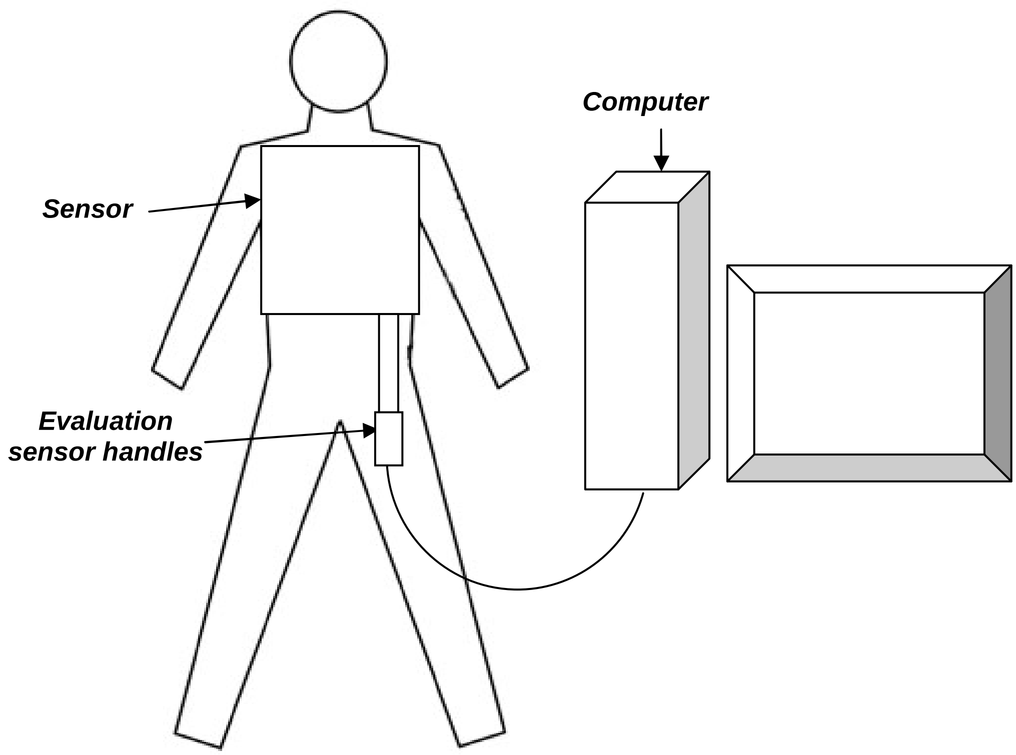
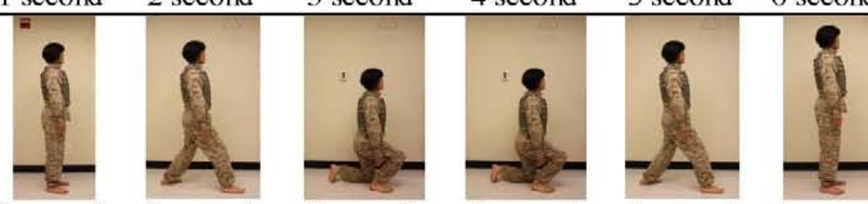


Figure 21. Diagram of Tekscan Pressure Sensor System

3. While wearing garment C, which was attached to the pressure sensor, the subject performed all four different movements, repeating five cycles of each movement in one trial. Each subject conducted three trials per movement. To control the speed of all subjects' movements, the researcher performed the same movement in front of the

subject while following the metronome. The movement cycle for all four selected are presented in Table 13.

Table 13. Speeds of Cycles for All Four Movements

Movements	Cycle
Shoulder Flexion	 1 second 2 second 3 second 4 second 5 second 6 second
Shoulder H. Adduction	 1 second 2 second 3 second 4 second 5 second 6 second
Trunk Flexion	 1 second 2 second 3 second 4 second 5 second 6 second
Hip F. with Kneeling	 1 second 2 second 3 second 4 second 5 second 6 second

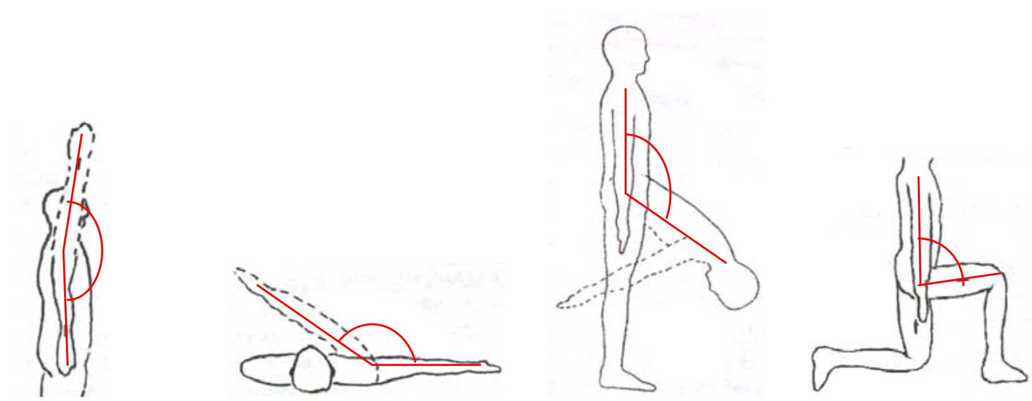
4. After completing all tests, the subjects changed into their own clothes and received an incentive from the researcher.

Data Extraction

Range of Motion (ROM)

For the range of motion tests, three sets of trials were conducted for each movement, and each set of data was collected over a period of 30 seconds. Thus, a large amount of raw data was generated. Before analyzing range of motion data, data extraction procedures were conducted.

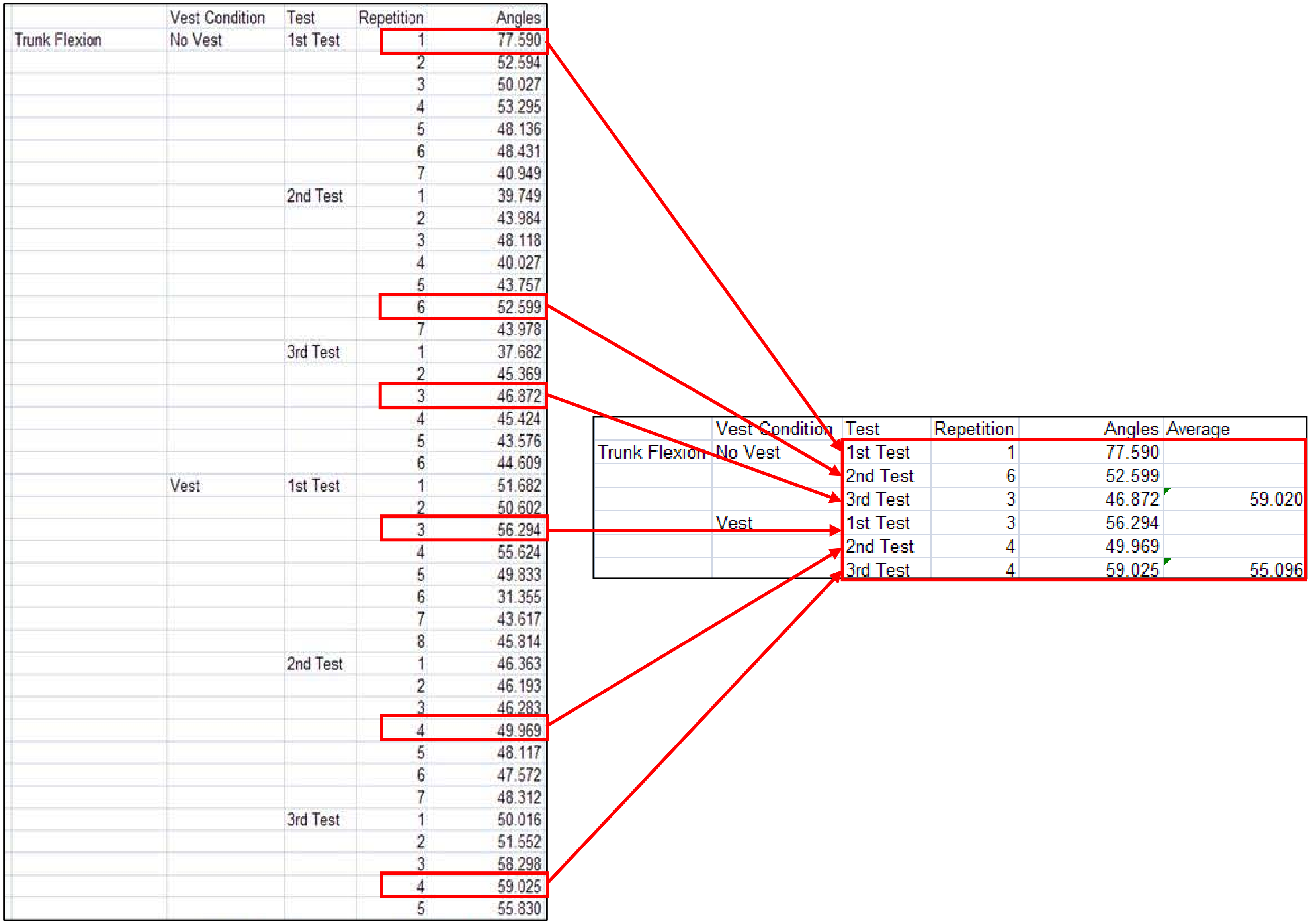
The captured and recorded data from the range of motion test were first transferred from the markers' motions to the subjects' motions. Using the BTS Smart – Tracker software program, the required markers of the specific captured motion were entered, labeled, and tracked according to the following movements: 1) shoulder flexion movement (right acromion, right elbow, and right wrist), 2) shoulder horizontal adduction movement (right acromion, left acromion, right elbow, and right wrist), 3) trunk flexion movement (right acromion, giugula, left acromion, right asis, sacrum, and left asis), 2) hip flexion with kneeling movement (right acromion, right trochanter, and right femoral condyle). Only data from the necessary markers tracked were used for each movement analysis. The BTS Smart – Analyzer software program was then used to measure the angle of the range of motion of each movement. The angles measured for each movement are presented in Figure 22.



Shoulder Flexion   ***Shoulder H. Adduction***   ***Trunk Flexion***   ***Hip F. with Kneeling***

Figure 22. Angles Measured for Each Movement

Each subject continued to perform each movement for 30 seconds, during which time the subjects performed the same movement as many times as they could. Each subject performed each movement three times with the vest and three times without the vest. Using the raw data, the maximum angles from each test were extracted for each movement. Thus, <u>the three maximum angles while wearing the vest and three maximum angles without wearing the vest from each movement (Figure 23) were used for data analysis. Based on these angles, the average of the maximum angles while wearing the vest and without the vest were calculated (Figure 23)</u>.



	Vest Condition	Test	Repetition	Angles
Trunk Flexion	No Vest	1st Test	1	77.590
			2	52.594
			3	50.027
			4	53.295
			5	48.136
			6	48.431
			7	40.949
		2nd Test	1	39.749
			2	43.984
			3	48.118
			4	40.027
			5	43.757
			6	52.599
			7	43.978
		3rd Test	1	37.682
			2	45.369
			3	46.872
			4	45.424
			5	43.576
			6	44.609
	Vest	1st Test	1	51.682
			2	50.602
			3	56.294
			4	55.624
			5	49.833
			6	31.355
			7	43.617
			8	45.814
		2nd Test	1	46.363
			2	46.193
			3	46.283
			4	49.969
			5	48.117
			6	47.572
			7	48.312
		3rd Test	1	50.016
			2	51.552
			3	58.298
			4	59.025
			5	55.830

	Vest Condition	Test	Repetition	Angles	Average
Trunk Flexion	No Vest	1st Test	1	77.590	
		2nd Test	6	52.599	
		3rd Test	3	46.872	59.020
	Vest	1st Test	3	56.294	
		2nd Test	4	49.969	
		3rd Test	4	59.025	55.096

Figure 23. Six Maximum Angles Extracted from Raw Data and Two Average Maximum Angles

For each movement, the researcher calculated the difference between the two average maximum angles (with-vest data and without-vest data). Each subject's percent difference in range of motion was calculated using the equation shown in Figure 24. For example, if the average maximum angle while wearing the vest was 55.096 degrees and the average maximum angle without the vest was 59.020 degrees when performing the trunk flexion movement, the difference between the maximum angles is -6.649%, indicating that the range of motion was reduced 6.649% while wearing the vest.

$$PDMA = \frac{MAV - MANV}{MANV} \times 100\%$$

PDMA: Percent Difference Maximum Angles
MAV: Maximum Angle with Vest
MANV: Maximum Angle with No Vest

Figure 24. Equation Used to Calculate the Percent Difference of Two Maximum Angles between Wearing the Vest and Not Wearing Vest

For each movement, <u>the percent difference (representing the change in range of motion while wearing the ballistic vest) was measured and used as the dependent variable</u> to analyze how the ballistic vest affected the wearer's performance according to bust size.

Pressure-Contact Area

For the pressure test, pressure-contact area data were continuously recorded during five cycles of three trials for each movement. Four pressure-contact area data were recorded every second using the Tekscan software. Figure 25 shows a subject completing one cycle of the trunk flexion movement, which should have taken six seconds. Each second represented one position as shown in Figure 25. For trunk flexion, there are six positions per cycle selected as reference points to coordinate with the pressure data. Since the speed of the movement in each cycle was controlled by the metronome, theoretically, the pressure data of the two positions (1st & 6th) should be similar (Figure 25). However, the pressure data in these two positions were different as shown in Figure 26, where the pressure-contact area data were graphed using Tekscan software over time. This may be due to the subjects moving in a different rhythm when going down and/or up. Similarly, the 2nd and 5th movements might be expected to yield similar pressure data. However, this is not the case as shown in Figure 26. This may be due to timing as previously discussed or it may be that the downward and upward movements do yield different pressure data.

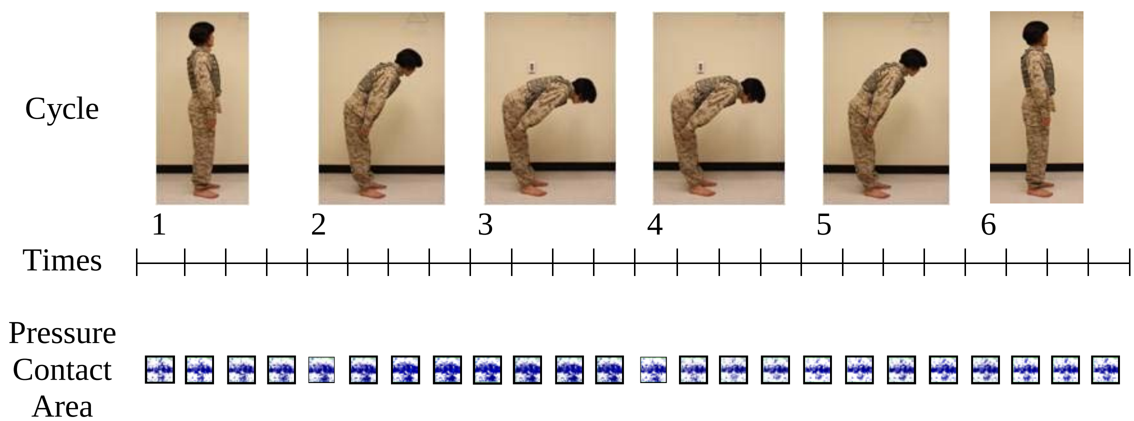


Figure 25. Cycle and Four Pressure-Contact Areas in Second

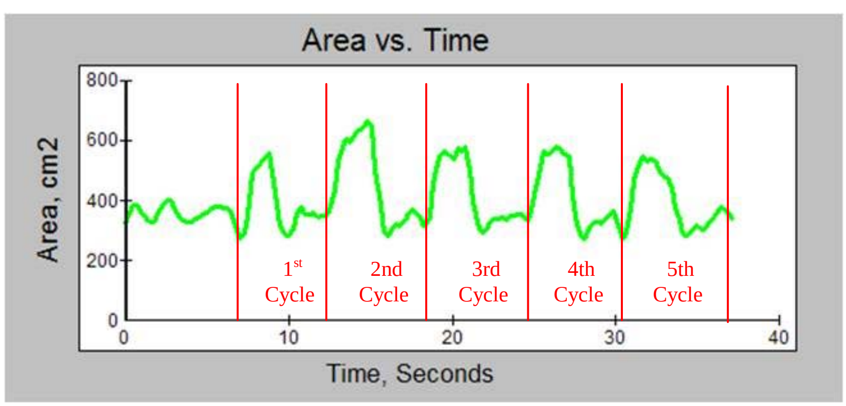


Figure 26. Pressure-Contact Area Graph of Five Cycles in One Trial

Figure 27 shows one of the pressure maps with the times in the lower left-hand corner and the pressure-contact area given in the upper right-hand corner.

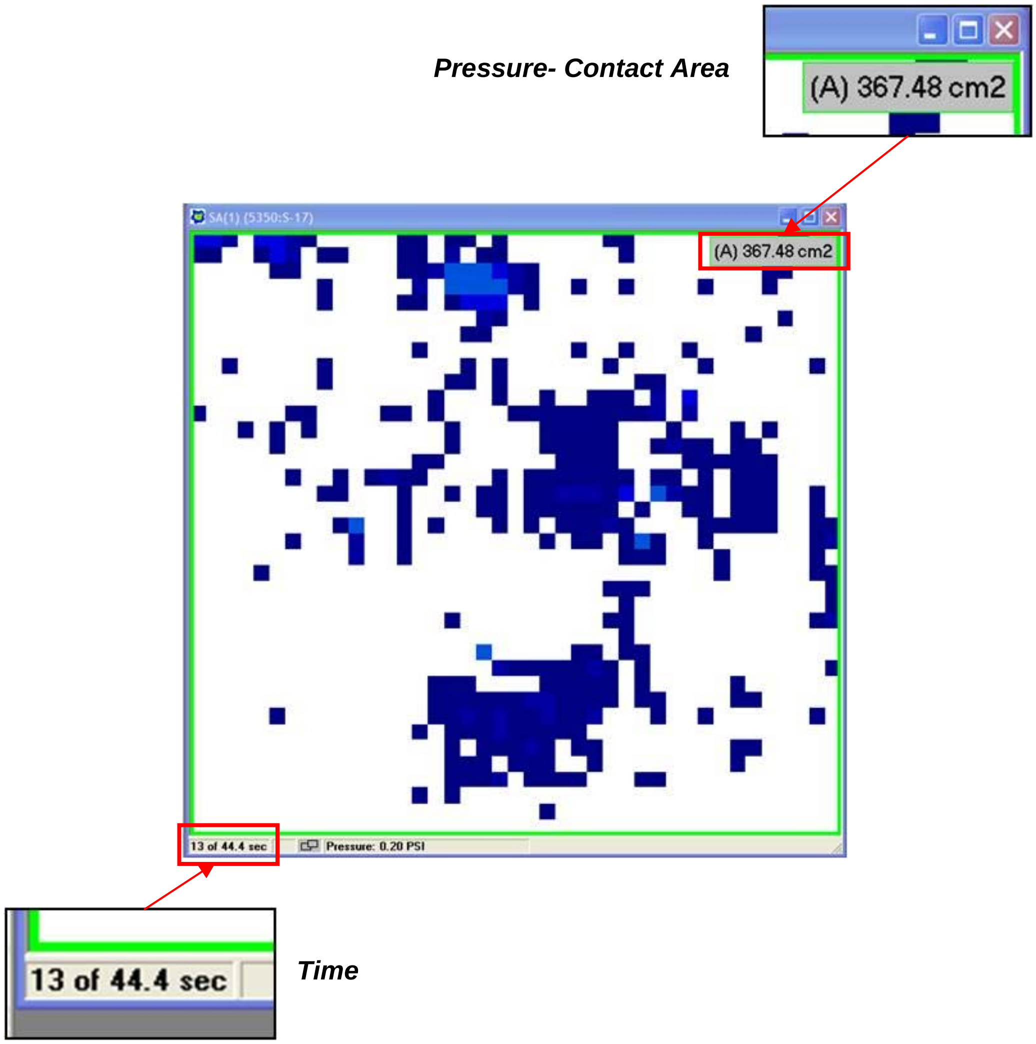


Figure 27. Pressure Maps with Pressure-Contact Area and Time

From the three trials, <u>only the second trial was used for data analysis</u> since the first trial provided the subject with experience performing the movement. Using the pressure-contact area graph of the second trial, the five maximum pressure-contact areas in the five cycles were extracted as shown in Figure 28. Because the pressure-contact area in the graphs did not always correspond to the cycle timing as previously described, the five maximum pressure-contact areas were extracted for each movement and saved for data analysis.

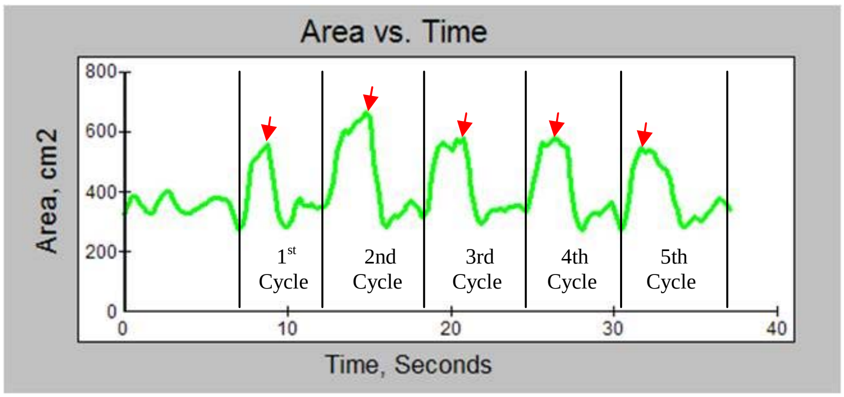


Figure 28. Extracted Five Maximum Pressure-Contact Areas in the Second Trial

Data Analysis

Range of motion data were measured in degrees while pressure-contact area data reported using cm^2 units.

For both tests, one-way ANOVA and two-way ANOVA were used to examine group differences according to bust size for the four movements. Appropriate post hoc analyses and descriptive statistics were also used. Data were analyzed using the Statistical Package for the Social Sciences (SPSS) 17.0 software.

CHAPTER IV

RESULTS

This chapter focuses on data analysis and results of the data analysis for the two-part laboratory experiment. The final sample of female volunteers and the selected grouping method are described. Data analyses for both range of motion and pressure-contact area are given and the results of the two-part experiment are discussed.

Sample

A total of 48 females volunteered to participate in the laboratory experiment. All were scanned in the IPART lab, where the 3D scanner is located. After scanning, 26 subjects were selected to represent the female soldier population. These 26 subjects completed both laboratory tests (i.e., range of motion and pressure-contact area) according to the test procedures described on pages 75 to 81.

The 26 subjects ranged in age from 19 to 31 years, with a mean age of 22.77 years. During the tests, they wore a size small Interceptor™ vest and a size small or medium BDU. The participants included 18 Caucasians, six Asians, one Native American, and one African. Their bust and under-bust circumferences were measured from scan images obtained with a 3D body scanner using AnthroScan software. Table 14 shows the range of body measurement data. The bust circumferences of the 26 subjects ranged from 32.28 to 41.69 inches, with a mean of 36.57 inches. The under-bust circumferences ranged from 27.13 to 37.20 inches, with a mean of 31.56 inches.

Table 14. Descriptive Statistics of 26 Subjects

	N	Minimum	Maximum	Mean	Std. Deviation
Bust Circumference (inch)	26	32.28	41.69	36.57	2.470
Under Bust Circumference (inch)	26	27.13	37.20	31.56	2.351
Age (year)	26	19	31	22.77	3.691

Six subjects had a bust circumference over 37.99 inches and one subject had a bust circumference less than 33 inches. Even though the bust circumferences of the seven subjects were outside of the desired range, they were used as subjects. Of the six subjects whose bust circumferences exceeded 37.99 inches, four subjects were placed in the large bust group, one was placed in the medium bust group, and one was placed in the small bust group, using Method C, inclined plane. The seven volunteers were retained as subjects due to the difficulty in recruiting subjects given the stated criteria and size of the subject pool, and since they did not fall into the same group.

To examine whether significant differences existed between the army personnel group data and the data for subject groups in this study, only 2,043 female army personnel data, who ranged in age from 18 to 35, were taken and an independent T-test was conducted using two measurement dimensions namely, bust and under-bust circumferences. As indicated in Table 15, Levene's Test for Equality of Variances showed that the two groups had approximately equal variances for bust and under-bust circumferences as Levene's Test results were not significant (bust circumference = .874, under-bust circumferences = .231). Thus, the army personnel group and the subject groups were regarded as having equal variances in the two body measurements.

Table 15. T-test Results for Bust and Under-Bust Circumference between the Army Personnel Group and Subject Group

		N	Mean (inch)	SD (inch)	Levene's Test for Equality of Variances	
					F	Sig.
Bust Circumferences	Army	2043	35.59	2.40	.025	.874
	Subject	26	36.57	2.47		
Under-Bust Circumferences	Army	2043	30.21	1.93	1.432	.231
	Subject	26	31.56	2.35		

Sample Groups

After exploring three alternative methods to group the sample by bust size, the method that used an inclined plane to measure the right breast thickness was selected. An inclined plane was created for each subject using three points in the 3D scan images and the distance from the right bust point to the inclined plane was determined and used as the basis for grouping the 26 subjects into three groups. Chapter III, pages 64 to 69, presents an overview of the selected method and the other two alternative methods that were explored.

Results

The overall purpose of this study was to compare group differences according to bust size in regard to range of motion while wearing and not wearing the Interceptor™ vest ballistic vest, and to examine pressure-contact area while wearing the Interceptor™ vest and performing four specific movements.

Range of Motion (ROM)

<u>Garment Treatment for Four Movements</u>

ROM measurements were determined for each subject in two different garment treatments. Garment A consisted of a sports bra, long knit pants, and a sleeveless 100% cotton shirt. Garment B consisted of a sports bra, long knit pants, a sleeveless 100% cotton shirt, and an Interceptor™ ballistic vest with front and back hard plates inserted into the vest. Each subject performed four movements while wearing each garment treatment. The BTS motion-capture system captured data in the form of angles and graphs of angles over times for each movement performed in each garment treatment. One maximum angle was selected for each test and each movement in both garments. Since there were three tests per movement and garment, the three maximum angles were averaged to determine a maximum angle for each movement in each garment.

As previously stated, four hypotheses were developed in regard to the four selected movements and the garment treatments.

H^0_1: There are no significant differences in range of motion by garment treatment for shoulder flexion movement.

H^0_2: There are no significant differences in range of motion by garment treatment for shoulder horizontal adduction movement.

H^0_3: There are no significant differences in range of motion by garment treatment for trunk flexion movement.

H^0_4: There are no significant differences in range of motion by garment treatment for hip flexion with kneeling movement.

To examine the differences based on garment treatment, the average maximum angle for each movement in each garment treatment was used. One-way repeated measures ANOVA was conducted with four dependent variables (i.e., shoulder flexion, shoulder horizontal adduction, trunk flexion, and hip flexion with kneeling) and one independent variable with two levels (i.e., vest and no vest).

ANOVA (Table 16) revealed significant differences in ROM by garment treatment (vest vs. no vest) for shoulder flexion, F (1, 50) = 12.28, $p < .001$, shoulder horizontal adduction, F (1, 50) = 31.97, $p < .000$, and trunk flexion, F (1, 50) = 10.05, $p < .003$. However, no significant difference was found for hip flexion with kneeling, F (1, 50) = 1.19, $p > .280$.

Table 16. ANOVA Table for Range of Motion by Garment Treatment

Movements		Mean° (SD°)	df	F	Sig.
Shoulder Flexion			1, 50	12.28	.001
	No Vest	155.3 (7.1)			
	Vest	147.5 (8.9)			
Shoulder H. Adduction			1, 50	31.97	.000
	No Vest	156.8 (24.2)			
	Vest	124.6 (16.1)			
Trunk Flexion			1, 50	10.05	.003
	No Vest	68.9 (19.6)			
	Vest	53.2 (16.0)			
Hip Flexion with Kneeling			1, 50	1.19	.280
	No Vest	100.1 (10.5)			
	Vest	97.0 (10.0)			

Means and standard deviations for ROM for each movement for garment treatments are presented in Table 16 and the estimated marginal means of angles in garment treatment and movements are shown in Figure 29. When wearing the vest, ROM was restricted for three movements: shoulder flexion, shoulder horizontal adduction, and trunk flexion. For shoulder flexion, the angle without the vest (mean = 155.3˚, SD = 7.1˚) was larger than the angle with the vest (mean = 147.5˚, SD = 8.9˚), indicating that subjects demonstrated a reduction in ROM for shoulder flexion. For shoulder horizontal adduction, the angle without the vest (mean = 156.8˚, SD = 24.2˚) was also larger than the angle with the vest (mean = 124.6˚, SD = 16.1˚), again indicating subjects demonstrated a restriction in ROM. Similarly, for trunk flexion, the lower angle with the vest (mean = 53.2˚, SD = 16.0˚) as compared to the angle without the vest (mean = 68.9˚, SD = 19.6˚) indicated a restriction in ROM when subjects wore the vest. Although no significant difference was found for hip flexion with kneeling, the angle with the vest (mean = 97.0˚, SD = 10.0˚) was slightly lower than the angle without the vest (mean = 100.1˚, SD = 10.5˚). Thus, the ROM data shows that the vest restricted subjects' ROM for three of the four movements.

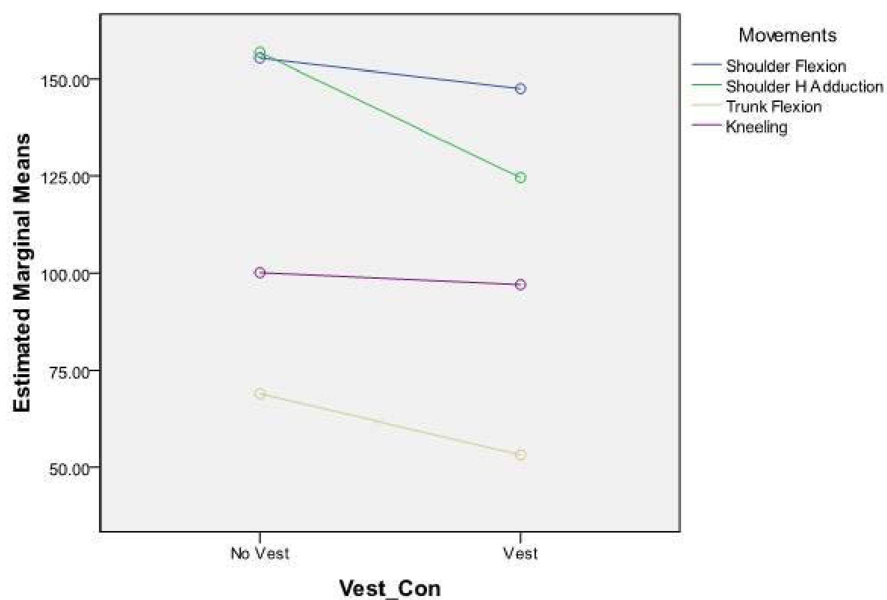


Figure 29. Estimated Marginal Means of ROM Angles
for Four Movements With and Without the Vest

Bust Size Treatment in Four Movements

Four hypotheses were tested to examine group differences by the subjects' bust sizes in regard to ROM for the four movements:

H^{0}_{5}: There are no significant differences in range of motion for shoulder flexion while females wear the Interceptor™ vest based on differences in the subjects' bust sizes.

H^{0}_{6}: There are no significant differences in range of motion for shoulder horizontal adduction while females wear the Interceptor™ vest based on differences in the subjects' bust sizes.

H^{0}_{7}: There are no significant differences in range of motion for trunk flexion while females wear the Interceptor™ vest based on differences in the subjects' bust sizes.

H^{0}_{8}: There are no significant differences in range of motion for hip flexion with kneeling while females wear the Interceptor™ vest based on differences in the subjects' bust sizes.

In order to determine significance of bust size for the four movements, three extracted maximum angles for each movement in each garment treatment were used to calculate the average maximum angles (as further described in Figure 23, Chapter III). Based on the average maximum angles, the percent difference (representing the change in ROM while wearing the ballistic vest) was calculated and used as a dependent variable. Thus, each subject had a percent difference determined for the four movements. Table 17 presents the ANOVA results for ROM for each movement by bust size treatment.

Table 17. ANOVA Table for Percent Difference of Range of Motion by Bust Size

Movements		Mean % (SD %)	df	F	Sig.
Shoulder Flexion			2, 23	.48	.624
	Small	-5.67 % (3.5 %)			
	Medium	-5.5 % (4.7 %)			
	Large	-4.0 % (2.0 %)			
Shoulder H. Adduction			2, 23	3.70	.040
	Small	-17.1 % (6.9 %)			
	Medium	-17.0 % (9.8 %)			
	Large	-26.9 % (6.5 %)			
Trunk Flexion			2, 23	.76	.480
	Small	-19.4 % (20.3 %)			
	Medium	-16.9 % (15.1 %)			
	Large	-28.8 % (26.9 %)			
Hip Flexion with Kneeling			2, 23	2.07	.149
	Small	-3.3 % (4.8 %)			
	Medium	-5.8 % (5.5 %)			
	Large	2.8 % (14.9 %)			

Table 17 indicates that a significant difference in ROM by bust size treatment emerged for the shoulder horizontal adduction movement, F (2, 23) = 3.70, $p < .040$. However, no significant differences in ROM emerged for shoulder flexion (F (2, 23) = .48, $p > .624$), trunk flexion (F (2, 23) = .76, $p > .480$), or hip flexion with kneeling (F (2, 23) = 2.07, $p > .149$) based on differences in subjects' bust sizes.

Because of the results of the ANOVA, a post hoc LSD test for shoulder horizontal adduction was performed to examine how the groups differed. Figure 30 shows that bust size treatments formed two groups: the small group (mean = -17.1 %, SD = 6.9 %) was grouped with the medium group (mean = -17.0 %, SD = 9.8 %) while the large group (mean = -26.9 %, SD = 6.5 %) remained its own group, indicating no significant difference for small and medium groups, large group was significant difference than the other two groups.

Figure 30. LSD Post Hoc Test Results for Percent Difference of Range of Motion for Shoulder Horizontal Adduction among Bust Groups

	Small group	Medium Group	Large Group
	M = -17.1 %	M = -17.0 %	
Shoulder Horizontal Adduction			M = -26.9 %

Means and standard deviations for ROM for each movement by bust size treatment are presented in Table 17. Although significant differences were not found by bust size for shoulder flexion, trunk flexion, and hip flexion with kneeling, yet, interesting observations can be made by studying Table 20. For shoulder flexion, percent differences of the small group (mean = -5.8 %, SD = 3.5 %) and the medium group (mean = -5.5 %, SD = 4.7 %) are similar and larger than the percent difference found for the large group (mean = -4.0 %, SD = 2.0 %). This indicates that the subjects in the large bust group had less restriction than the subjects in the small and medium bust groups. In trunk flexion, the small bust group (mean = -19.4 %, SD = 20.3 %) had a similar decrease in ROM as the medium group (mean = -16.9 %, SD = 15.1 %). The large group (mean = -28.8 %, SD = 26.9 %) had the most restriction for the trunk flexion movement, indicating that subjects with large busts experienced have more restriction than the subjects with the small and medium bust sizes for trunk flexion.

Way of Kneeling

Some interesting results emerged in regard to hip flexion with kneeling. No significant differences in ROM were found for garment treatment ($F(1, 50) = 1.19$, *p*

> .280) (Table 16) nor for bust size treatment (F (2, 23) = 2.07, $p > .149$) (Table 17). However, Table 17 shows that the percent difference in the large group in regard to hip flexion with kneeling was positive (mean = 2.8 %) while all percent differences in all other movements (i.e., shoulder flexion, shoulder horizontal adduction, and trunk flexion) for all bust sizes were negative, indicating that some restrictions occurred while wearing the vest.

To understand these surprising results, the raw movement data were re-examined one more time. The researcher found that two different ways of kneeling were evident while performing hip flexion with kneeling: some subjects bent at the waist while other did not bend at the waist (Figure 31). Among the 26 subjects, 15 subjects appeared to bend at the waist and the other 11 subjects did not bend at the waist.

Figure 31. Bending Kneeling Method (left) and No Bending Kneeling Method (right)

Thus, a two-way repeated measure ANOVA was conducted, with way of kneeling and bust size as the independent variables and percent difference in hip flexion with kneeling movement as the dependent variable. A significant interaction effect was found for way of kneeling by bust size treatment, F (2, 20) = 5.04, $p < .017$, as shown in Table

18. Figure 32 shows that the subjects in the small bust group had a similar percent reduction in ROM whether they bent over or not. However, in the medium group, the subjects who bent over had an 8 % reduction in ROM while the subjects who did not bend over had a 1 % reduction in ROM. The subjects in the large group who bent over had a 6 % reduction and the subjects who did not bend over experienced a 15 % increase in ROM for hip flexion with kneeling. This might be because while wearing the vest, the heavy weight of the vest and the stiffness of the vest might have caused the large busted subjects to move their back backward when performing hip flexion with kneeling movement. Table 19 presents the percent difference means and standard deviations for way of kneeling by bust size.

Table 18. ANOVA Table for Hip Flexion with Kneeling Range of Motion by Way of Kneeling and Bust Size Treatments

Source	Sum of Squares	df	df_{error}	Mean Square	F	Sig.
Way of Kneeling	541.7 %	1	20	541.7 %	12.21	.002
Bust Size	382.1 %	2	20	191.1 %	4.31	.028
Way of Kneeling*Bust Size	447.1 %	2	20	223.6 %	5.04	.017

Table 19. Percent Difference Means and Standard Deviations by Way of Kneeling and Bust Size Treatments

Movements	Small Group		Medium Group		Large Group	
	Mean %	SD %	Mean %	SD %	Mean %	SD %
Bending	- 3.5	6.1	- 8.1	5.1	- 6.5	3.3
No Bending	- 3.1	4.0	- 1.9	4.1	15.3	15.7

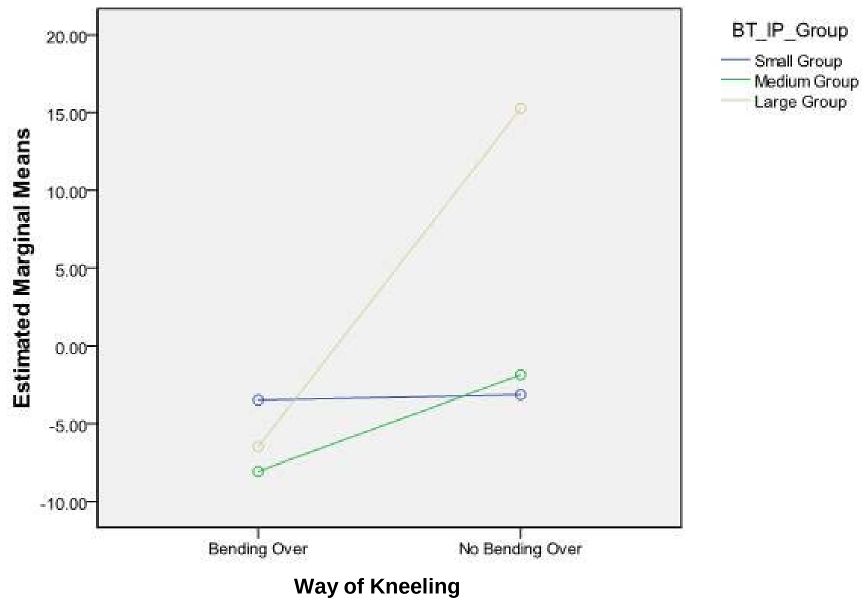


Figure 32. Estimated Marginal of Percent Difference of Hip Flexion with Kneeling

Pressure-Contact Area

Bust Size Treatment in Four Movements

Four hypotheses were developed related to bust size groups and pressure-contact area:

H^0_9: There are no significant differences in pressure-contact area during shoulder flexion by bust size.

H^0_{10}: There are no significant differences in pressure-contact area during shoulder horizontal adduction by bust size.

H^0_{11}: There are no significant differences in pressure-contact area during trunk flexion by bust size.

H^0_{12}: There are no significant differences in pressure-contact area during hip flexion with kneeling by bust size.

The pressure-contact area was determined for each subject while wearing garment C and completing the four selected movements. Garment C consisted of the T-shirt, BDU blouse/jacket, BDU pant, and the Interceptor™ ballistic vest. Each subject performed three trials for each movement. In each trial, five cycles were conducted. Five maximum peak pressure-contact areas from the second trial were used for data analysis because pressure-contact area in the graphs did not always correspond to the cycle timing as previously described.

Thus, five peak pressure-contact areas were used as the dependent variable while the bust size treatment with three levels was used as the independent variable. A one-way repeated measures ANOVA was conducted for each movement.

Table 20 shows the significant differences for pressure-contact area for two movements, shoulder flexion (F (2, 127) = 3.34, p < .038) and trunk flexion (F (2, 127) = 7.37, p < .001). However, no significant pressure-contact area differences were found for shoulder horizontal adduction (F (2, 127) = 2.10, p < .127) and hip flexion with kneeling (F (2, 127) = .50, p < .606).

Table 20. ANOVA Table for Pressure-Contact Area According to Bust Size Treatment

Movements		Mean cm^2 (SD cm^2)	df	F	Sig.
Shoulder Flexion			2, 127	3.34	.038
	Small	402.1 cm^2 (44.9 cm^2)			
	Medium	377.1 cm^2 (51.6 cm^2)			
	Large	400.1 cm^2 (61.1 cm^2)			
Shoulder H. Adduction			2, 127	2.10	.127
	Small	400.8 cm^2 (57.7 cm^2)			
	Medium	381.5 cm^2 (52.2 cm^2)			
	Large	403.3 cm^2 (61.1 cm^2)			
Trunk Flexion			2, 127	7.37	.001
	Small	591.8 cm^2 (149.5 cm^2)			
	Medium	597.3 cm^2 (128.0 cm^2)			
	Large	495.9 cm^2 (110.3 cm^2)			
Hip Flexion with Kneeling			2, 127	.50	.606
	Small	512.6 cm^2 (122.9 cm^2)			
	Medium	490.2 cm^2 (99.3 cm^2)			
	Large	502.5 cm^2 (105.0 cm^2)			

Means and standard deviations of pressure-contact areas are presented in Table 20 and estimated marginal means of maximum pressure-contact area are plotted in Figure 33. For shoulder flexion, the subjects in the small (mean = 402.1 cm^2, SD = 44.9 cm^2) and the large (mean = 400.1 cm^2, SD = 61.1 cm^2) bust groups had a larger pressure-contact area over the bust area than the subjects in the medium group (mean = 377.1 cm^2, SD = 51.6 cm^2). For trunk flexion, the subjects in the small (mean = 591.8 cm^2, SD = 149.5 cm^2) and medium (mean = 597.3 cm^2, SD = 128.0 cm^2) bust groups had smaller pressure contact areas than the subjects in the large bust group (mean = 495.9 cm^2, SD = 110.3 cm^2). Even though no significant differences were found for shoulder horizontal adduction and hip flexion with kneeling, slight differences in means are evident as shown in Table 20. For shoulder horizontal adduction, the pressure-contact area for the medium group (mean = 381.5 cm^2, SD = 52.2 cm^2) shows the smallest value, followed by the pressure-contact areas for the small group (mean = 400.8 cm^2, SD = 57.7 cm^2) and the large group (mean = 403.3 cm^2, SD = 61.1 cm^2). In addition, for the hip flexion with kneeling movement, the medium group (mean = 490.2 cm^2, SD = 99.3 cm^2) had the smallest pressure-contact area as compared to the large (mean = 502.5 cm^2, SD = 104.9 cm^2) and the small (mean = 512.6 cm^2, SD = 122.9 cm^2) bust groups.

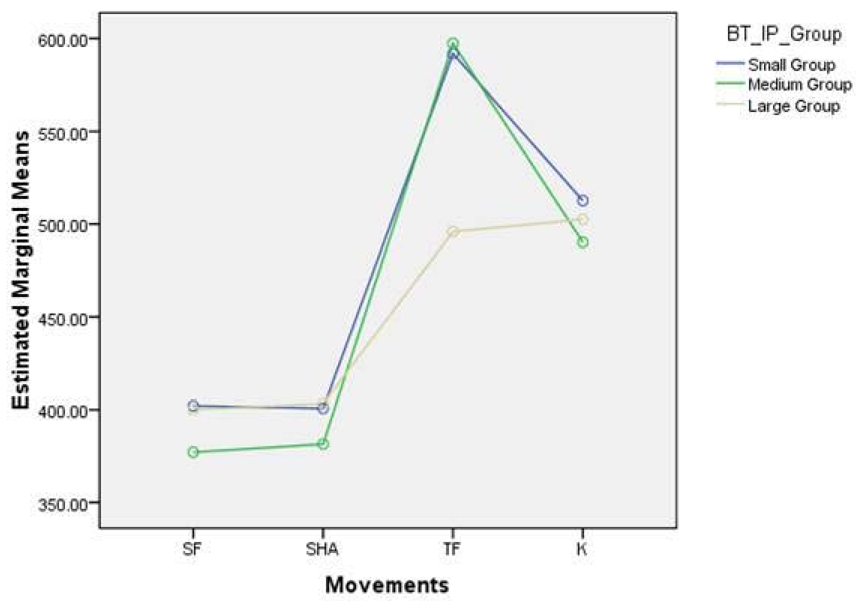


Figure 33. Estimated Marginal Means of Pressure-Contact Area
According to Movements and Bust Size

The post hoc LSD was conducted for the statistically supported movements namely, shoulder flexion and trunk flexion. The results are described in Figure 34 and Figure 35. In Figure 34, for the shoulder flexion movement, pressure-contact area means for the small and large groups significantly differed from the pressure-contact area for the medium group, indicating that the subjects with small and large busts had larger pressure-contact area over the bust than the subjects in the medium bust group. For the trunk flexion movement (Figure 35), the pressure-contact area means found for the small and medium groups are similar, and both are larger than those found for the large busted group. This shows that the pressure-contact areas of subjects in the small and medium bust groups were larger than the subjects in the large bust group during trunk flexion.

Figure 34. LSD Post Hoc Test Results for Pressure-Contact Areas by Shoulder Flexion among Bust Groups

	Small group	Large Group	Medium Group
	M = 402.1 cm^2	M = 400.1 cm^2	
Shoulder Flexion			M = 377.1 cm^2

Figure 35. LSD Post Hoc Test Results for Pressure-Contact Areas by Trunk Flexion among Bust Groups

	Small group	Medium Group	Large Group
	M = 591.8 cm^2	M = 597.3 cm^2	
Trunk Flexion			M = 495.9 cm^2

Summary of Results and Discussion

Range of Motion (ROM)

The significant results related to ROM are summarized in Table 21.

Table 21. Summary of Results for Range of Motion Data

Independent Variable	Movements	One-Way ANOVA Results
Vest Treatment	Shoulder Flexion	Significant
	Shoulder Horizontal Adduction	Significant
	Trunk Flexion	Significant
	Hip Flexion with Kneeling	Not Significant
Bust Size Treatment	Shoulder Flexion	Not Significant
	Shoulder Horizontal Adduction	Significant
	Trunk Flexion	Not Significant
	Hip Flexion with Kneeling	Not Significant

In regard to the garment treatment (i.e., wearing vs. not wearing an Interceptor™ vest), significant differences were found for ROM for three movements, namely: shoulder flexion, shoulder horizontal adduction, and trunk flexion. However, no significant difference was found for hip flexion with kneeling.

Thus, $\boldsymbol{H^0_1}$ (There are no significant differences in range of motion by garment treatment for shoulder flexion movement), $\boldsymbol{H^0_2}$ (There are no significant differences in range of motion by garment treatment for shoulder horizontal adduction movement), and $\boldsymbol{H^0_3}$ (There are no significant differences in range of motion by garment treatment for trunk flexion movement) were rejected. However, $\boldsymbol{H^0_4}$ (There are no significant differences in range of motion by garment treatment for hip flexion with kneeling movement) could not be rejected for hip flexion with kneeling. Thus, ANOVA found that ROM was reduced when wearing the vest for three movements, shoulder flexion, shoulder horizontal adduction, and trunk flexion, but not for hip flexion with kneeling.

Second, the ANOVA results for bust size treatment revealed no significant differences in ROM for shoulder flexion, trunk flexion, and hip flexion with kneeling movements. However, for shoulder horizontal adduction, a significant bust group difference was found and the post hoc LSD performed revealed that the small and medium bust size groups significantly differed in ROM from the large bust size group. Thus, H^0_5(There are no significant differences in range of motion for shoulder flexion while females wear the Interceptor™ vest based on differences in the subjects' bust sizes), H^0_7 (There are no significant differences in range of motion for trunk flexion while females wear the Interceptor™ vest based on differences in the subjects' bust sizes), and H^0_8 (There are no significant differences in range of motion for hip flexion with kneeling while females wear the Interceptor™ vest based on differences in the subjects' bust sizes) could not be rejected. These data analyses show that bust size did not influence ROM for shoulder flexion, trunk flexion, and hip flexion with kneeling. However, H^0_6 (There are no significant differences in range of motion for shoulder horizontal adduction while females wear the Interceptor™ vest based on differences in the subjects' bust sizes) was rejected. In regard to the shoulder horizontal adduction movement, the subjects in the small and medium groups encountered less restriction in ROM while wearing the vest than the subjects in the large bust group.

Based on the data analysis of garment and bust size treatments, interesting results were observed for hip flexion with kneeling. Examination of hip flexion with kneeling raw data showed that two ways of kneeling could be identified. Among the 26 subjects, 15 subjects bent over at the waist as they knelt and the other 11 subjects did not bend over at the waist when performing hip flexion with kneeling. In order to see the influence of kneeling methods on ROM, a two-way ANOVA was run. A significant interaction effect between the kneeling method and bust size group was found. In the small group, the subjects' ROM were similar. In the medium group, the subjects who bent over had more percent reduction in ROM than the subjects who did not bend over. For the large group, a large different in ROM was found. Those who bent over had an approximately 6% reduction in ROM. However, those who did not bend over had a 15% increase in ROM. This result points out the importance of assuring that all subjects perform all movements in the same way.

ROM of female subjects was reduced by wearing the vest when performing three movements. Shoulder flexion was chosen because it simulated holding a handle while getting into a truck and loading something into a truck. Shoulder horizontal adduction was selected to simulate moving the arm across the front of the torso to reach for something or to position rifle for shooting. To simulate bending the torso when getting into a truck or when picking up something on the floor, trunk flexion was selected. These tasks are important for soldiers carrying out their duties as well as performing normal activities of daily life.

However, for hip flexion with kneeling, no significant difference by wearing the vest was found. The reason might be the two ways that subjects performed the kneeling movement; bending and no bending. This issue emphasizes the importance of careful methodological attention needed for planning, training subjects and executing a movement study. It also points out the advantage of having the BTS system so that the raw data could be re-examined. Clearly, a procedure for how to kneel should have been more careful developed, and subjects should have been trained to perform the movement accordingly in order to decrease the potential for obtaining ROM data with large variation. Thus, for future research, a specific protocol for all movements should be carefully defined and every effort should be made to ensure that the movement is performed by subjects as defined.

For the bust size treatment, ROM was significantly reduced for one movement, shoulder horizontal adduction. Post hoc analysis found two significant groups with the large bust group experiencing a greater restriction in ROM as compared to the small and medium bust groups. Specifically, in the large bust group, ROM was 26 % less when subjects wore the vest while small and medium busted subjects had an approximately 17 % reductions. This movement simulated moving the arm across the front torso as is done when assuming the standing shooting position.

Pressure-Contact Area

Table 22. Summary of Results for Pressure-Contact Area Data

Independent Variables	Movements	One-Way ANOVA Results
Bust Size Treatment	Shoulder Flexion	Significant
	Shoulder Horizontal Adduction	Not Significant
	Trunk Flexion	Significant
	Hip Flexion with Kneeling	Not Significant

Table 22 presents the ANOVA results for pressure-contact area for the four movements. Significant bust size group differences occurred for shoulder flexion and trunk flexion movements. However, for the shoulder horizontal adduction and hip flexion with kneeling movements, no statistical significant differences by bust size were identified. Thus, $\boldsymbol{H^0_9}$ (There are no significant differences in pressure-contact area during shoulder flexion by bust size) and $\boldsymbol{H^0_{11}}$ (There are no significant differences in pressure-contact area during trunk flexion by bust size) were rejected. However, $\boldsymbol{H^0_{10}}$ (There are no significant differences in pressure-contact area during shoulder horizontal adduction by bust size) and $\boldsymbol{H^0_{12}}$ (There are no significant differences in pressure-contact area during hip flexion with kneeling by bust size) could not be rejected.

The results of the post hoc LSD tests for the statistically supported movements showed: 1) for shoulder flexion, the small and large bust groups experienced larger pressure-contact areas than the medium group, and 2) for trunk flexion, the small and medium bust groups significantly differed from the large group, by experiencing larger pressure area than the subjects in the large bust group while wearing the vest.

The pressure-contact area laboratory experiment revealed that subjects in the small and large bust groups have a larger area of pressure over the bust while performing shoulder flexion than the subjects in the medium bust group. Thus, female soldiers with small and large busts might have a larger pressure area over the front torso while wearing the vest than subjects with a medium bust in while performing shoulder flexion movement. This movement was chosen because components of the movements were similar to movement required to loading something into a truck or getting into a tall truck. During trunk flexion, subjects with small and medium bust sizes had more pressure-contact areas than the subjects with large busts. Thus, small and medium busted female soldiers wearing the vest might have more pressure-contact area than large busted female soldiers when performing the following movements associated with trunk flexion: 1) grabbing something on the floor; 2) bending the torso; and 3) getting into the truck. Comparing these two results, the pressure contact area tests showed inconsistency. Perhaps, this inconsistency could be explained by factors other than bust size that could influence the pressure-contact area. For example, the various tightness of the vest could be one possible factor because it could determine an initial pressure-contact area. The circumference of the subject's mid-section also could be another potential reason. For example, subjects with small busts and large mid-sections might have more pressure-contact area than the subjects with large busts but small mid-sections. Furthermore, variations in bust shape, body shape, and muscle could contribute to the inconsistency.

CHAPTER V

SUMMARY AND CONCLUSIONS

The current study explored whether wearing the Interceptor^{TM} ballistic vest, a unisex-sized vest, by females resulted in restrictions in range of motion for the females. Moreover, this study explored pressure area over the front torso associated with wearing the Interceptor^{TM} vest while performing selected movements. This was done by determining the area in which pressure-contact occurred over the front torso while subjects performed the selected four movements while wearing a ballistic vest. This chapter presents the conclusions of this study, summarizing the major findings as well as exploring implications of this study. Recommendations for future research are also provided.

The Interceptor^{TM} vest, a ballistic vest that female soldiers use during training and for other situations, was found to be is problematic in regard to fit and restriction of performance, especially for female military personnel (Tung, 2008). In order to explore whether ROM was decreased and pressure was experienced by females on the front torso while wearing the Interceptor^{TM} ballistic vest, a three-phase study was conducted. In Phase I, the military anthropometric database (Gordon, 1986) was analyzed to determine the female soldiers' body measurements while the designation of cup sizes based on data from the female soldiers' database was investigated in order to propose a grouping scheme. In Phase II, a focus group interview was held to gather more information about female soldiers' duties, activities, and type of clothing worn, for planning the laboratory test. Finally, in Phase III, a two-part laboratory experiment was conducted.

Phase I focused on obtaining information to plan three key components needed for the specification of samples for this study. First, in order to determine female soldiers' bust size distribution, the most recent U.S. army anthropometric database, conducted from 1987 to 1988, was selected. This database consists of 3,982 soldiers' data, 2,208 females and 1,774 males. Since this study focused only on females, only female soldiers' data were analyzed to specify the criteria for accepting subjects according to the distribution of female population. First, ages of the 2,208 female soldiers' data were examined. Almost 10% were either under 19 or over 35 years of age, while the remaining 90.3% (1,996) were between 19 and 35 years of age. Thus, the desired age range for potential subjects was determined to be the range from 19 to 35 years of age.

Determination of recommended vest size was based on chest circumference. To determine the size of the Interceptor™ test vest, 1,996 female soldiers' data were examined; 348 females had a bust circumference of less than 33 inches (i.e., extra small), 1,387 females had a bust circumference between 33 and 37.99 inches (i.e., small), and 248 females had a bust circumference between 38 and 41.99 inches (i.e., medium). Thus, the small Interceptor™ vest, which would be fitted the largest number of female soldiers (1,387), was selected.

To group the 1,387 female soldiers' data according to bust size, the bra calculation methods for six bra manufacturers, five popular low cost bra manufacturers and one high quality bra manufacturer, were examined due to the lack of an accepted standard method. Two bra manufacturers used the same calculation method. Thus, five bra calculation methods were specified based on information found on manufacturers' websites and the researcher-designed rules specified on page 52 to eliminate ambiguity in the manufacturer methods. These five calculation methods were used to assign cup sizes to 1,387 female soldiers using measurements found in the database (Gordon, 1986). The results show an extensive range of cup sizes. The first three methods (Curvation, Hanes, Smart & Sexy, and Secret Treasures) provided a similar range of cup sizes, but different numbers of subjects in each cup size. Curvation had cup sizes 5A to D and Hanes, Smart & Sexy, and Secret Treasures had cup size 5A to DD whereas the methods used by Jing and Wacoal generated totally different cup sizes (Jing: A to I and Wacoal: 3A to G). It was also interesting to know that three manufacturers had the same distribution of subjects, but different cup size designations.

The process (i.e., analyzing the bust cup size of 1,387 female soldiers) clearly demonstrates the complexity facing women trying to determine an appropriate bra size when making purchasing decisions, providing a practical rationale for why such a large percent of women purchase ill-fitting bras. The results also provide convincing evidence for the need to develop a standard measurement and size designation methods. For this study, subjects' bra cup sizes were not determined by either asking subjects or using manufacturers' calculation methods for grouping the subjects by bust size because of the difficulties shown. Thus, all potential subjects were scanned to obtain accurate under-bust and bust circumferences and to assign subjects into one of three groups determined by analyzing data from 1,387 female soldiers.

In Phase II, focus group interviews were conducted in order to explore general information about female soldiers' problems while wearing the ballistic vest, activities and duties performed in order to define the selected test movements, and a clothing system for developing the test garments. Five female soldiers volunteered in the focus group interview, which was held at the Venture I Conference Room in the Oklahoma Technology & Research Park on November 7, 2009. The researcher and three faculty members from Oklahoma State University asked eight questions (Appendix D) which were allowed to discuss their duties and clothing system while wearing the ballistic vest.

All participants asserted that the Interceptor™ vest was too tight over the bust. Some noticed too much pressure over the bust area as a result of the hard plates. The clothing system was also discussed. All of them preferred to wear sports bras instead of regular bras when carrying out their duties, tasks, or training. Furthermore, participants reported difficulty performing the following movements while wearing the ballistic vest: 1) getting into a truck, 2) gripping the handle to get into a truck, 3) the standing shooting position, 4) the kneeling shooting position, 5) bending at the torso, 6) picking up something from the floor, 7) crawling, and 8) the prone position.

To specify the test garments, soldiers' responses to questions regarding their typical clothing were used. Three testing garments were developed: garment A (the sports bra + a sleeveless shirt + long knit pants), garment B (the sports bra + a sleeveless shirt + long knit pants + the Interceptor™ vest with hard plates), and garment C (the sports bra + T-shirt + BDU + the Interceptor™ vest with hard plates). Garment A and B were used for the range of motion test, and garment C was used for a pressure test. Finally, soldiers' responses to questions regarding their typical movements led to the selection of four basic movements to be used in the Phase III experiment. These four critical movements were: 1) shoulder flexion, 2) shoulder horizontal adduction, 3) trunk flexion, and 4) hip flexion with kneeling.

In Phase III, a two-part laboratory experiment was performed. The data were gathered at two times. The first data collection was conducted from March 1 to 14, 2010. A total of 38 potential subjects were scanned to measure their bust and under-bust circumferences to identify potential subjects that satisfied the sampling criteria, namely, age (19 to 35 years old), bust circumference (33 to 37.99 inches), and difference between bust and under-bust circumference that permitted allocating subjects to one of three groups. However, only 16 subjects satisfied the criteria, and no one satisfied the criteria for the third group (6 to 6.99 inches difference). Thus, the second data collection was conducted May 15 to June 4, 2010, after developing and displaying the amended flyer (Appendix F). The amended flyer extended subjects' age range to include 18 to 35 year olds, and identified specific cup sizes (i.e., 32 C, D, or above) to hopefully recruit large busted subjects. Ten additional subjects were recruited after posting the amended flyer. Among them, six subjects had bust circumferences greater than 37.99 inches. They were accepted because of the need for and difficulty in recruiting large busted subjects.

In sum, a total of 48 female subjects were scanned to determine their under-bust and bust measurements. Of the 48 subjects, only 26 subjects (18 to 35 years old) were chosen as participants and assigned to one of the bust size groups using grouping method A. However, method A proved not to be an appropriate grouping method for use with the 26 subjects because the three groups were not well balanced; 11 subjects were in the small group (difference between bust and under-bust circumferences of 4 to 4.99 inches), 14 were in the medium group (5 to 5.99 inch difference), and only one subject was in the large group (6 to 6.99 inch difference).

Thus, two alternative grouping methods, Methods B and C, were created. Method B was based on the thickness of the right breast from the vertical plane created at the right under-bust point. Using this method, the small group included 14 subjects (breast thickness from 0.5 to 2.0 cm), the medium group included nine subjects (breast thickness from 2.1 to 3.5 cm), and the large group included three subjects (breast thickness from 3.6 to 5.0 cm). As with method A, method B did not allow for a sufficient number of subjects into the third group.

Finally, grouping method C used an inclined plane instead of a vertical plane when measuring the right breast thickness. The grouping distribution of the 26 subjects using method C improved balance of number of subjects per group. The small group included eight subjects (breast thickness from 2.0 to 3.5 cm), the medium group included 11 subjects (breast thickness from 3.6 to 5.0 cm), and the large group included seven subjects (breast thickness from 5.1 to 6.5 cm). Thus, all 26 subjects were assigned into one of the three bust size groups using grouping method C.

A total of 12 null hypotheses were created for the two-part laboratory experiment. For the range of motion test, eight hypotheses were developed. Four hypotheses were tested that related to ROM to garment treatment for each of four selected movements. The other four hypotheses were created to examine the relationship of bust size differences to ROM achieved in each of the four movements. For the pressure test, four additional hypotheses were also created to test bust size differences as related to pressure-contact area while performing each movement in the vest.

The data indicated that female subjects' range of motion was significantly restricted when wearing an Interceptor^{TM} vest when performing shoulder flexion, shoulder horizontal adduction, and trunk flexion movements. Interestingly, for the hip flexion with kneeling movement, female subjects did not encounter a significant restriction in range of motion while wearing the ballistic vest, an obviously unexpected result. To better understand this unexpected result, the raw data were re-examined and one variable factor was identified. When performing the hip flexion with kneeling movement, 15 subjects bent at the waist while the other 11 subjects did not. Possibly, this uncontrolled factor led to the finding of no significant difference by garment treatment. Thus, in future studies, it is suggested that considerable care be exerted in defining and illustrating desired test movements to all subjects in order to ensure reliable data when examining range of motion.

Furthermore, the anticipated extent of bust group differences for range of motion did not occur except for one movement, shoulder horizontal adduction. By considering the significance of bust size in shoulder horizontal adduction, it was concluded that subjects with a large bust (ranging from 5.1 cm to 6.5 cm bust thickness from the inclined plane) have a larger difference in range of motion than the other subjects. In other words, subjects with a large bust may face more restrictions in their range of motion while performing shoulder horizontal adduction than subjects with small and medium sized busts. The large bust may restrict arm movement across the body because of the protruding shape of the breast. Thus, to improve female soldiers' ROM, female soldiers' ballistic vests and hard plates, could be designed to conform to the curved shape of the female body, with bust size variation.

In regard to the test for pressure-contact area, significant differences in two movements according to bust size occurred. In the shoulder flexion movement, small and large busted subjects demonstrated a larger pressure-contact area than medium busted subjects. Meanwhile, in the trunk flexion movement, subjects with large busts demonstrated smaller pressure-contact area than those with small and medium busts. The pressure-contact area in the bust region could be an important factor affecting female soldiers' endurance and performance while wearing a ballistic vest. However, ironically, the results highlighted an inconsistency in the findings. This inconsistency might stem from other (i.e., non-bust size) factors that influenced the pressure-contact area, such as the tightness of the vest, which can affect the pressure-contact area in the beginning of the test. Bust shape, body shape, muscle, and fat tissue, which can contribute to large variations, could also be a possible explanation. Thus, further exploration into appropriate protocols for acquiring accurate pressure-contact area data is warranted. Further exploration into the qualitative pressure map data is also warranted. Lastly, consideration for exploring the bust size range is warranted. The database used in this study for determining the bust size range was conducted in 1988, 22 years ago. It is entirely possible that these data do not adequately represent measurement data for the female soldier of today.

These results suggest the need to develop a more flexible and lightweight ballistic vest to minimize female soldiers' motion restrictions, although since no study was found that examined this issue for male soldiers, such a vest might be helpful to males also. Another possibility to improve ROM of female soldiers might be to develop a female version of the ballistic vest based on the female body shape.

Recommendations for Future Research

1. This study only considered breast thicknesses ranging from 4.1 cm to 6.5 cm. If this range were extended, it is likely that significant differences between sizes would emerge in the other movements as well. Future researchers should consider extending the bust size range and selected movements.
2. Future researchers could compare male and female subjects to determine how much body shape, especially bust shape, affects an individual's performance when wearing a ballistic vest.
3. The current study focused exclusively on size of pressure-contact area over the bust area to determine bust group difference while wearing a ballistic vest. However, in future, additional areas, such as the side and back pressure-contact area, should be included to obtain more effective pressure data.
4. A perceived fit analysis ballot could be used to clarify subjects' comfort level while wearing the ballistic vest. It could be used as additional information in quantitative analyses.
5. The current data sets for this study could be re-analyzed in multiple ways. For example, both ROM and pressure data analyses rely on grouping of subjects. It would be interesting to re-analyze data using all three grouping methods. This might require using only two groups rather than three. Secondly, qualitative analysis could be performed using pressure map data.
6. Criteria for selection of subjects was based on a 22 year old military database, yet the sample was a civilian sample. Perhaps, a civilian database should have been used to define the criteria for acceptance of subjects.

REFERENCES

An, S. K., Park, H., Cao, H., Peksoz, S., & Branson, D. (2009, October). *Development of estimation model to predict firefighter's core temperature from microclimate data*. Paper presented at the meeting of the International Textile and Apparel Association, Seattle, WA.

Anthropometry of U.S. military personnel (METRIC). (1991). *U.S. Army Soldier Systems Center.* Retrieved June 22, 2009, from http://aerodefense.ihs.com/document/abstract/PYTVDA

Armor Holdings: Products Division. (2003, September 19). *FAQs about Zylon® materials in body armor*. Retrieved Aug 05, 2009, from http://www.policeone.com/bodyarmor/AH_FAQs.pdf

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

Ashdown, S. P., & Watkins, S. M. (1992). Movement analysis as the basis for the development and evaluation of a protective coverall design for asbestos abatement. In J. P. McBriarty., & N. W. Henry (Eds.), *Performance of Protective Clothing*, 1st Edition (pp. 660-674). West Conshohocken, PA: American Society for Testing and Materials.

Ashcroft, J., Daniels, D. J., & Hart, S. V. (2001). *Selection and application guided to personal body armor* (NIJ Guide 100-01). Rockville, MD: The National Institute of Justice's National Law Enforcement and Corrections Technology Center.

Barker, J. F. (2007). *Comfort perceptions of police officers toward ballistic vests*. Unpublished master's thesis, Florida State University, Tallahassee, FL.

Body Armor – Technological Issues. (2006, April). *Military Technology: MILTECH*, pp. 72-79.

Bowles, K. A., Steele, J. R., & Munro, B. (2008). What are the breast support choices of Australian women during physical activity? *British Journal of Sports Medicine, 42*, 670 - 673.

Bradley, J. V. (1969[a]). Effect of gloves on control operation time. *Human Factors, 11*(1), 13-20.

Bradley, J. V. (1969[b]). Glove characteristics influencing control manipulability. *Human Factors, 11*(1), 21-36.

Brantley, J. D. (2000). *Field evaluation of the sizing and tariff of the U.S. Marine Corps interceptor body armor* (NATICK/TR-00/014). Natick, MA: U.S. Army Soldier and Biological Chemical Command Soldier System Center. Retrieved July 10, 2009, from http://stinet.dtic.mil/cgi-bin/GetTRDoc?AD=A379872&Location =U2&doc=GetTRDoc.pdf

Bressler, K., Newman, K., & Proctor, G. (1998). *A Century of Style: Lingerie*. London, UK: Quarto Publishing Plc.

Bygrave, S., Legg, S. T., Myers, S., & Llewellyn, M. (2004). Effect of backpack fit on lung function. *Ergonomics, 47*(3), 324-329.

Cain, G. (1950). *The American Way of Designing*. New York, NY: Fairchild Publications.

Calasibetta, C. M. (1998). *Fairchild's Dictionary of Fashion*. New York, NY: Fairchild Publication.

Carothers, J . P. (1988). *Body armor: A historical perspective*. Retrieved July 26, 2009, from http://www.globalsecurity.org/military/library/report/1988/CJ2.htm.

Chamber, H. (1969). *Clothing Selection: Fashions, Figures, & Fabrics*. Philadelphia, PA: Lippincott Publication.

Chen, C. M. (2007). *Female body characteristics related to bra fit*. Unpublished doctorial dissertation, University of Minnesota, Minneapolis, MN.

Chen, X., & Chaudhry, I. (2005). Ballistic protection. In R. A. Scott (Eds.), *Textiles for Protection* (pp. 529-556). Boca Raton, FL: CRC Press LLC.

Chen, Y., Cochran, D. J., & Bishu, R. R. (1989). Glove size and material effects on task performance. *Proceedings of the Human Factors Society, USA, 33*, 708-712.

Daanen, H. A. M., & Reffeltrath, P. A. (2007). Function, fit and sizing. In S. P. Ashdown. (Eds.), *Sizing in clothing: Developing Effective Sizing Systems for Ready-to-Wear Clothing.* (pp. 203-219). Cambridge, UK: Woodhead Publishing Limited.

Donelson, S. N., & Gordon, C. C. (1996). *1995 matched anthropometric database of U. S. marine corps personnel: Summary statistics* (NATICK/TR-96/036). Natick, MA: U. S. Army Soldier System Command NATICK Research, Development, and Engineering Center.

Efrat, S. (1982). *The development of a method of generating patterns for clothing that conform to the shape of the human body*. Unpublished doctoral dissertation, Leicester Polytechnic, Leicester, UK.

Erwin, M. D. (1949). *Clothing for Moderns* (1st Edition). New York, NY: Macmillan.

Ferguson, W. J. (1978). *Armor Plate (U.S. Patent Documents).* Retrieved July 06, 2009, from http://www.google.com/patents?id=ymkzAAAAEBAJ&printsec=abstract &zoom=4&source=gbs_overview_r&cad=0.

Fowler, J. (2003). *The evaluation and testing of two ballistic vests: A comparison of comfort*. Unpublished master's thesis, Florida State University, Tallahassee, FL.

Gehlsen, G., & Stoner, L. J. (1987). The female's breast in sport and exercise. In M. J. Adrian (Eds.), *Sports Women* (pp. 13-22). Basel, Switzerland: Karger.

Gain, G. (1950). *The American Way of Designing*. New York, NY: Fairchild Publication.

Gordon, C. C. (1986). Anthropometric sizing and fit testing of a single battledress uniform for United States Army men and women. In R. L. Barker., & G. C. Colerra (Eds.), *Performance of Protective Clothing*, 1st Edition (pp. 581-592). Philadelphia, PA: American Society for Testing and Materials.

Gordon, C. C., Churchill, T., Clauser, C. E., Bradtmiller, B., McConville, J. T., Tebbetts, I., & Walker, R. A. (1989). *1988 anthropometric survey of U. S. army personnel: Methods and summary statistics* (No. Natick-TR-89-044). Natick, MA: U. S. Army Natick Research & Design Center.

Greenbaum, A. R., Heslop, T., & Morris, J. (2003). An investigation of the suitability of bra fit in women referred for reduction mammaplasty. *British Journal of Plastic Surgery, 56*, 230-236.

Griffey, J. V., & Ashdown, S. P. (2006). Development of an automated process for the creation of a basic skirt block pattern from 3D body scan data. *Clothing and Textiles Research Journal, 24*(2), 112-120.

Haggar, A. (2004). *Pattern cutting for lingerie, beachwear and leisurewear* (2nd Edition). Oxford, UK: Blackwell Publishing LTD.

Hamilton, M. (2007). *The shape of women's body armor: Ballistic vest manufacturers are finidng new ways to meet female officers' needs.* Retrieved September 23, 2008, from http://www.policemag.com/Articles/2007/10/The-Sahpe-of-Womens-Body-Armor.aspx

Horsfall, I., Champion, S. M., & Watson, C. H. (2005). The development of a quantitative flexibility test for body armour and comparison with wearer trials. *Applied Ergonomics 36*, 283-292.

Huck, J. (1988). Protective clothing systems: A technique for evaluating restriction of wearer mobility. *Applied Ergonomics, 19*(3), 185-190.

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.

Jones, P. R. M., Lie, P., Brooke-Well, K., & West, G. (1995). Format for human body modeling from 3-D body scanning. *International Journal of Clothing Science & Technology, 7*(1), 7-16.

Kang, T. J., & Kim, S. M. (2000). Optimized garment pattern generalization based on three-dimensional measurement. *International journal of Clothing Science & Technology, 12*(4), 240-254.

Kanhai, R.C., & Hage, J. J. (1999). Bra cup size depends on band size. *Plastic and Reconstructive Surgery, 104*, 300-309.

Keeble, V. B., Prevatt, M. B., & Mellian, S. A. (1992). An evaluation of fit of protective coveralls manufactured to a proposed revision of ANSI/ISEA 101. In J. T. McBriarty., & N. W. Henry. (Eds.), *Performance of Protective Clothing*, 1st Edition (pp.675-697). Philadelphia, PA: American Society for Testing and Materials.

Kim, H., Suh, C., Suk, E., Park, S., & Lim, J. (2001). A study on the comparative evaluation of wearing fitness of women's ready-made jackets using 3D scanner. *Journal of the Korean Society of Clothing and Textiles, 25*(10), 1707-1718.

Kreighbaum, E., & Barthels, K. M. (1996). *Biomechanics: A Qualitative Approach for Studying Human Movement* (4th Edition). San Francisco, CA: Benjamin-Cummings Publishing Company.

Lafayette Anthropometers. (n.d.). *Model 01290 large anthropometer*. Retrieved July 08, 2009, from http://www.nexgenergo.com/medical/images/lafayettea1.jpG

Laing, R. M., & Sleivert, G. G. (2002). Clothing, textiles and human performance. *Textile Progress, 32*(2), 1-124.

Le Pechoux, B., & Ghosh, T. K. (2002). Apparel sizing and fit. *Textile Progress, 32*(1), 1-59.

Lorentzen, D., & Lawson, L. (1987). Selected sports bras: A biomechanical analysis of breast motion while jogging. *Sport Medicine, 15*(5), 128-130, 132-134, 136, 139.

Macaulay, D. (2008, Aug 16). *Suspect in Hampton police officer's shooting off critical list: The wounded man hasn't been charged yet*. Retrieved July 29, 2009, from http://search.ebscohost.com/login.aspx?direct=true&db=nfn&AN=2W62W63121865790&site=ehost-live

Mason, B, R., Page, K. A., & Fallon, K. (1999). An analysis of movement and discofmrot of the female breast during exercise and the effects of breast support in three case studies. *Journal of Science and Medicine in Sport*, *2*(2), 134-144.

McGhee, D. E., & Steele, J. R. (2006). How do respiratory state and measurement method affect bra size calculations? *British Journal of Sports Medicine, 40,* 970-974.

Michael, A. (2006, Aug 7). Body armor fit for a superhero: Military & Government Collection. *BusinessWeek*, pp. 76.

Morris, D., Mee, J., & Salt, H. (2002). *The calibration of female breast size by modeling*. Paper presented at the meeting of the International foundation of Fashion Technology Institutes, Hong Kong.

Moss, M. (2006). Pentagon study links fatalities to body armor. *The New York Times*, Retrieved June 06, 2009, from http://www.nytimes.com/2006/01/07/politics/07armor.html?scp=1&sq=Pentagon%20study

Nam, J. H. (2004). *Development, modification and fit analysis of liquid cooled vest prototypes using 3D body scanner*. Unpublished master's thesis, Oklahoma State University, Stillwater, OK.

Nam, J. H. (2009). *Arm armor systems: Fit analysis and performance factors*. Unpublished doctoral dissertation, Oklahoma State University, Stillwater, OK.

National Institute of Justice. (2004). *Annual Report.* Retrieved February 5, 2008, from http://www.ncjrs.gov/pdffiles1/nij/209274.pdf

National Institute of Justice. (2008). *Ballistic Resistance of Body Armor NIJ Standard-0101.06, U.S. Department of Justice Office of Justice Programs National Institute of Justice.* Retrieved Aug 22, 2009, from http://www.ncjrs.gov/pdffiles1/nij/223054.pdf

National Law Enforcement and Corrections Technology Center (NLECTC). (2006). 30 year, 3,000 savers. *TechBeat*. Retrieved June 22, 2009, from http://www.nlectc.org/techbeat/fall2006/30Years3000Saves.pdf

Nielsen, R., Gavhed, D. C., & Nilsson, H. (1989). Thermal function of a clothing ensemble during work: Dependence on inner clothing layer fit. *Ergonomics*, *32*(12), 1581-1594.

Office of Army Demographics. (2005). *Army profile (FY05)*. Retrieved June 22, 2009, from http://www.armyg1.army.mil/hr/demographics.asp

Paquette, S. (1996). 3D scanning in apparel design and human engineering. *IEEE Computer Graphics and Application, 16*(5), 11-15.

Pechter, E. A. (1998). A new method for determining bra size and predicting post augmentation breast size. *Plastic and Reconstruction Surgery*, 102, 1259-1265.

Peksoz, S. (2005). *A physiological study of the effectiveness of two prototype portable cooling vests.* Unpublished doctoral dissertation, Oklahoma State University, Stillwater, OK.

Petrova, A. (2007). Creating sizing systems. In S. P. Ashdown. (Eds.), *Sizing in Clothing: Developing Effective Sizing Systems for Ready-to-Wear Clothing* (pp. 57-87). Cambridge, UK: Woodhead Publishing Limited.

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

Precise body measurement. (n.d.). Retrieved Oct 10, 2009, from http://human-solutions.com/apparel/technology_scanning_en.php

Read, C. (1993). *A Women's Breast*. Melbourne (VIC): Ashwood Medical House.

Ricciardi, R. (2007). Effects of gender and body adiposity on physiological responses to physical work while wearing body armor. *Military Medicine, 179*(7), 743-748.

Rosenblad-Wallin, E. (1987). An anthropometric study as the basis of sizing anatomically designed mittens. *Applied Ergonomics, 18*(4), 329-333.

Shanley, L., Slaten, B., & Shanley, P. (1993). Military protective clothing: Implications for clothing and textiles curriculum and research. *Clothing and Textiles Research Journal*, *11*(3), 55-59.

Sontag, M. S. (1985). Comfort dimensions of actual and ideal insulative clothing for older women. *Clothing and Textiles Research Journal*, *4*, 9-17.

Todd, M. L. (2007). Sizing for the military. In S. P. Ashdown. (Eds.), *Sizing in Clothing: Developing Effective Sizing Systems for Ready-to-Wear Clothing* (pp. 277-308). Cambridge, UK: Woodhead Publishing Limited.

Todd, W. L., Paquette, S. P., & Bensel, C. K. (1997). *Compatibility of army systems with anthropometric characteristics of female soldiers* (NATICK/TR-97/017). Natick, MA: U.S. Army Solider Systems Command Natick Research, Development, and Engineering Center.

Tremblay, J. F. (1989). *Ebaluation of functional fit and comfort of chemical protective cloves for agricultural workers.* Unpublished master's thesis, the University of Alberta, Edmonton, Alberta, Canada.

Tremblay, J. F., & Weihrer, S. T. (1996). Functional fit evaluation to determine optimal ease requirements in Chemical protective gloves. In J. S. Johnson., & S. Z. Mansdorf (Eds.), *Performance of Protective Clothing,* 5th Edition (pp.367-383). Philadelphia, PA: American Society for Testing and Materials.

Tung, T. Y. (2008). *Design criteria of type IV body armor for women*. Unpublished master's thesis, Oregon State University, Corvallis, OR.

Valdes, R. (n.d.). *How breast implants work*. Retrieved Oct 10, 2009, from http://health.howstuffworks.com/breast-implant.htm/printable

Westrick, A. (2001). Body armor facts: Protecting the protectors. *Law & Order, 47*(7), 131-134.

Wise, R. J. (1956). A preliminary report on a method of planning the mammaplasty. *Plastic and Reconstructive Surgery*, 17, 367-375.

Wolf, J. (2008, July 8). *SAVVY, a new line of body armor design women*. Retrieved Sep 23, 2008, from http://www.officer.com/web/online/Industry-Business-Wire

Wright, M. C. M. (2002). Graphical analysis of bra size calculation procedures. *International Journal of Clothing Science and Technology, 14*(1), 41-45.

Yu, W. (2004[a]). Subjective assessment of clothing fit. In J. Fan., W. Yu., & L. Hunter. (Eds.), *Clothing Appearance and Fit: Science and Technology* (pp.31-42). Cambridge, UK: The Textile Institute.

Yu, W. (2004[b]). 3D body scanning. In J. Fan., W. Yu., & L. Hunter. (Eds.), *Clothing Appearance and Fit: Science and Technology* (pp.135-168). Cambridge, UK: The Textile Institute.

Zehner, G. F., Ervin, C., Robinette, K. M., & Daziens, P. (1987). *Fit evaluation of female body armor* (AAMRL-TR-87-046), Wright-Patterson AFB, OH: Anthropology Research Project, Harry G. Armstrong Aerospace Medical Research Laboratory.

Zheng, R. (2006). *Breast sizing and development of 3D seamless bra*. Unpublished doctoral dissertation, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong.

Zheng, R., Yu, W., & Fan, J. (2007). Development of a new Chinese bra sizing system based on breast anthropometric measurements. *International Journal of Industrial Ergonomics, 37*, 697–705.

APPENDICES

APPENDIX A

Oklahoma State University Institutional Review Board

Date:	Thursday, November 05, 2009
IRB Application No	HE0966
Proposal Title:	Exploration of Fit Problems of Ballistic Vests Worn by Female Soldiers
Reviewed and Processed as:	Exempt

Status Recommended by Reviewer(s): Approved Protocol Expires: 11/4/2010

Principal Investigator(s):

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The IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46.

☒ The final versions of any printed recruitment, consent and assent documents bearing the IRB approval stamp are attached to this letter. These are the versions that must be used during the study.

As Principal Investigator, it is your responsibility to do the following:

1. Conduct this study exactly as it has been approved. Any modifications to the research protocol must be submitted with the appropriate signatures for IRB approval.
2. Submit a request for continuation if the study extends beyond the approval period of one calendar year. This continuation must receive IRB review and approval before the research can continue.
3. Report any adverse events to the IRB Chair promptly. Adverse events are those which are unanticipated and impact the subjects during the course of this research; and
4. Notify the IRB office in writing when your research project is complete.

Please note that approved protocols are subject to monitoring by the IRB and that the IRB office has the authority to inspect research records associated with this protocol at any time. If you have questions about the IRB procedures or need any assistance from the Board, please contact Beth McTernan in 219 Cordell North (phone: 405-744-5700, beth.mcternan@okstate.edu).

Sincerely,

Shelia Kennison, Chair
Institutional Review Board

APPENDIX B

Script

A study, entitled "Exploration of Fit Problems of Ballistic Vests worn by Female Soldiers," is being initiated to determine fit of the ballistic vest by female soldiers while performing routine activities typically performed while wearing the vest.

As part of the study, a focus group interview will be conducted. Female soldier participation in the focus group interview, which will take about 60 – 90 minutes, is absolutely vital to the success of the whole project. We very much need input from female soldiers regarding their experiences with wearing the vest, so that we can better design the 2nd phase of the study, and ultimately to improve the design of the ballistic vest for females. We hope to have about 10 participants in the discussion. We will be asking participants to tell us about activities that they have performed while wearing the vest.

The discussion will be recorded and transcribed by a researcher for future data analysis. Individuals will not be identified by name in the transcription, thus, there will be no way to associate a particular individual's responses with a particular soldier. Thus, participants can be assured that their responses will remain confidential. During the interview, participants may choose to end their participation at any time, and may decline to answer specific questions.

We hope that many of you will be interested in participating in this project. Your assistance is greatly appreciated. If you have any questions, please call or email one of us. Thank you for your consideration.

Sincerely,

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Okla. State Univ.
IRB
Approved 11/5/09
Expires 11/4/10
IRB# HE0966

APPENDIX C

INFORMED CONSENT FORM

You are asked to be a participant in the research project entitled "Exploration of Fit Problems of Ballistic Vests worn by Female Soldiers." Su Kyoung An, a doctoral student at Oklahoma State University, will conduct this project under the supervision of Drs. Donna Branson, Semra Peksoz, and Adriana Petrova (Oklahoma State University, Institute for Protective Apparel Research and Technology, Department of Design, Housing, & Merchandising).

The purpose of this research is to hone the female soldier's routine and the discomfort area of the ballistic vest. User input is critical for development of a study that will evaluate the fit of ballistic vests worn by female soldiers while performing the routine movements. This focus group interview will provide vital practical perspectives for this research goal.

The focus group interview will take about 60 - 90 minutes. Your participation is totally voluntary, and you may withdraw from the study at any time for any reason. Also, you may choose not to answer any question without explaining your reason. Your responses will be recorded on an audio tape, and a transcription of the recording will be prepared by a researcher with a code numbers to identify subject's comments. Thus, the name and contact information of subjects will not be retained at all.

There are no known risks associated with this project that are greater than those ordinarily encountered in daily life. The resulting data will be used to design a follow-up study that will analyze the fit of ballistic vests worn by female soldiers.

The research records will be stored securely in a locked filing cabinet, and only researchers and individuals responsible for research oversight will have access to them. It is possible that the consent process and data collection will be observed by the research oversight staff responsible for safeguarding the rights and well-being of the people who voluntarily participate in the research project.

If you have questions about your rights as a research volunteer, you may contact Dr. Shelia Kennison, IRB Chair, at 219 Cordell North, Stillwater, OK 74078. Dr. Kennison's phone number is 405-744-3377, and her e-mail address is irb@okstate.edu.

If you have any questions concerning the study, you may contact the following researchers:

Su Kyoung An at (405) 926-0324, email to sukyoung.an(a)okstate.edu
Dr. Donna Branson at (405) 744-5050, email to donna.bransone okstate.edu
Dr. Semra Peksoz at (405)744-9520, email to semra.oeksozeokstate.edu
Dr. Adriana Petrova at (405) 744-9574, email to adriana.petrova(ahokstate.edu

"I have read and been given information about this research study and the risks involved have been explained to me. I have fully understood the consent form. Any questions I may have had were answered to my satisfaction and I have been told who to contact should additional questions arise. As a result, I give my informed consent to participate in this research. I have received a copy of this consent form."

Signature of Participant _______________ Date _______________

"I certify that I have personally explained this document before requesting that the participant sign it."

Signature of PI _______________ Date _______________

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Approved 11/5/09
Expires 11/4/10
IRB# HE0966

APPENDIX D

Focus Group Interview Questionnaire

A. Introduce the researchers, provide an overview of the type of research that we do, and review the purpose of the focus group.

B. Focus group questions

1. Tell us how long you have been in the army and where you have been assigned.
   Probe: Ask if any have served in Iraq and Afghanistan and what their duties entailed.

2. Tell us about your overall experience in wearing ballistic vests.
   Probe: Have you worn the Interceptor vest? If yes, how many and for what activities?
   Probe: Have you worn the newly designed army vest? If yes, how many and for what activities?
   Probe: On a scale of 1 to 5 with 5 being very satisfied, how satisfied are you with how the interceptor vest fits you?
   Probe: On a scale of 1 to 5 with 5 being very satisfied, how satisfied are you with how the new army vest fits you?

3. Tell us about the entire clothing system that you wear when using the ballistic vest.
   Probe: Do you wear a bra while wearing the ballistic vest? If so, what type? Please explain.
   Probe: Do you wear an undershirt with your vest? If yes, what type? Is it over a bra?
   Probe: How often do you wear the hard plates with the vest? Please explain.
   Probe: Have you used the side hard plates? If yes, for what activities?

4. What types of duties do you perform while wearing the ballistic vest?
   Probe: Can you tell us about the movements associated with your duties while wearing a ballistic vest? For example, if a soldier said driving a truck, then suggest possible movements, such as getting into and out of the truck.

5. Do you feel any discomfort associated with these duties and common movements?
   Probe: If you do, please tell us the location of and type of discomfort you have experienced.
   Probe: Have you felt any discomfort in your breast area when you performed movements? If yes, explain.

6. Let's go around and I would like each of you to tell us the features that you particularly like in the ballistic vests that you have worn.

7. Let's go around and this time, I would like each of you to tell us the features that you particularly dislike in the ballistic vests that you have worn.

8. If you had the opportunity to make changes to improve the fit of the ballistic vest for a female soldier, what feature of the ballistic vest would you modify?

C. Thank you so much for your participation!!!

APPENDIX E

We need female volunteers to participate in research to improve the fit of the ballistic vest for female soldiers

WHO: **Females ages 19 to 35** with bust measurement **between 33" and 37.99"**

MEASUREMENT VERIFICATION: Surface body – scanning

RESEARCH TEST: Motion capture & Pressure testing, 1 ½ Hrs.

WHEN: Feb 15th through July 15th 2010

WHERE: IPART (Institute for Protective Apparel Research and Technology) Laboratory in the Oklahoma Technology & Research Park

After completing the test, a $20 gift card will be provided to all participants.

If interested, please contact Su Kyoung An at 405-926-0324 or email sukyoung.an@okstate.edu

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Approved 2/15/10
Expires 2/14/11
IRB# HE-09-75

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APPENDIX F

We need female volunteers to participate in research to improve the fit of the ballistic vest for female soldiers

WHO: <u>**Females ages 18 to 35**</u> who wear bra size 30 or 32, cup size C, D, or above

MEASUREMENT VERIFICATION: Surface body – scanning

RESEARCH TEST: Motion capture & Pressure testing, 1 ½ Hrs.

WHEN: <u>May 19th through July 15th 2010</u>

WHERE: IPART (Institute for Protective Apparel Research and Technology)
Laboratory in the Oklahoma Technology & Research Park

After completing the test, $20 cash will be provided to all participants.

If interested, please contact Su Kyoung An
at <u>405-926-0324</u> or email <u>sukyoung.an@okstate.edu</u>

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IRB
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Expires 2/14/11
IRB # HE0975

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APPENDIX G

Oklahoma State University Institutional Review Board

Date:	Monday, February 15, 2010
IRB Application No	HE0975
Proposal Title:	Laboratory Assessment of Range of Motion and Pressure Associated with Female Soldiers Wearing a Ballistic Vest
Reviewed and Processed as:	Expedited

Status Recommended by Reviewer(s): Approved   Protocol Expires: 2/14/2011

Principal Investigator(s):

Su Kyoung An	Donna Branson
431 HES	431 HES
Stillwater, OK 74078	Stillwater, OK 74078

The IRB application referenced above has been approved. It is the judgment of the reviewers that the rights and welfare of individuals who may be asked to participate in this study will be respected, and that the research will be conducted in a manner consistent with the IRB requirements as outlined in section 45 CFR 46.

☒ The final versions of any printed recruitment, consent and assent documents bearing the IRB approval stamp are attached to this letter. These are the versions that must be used during the study.

As Principal Investigator, it is your responsibility to do the following:

1. Conduct this study exactly as it has been approved. Any modifications to the research protocol must be submitted with the appropriate signatures for IRB approval.
2. Submit a request for continuation if the study extends beyond the approval period of one calendar year. This continuation must receive IRB review and approval before the research can continue.
3. Report any adverse events to the IRB Chair promptly. Adverse events are those which are unanticipated and impact the subjects during the course of this research; and
4. Notify the IRB office in writing when your research project is complete.

Please note that approved protocols are subject to monitoring by the IRB and that the IRB office has the authority to inspect research records associated with this protocol at any time. If you have questions about the IRB procedures or need any assistance from the Board, please contact Beth McTernan in 219 Cordell North (phone: 405-744-5700, beth.mcternan@okstate.edu).

Sincerely,

Shelia M. Kennison

Shelia Kennison, Chair
Institutional Review Board

APPENDIX H

INFORMED CONSENT FORM

You are asked to be a participant in the research project entitled "Laboratory assessment of range of motion and pressure associated with female sliders wearing a ballistic vest." Su Kyoung An, a doctoral student at Oklahoma State University, will conduct this project under the supervision of Dr. Donna Branson (Oklahoma State University, Institute for Protective Apparel Research and Technology, Department of Design, Housing, & Merchandising).

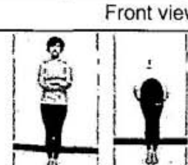
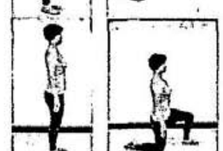
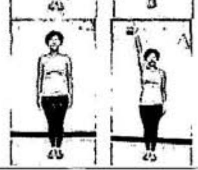
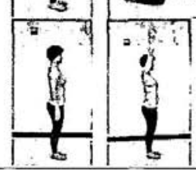
The purpose of this research is to explore how and to what extent restrictions in performance and problems in comfort confront female soldiers wearing ballistic vests by measuring range of motion and pressure-contact area. This study will be used to determine the problems associated with wearing the ballistic vest.

This study will be conducted in three sessions: 1) 30 minutes for sampling test, 2) 40 minutes for range of motion test, and 3) 30 minutes for pressure test. All procedures will be conducted at the IPART (Institute for Protective Apparel Research and Technology) laboratory located at the Venture I laboratory in the Oklahoma Technology & Research Park (Address: 1110 S. Innovation Way, Room 109 IPART Lab, Stillwater, OK 74074).

For the sampling test, you will be given and asked to wear the sleep bra, a sleeveless shirt, and long knit pants and to be scanned using the 3D body scanner to acquire your under-bust and bust circumferences. The scanning process, which will take 12 seconds, is a safe and reliable method of measuring the human subject (http://www.human-solutions.com/sports/technology_scanning_vxxl_en.php). Four laser lights located at the corners of the booth will travel from the top of your body to your feet as a set of eight cameras record data of the surface of your body. The lights are safe to look at, so you do not need to close your eyes. There is no radiation exposure from the scan. The obtained human figure will be interpolated using Polyworks software produced by InnoMetric Software Inc. With this software, under-bust and bust circumference will be measured. According to your measurements, you will be assigned into one of three bust groups. If your measurements are outside of the parameters of the three groups, you will not be permitted to participate in this study as a subject.

Next, the range of motion test will be conducted. You will wear a sports bra, a sleeveless shirt, and long knit pants and practice four movements (trunk flexion, hip flexion with kneeling, shoulder flexion, and shoulder horizontal adduction) (Table 1).

Table 1. Four movements

Movements	Front views	Side views
Trunk Flexion		
Hip Flexion with Kneeling		
Shoulder Flexion		

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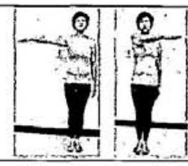
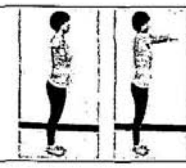
Expires 2/14/11
IRB# HE-09-75

Shoulder Horizontal Adduction		

Then, the researcher will attach ten markers for capturing your motion while you perform all four movements. The researcher will use two sides of tapes which were designed for this market to minimize discomfort of the subject when attaching the marker to you. One side of tape will be attached to the bottom of the base of marker and then another side of tape will be attached to the skin (Figure 1).

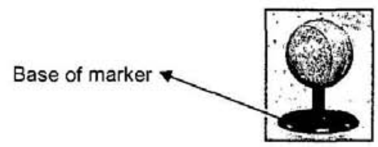


Figure 1. Marker

The appropriate locations of the markers are; 1) right acromion, 2) giugula, 3) left acromion, 4) right asis, 5) sacrum, 6) left asis, 7) right elbow, 8) right wrist, 9) left trochanter, and 10) left femoral condyle (Figure 2).

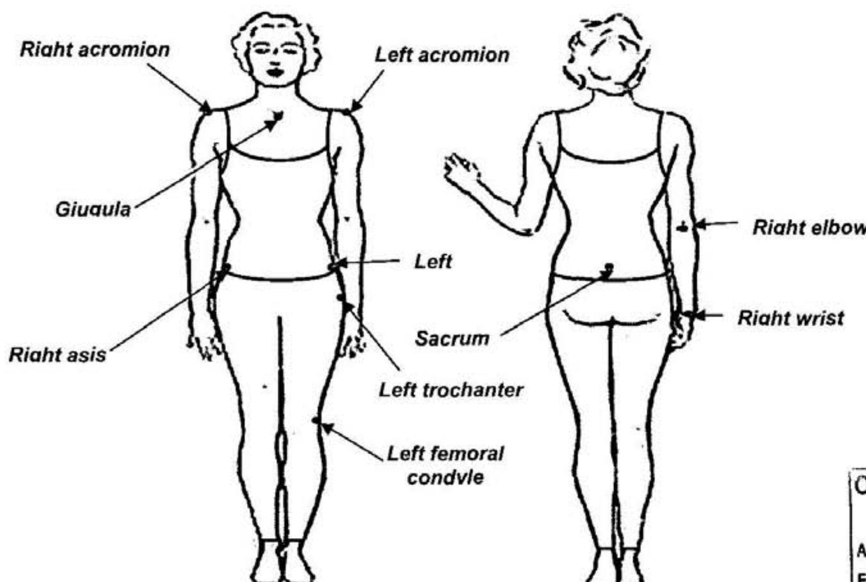


Figure 2. All ten markers' locations

BTS Smart – D Motion Capture System, which was developed by BTS Bioengineering, will be used to capture your motion while performing all four movements. After performing all movements without the vest, you will don the ballistic vest (Interceptor™) over your other test clothing and perform the same four movements to obtain range of motion data while wearing the ballistic vest.

After completing the range of motion test, you will change into a 2^{nd} test garment which consists of a sports bra, T-shirt, and BDU (Battle Dress Uniform) for the pressure test. Over the BDU, a pressure sensor will be placed on your bust area and the ballistic vest (Interceptor™) will be donned over the sensor with the researcher's help. All pressure data inside the Interceptor™ vest will be recorded and saved into the computer.

Upon completion of all test procedure, twenty dollars will be given to you to express our appreciation for your cooperation. If you do not complete the test or if you do not fit into one of three groups, twenty dollars will not be given to you.

The full process test procedure will take a maximum of 2 hours. Your participation is totally voluntary, and you may withdraw from the study at any time for any reason. There are no known risks associated with this project which are greater than those ordinarily encountered in daily life.

The face of scanned images will be obscured by the primary researcher to protect the confidentiality of the subject. Thus, the scan image cannot be identified with a person. All data obtained from motions capture test and pressure test will be saved in a portable hard drive with the password protected. Thus, the data will be accessible to the primary investigator and faculty advisor only. The research records will be stored securely in a locked filing cabinet. In any written reports or publications, scan images of your face will be altered so no individual will be identified or identifiable. The scan images will be discarded when the data are no longer needed for this project.

If you have questions about your rights as a research volunteer, you may contact Dr. Shelia Kennison, IRB Chair, at 219 Cordell North, Stillwater, OK 74078. Dr. Kennison's phone number is 405-744-3377, and her e-mail address is irb@okstate.edu.

If you have any questions concerning the study, you may contact the following researchers:

Su Kyoung An at (405) 926-0324, email to sukyoung.an@okstate.edu
Dr. Donna Branson at (405) 338-8538, email to donna.branson@okstate.edu

"I have read and been given information about this research study and the risks involved have been explained to me. I have fully understood the consent form. Any questions I may have had were answered to my satisfaction and I have been told who to contact should additional questions arise. As a result, I give my informed consent to participate in this research. I have received a copy of this consent form."

Signature of Participant ______________________ Date ______________

"I certify that I have personally explained this document before requesting that the participant sign it."

Signature of PI ______________________ Date ______________

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Expires 2/14/11
IRB# HE-09-75

APPENDIX I

Procedures to Develop the Protocols

1. Open the BTS Smart – Capture software.
   a. Calibration.
   b. After the calibration, click on the *Monitor* button to turn on all cameras.
   c. The subject with the markers attached stands in the calibration volume.
   d. Click on the *New* button in the main toolbar.
   e. Create a new subject by clicking on the *New Subject* button.
   f. The subject stays in the calibration volume to capture the movement.
   g. Click on the *Monitor* button in the main toolbar.
   h. Click on the *Capture* button to start capturing.
   i. The subject performs the movement five times.
   j. Click on the *Capture* button again to stop capturing.
   k. Click the *Go 3D* button in the main toolbar to run in the Smart – Tracker software.

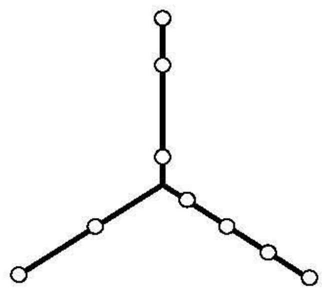
2. Open the BTS Smart – Tracker software.
   a. Open the acquired data.
   b. Create an appropriate anatomical model by linking and labeling the markers.
   c. Click on the *Save* model button to save it.
   d. Each point shown in the acquired data is labeled according to the existing model.
   e. While playing the data sequence, all points are tracked by labeling them.

3. Open the BTS Smart – Analyzer software.
   a. Click the Open button in the main toolbar to open the file.
   b. Click the Open archive button to open the info file.
   c. Click the New protocol button in the main toolbar to create a new blank protocol.
   d. A light yellow panel appears, with a vertical toolbar on the left side. This toolbar has the types of the functions to compute the angle of the movement.
   e. Click on the appropriate button on the toolbar, and create the appropriate algorithm to computer the angle.
   f. Drag the data into the input circle of the computation block.
   g. If you want to create more algorithms, repeat steps from e to g.
   h. Click on the *Save* protocol to save the protocol.

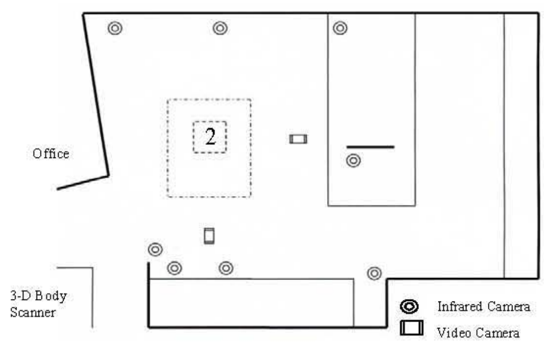
APPENDIX J

Calibration Procedures of BTS – Smart D Motion Capture System

1. Open the Smart – Capture software.
2. Click on the *New Calibration* button in the main toolbar.
3. Select the *Medium* (60 cm) as the calibration set and *Y-Up* orientation and click on *OK*.
4. The new calibration file appears at the left side of the main windows. The calibration folder has the two blocks: *Axes sequence* and *Wand sequence*.
5. Acquire an *Axes sequence* first.
   a. Assemble the wands as shown below.

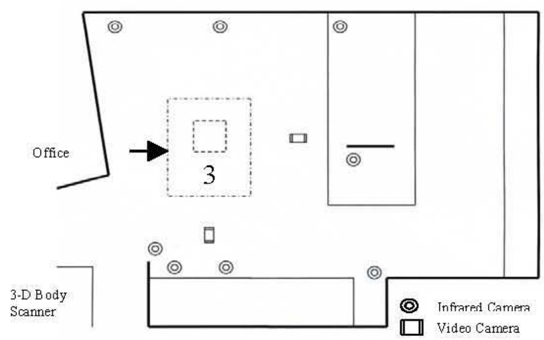


   b. Select the *Axes sequence* block in the File Viewer frame.
   c. Locate the assembled wands at the origin of the volume being calibrated (in the square marked 2).



   d. Click on the *Monitor* button in the main toolbar.
   e. Click on the *Capture* button in the main toolbar to start capturing.
   f. Click on the *Capture* button again to stop capturing after 5 seconds.
   g. Remove the assembled wands from the volume being calibrated.
6. Acquire a *Wand sequence*.
   a. Dissemble the wands and select only the wand with three markers as shown the below.

b. Select the *Wand sequence* block in the File Viewer frame.
c. Stay in the location marked by the arrow while holding the wand with three markers in hand to avoid the field of view of camera.



a. Click on the *Capture* button in the main toolbar to start capturing.
b. Sweep the square marked 3 in the above the map with the wand with three markers and move it up and down several times parallel to each axis to acquire the best calibration volume.
c. Click on the *Capture* button again to stop capturing after 90 seconds.
d. Remove the wand with three markers from the volume being calibrated.
e. As soon as the calibration is finished, the system calibration window is appeared.
f. Click the *Details* button and then the *Start* button in the system calibration window to calculate the mean and standard deviation for this calibrated volume.
g. The Mean should be smaller than 0.6mm. If it is larger than 0.4 mm, the calibration should be performed again.

VITA

Su Kyoung An

Candidate for the Degree of

Doctor of Philosophy/Education

Thesis: LABORATORY ASSESSMENT OF RANGE OF MOTION AND PRESSURE ASSOCIATED WITH FEMALE SOLDIERS WEARING A BALLISTIC VEST

Major Field: Apparel Design

Biographical:

Education:

Completed the requirements for the Doctor of Philosophy in Department of Design, Housing, and Merchandising at Oklahoma State University, Stillwater, Oklahoma in July, 2010.
Completed the requirements for the Master of Art in Department of Apparel, Merchandising, Design and Textiles at Washington State University, Pullman, Washington in 2005.
Completed the requirements for the Bachelor of Science in Department of Clothing and Textiles at Pai Chai University, Dae Jeon, Korea in February in 2001.

Experience:

Assistant Professor in Department of Apparel Merchandising and Design at Central Michigan University in Mt. Pleasant, Michigan, 2010 - present
Doctoral Graduate Associate at Oklahoma State University in Stillwater, Oklahoma, 2006 - 2009
Master Graduate Assistant at Washington State University in Pullman, Washington, 2004 - 2005

Professional Memberships:

International Textile and Apparel Association
American Quilter's Society
Korean Society of Clothing & Textiles

Name: Su Kyoung An Date of Degree: July, 2010

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: LABORATORY ASSESSMENT OF RANGE OF MOTION AND PRESSURE ASSOCIATED WITH FEMALE SOLDIERS WEARING A BALLISTIC VEST

Pages in Study: 152 Candidate for the Degree of Doctor of Philosophy

Major Field: Human Environmental Science – Apparel Design

Scope and Method of Study: The overall purpose of this research is to explore restrictions in performance and pressure exerted on the front torso of females wearing the Interceptor™ vests by measuring ROM and pressure-contact area. A three-phase study was conducted to meet the study objectives. Phase I examined military anthropometric database to determine age range, bust circumference range, and bust size groups for female soldiers in order to specify criteria for accepting subjects for the third phase. A focus group interview with female soldiers was the focus of Phase II in order to determine test garments and test movements to be used in the third phase to simulate female soldiers' typical movements and clothing. Phase III was a two-part laboratory experiment to determine ROM in subjects wearing and not wearing the ballistic vest while performing four selected movements. ROM was determined using the BTS Motion Capture System. Pressure-contact area was determined using Tekscan pressure sensors by subjects wearing the vest and performing the four movements. All volunteers were scanned using a 3D body scanner for selection as a subject and for placement into a bust size group.

Findings and Conclusions: Significant differences were found by vest for ROM for three of the four movements (shoulder flexion, shoulder horizontal adduction, and trunk flexion) with decreased ROM shown when subjects wore the vest. Examination of the ROM data for hip flexion with kneeling showed that the subjects used two ways of bending when performing this movement. A significant interaction effect was found for way of kneeling by bust size groups. For the bust size treatment, no significant differences were found for shoulder flexion, trunk flexion, and hip flexion with kneeling. A significant difference was found for shoulder horizontal adduction. Post hoc analysis found two significant groups with the large bust group having greater reduction in ROM as compared to the other bust groups. For pressure-contact area, significant bust size group differences occurred for shoulder and trunk flexion. However, post hoc analyses show conflicting results.

ADVISER'S APPROVAL: Dr. Donna Branson