ARM ARMOR SYSTEMS: FIT ANALYSIS AND PERFORMANCE FACTORS

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ARM ARMOR SYSTEMS: FIT ANALYSIS AND

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CHAPTER I

INTRODUCTION

Background of Research

Soldiers are exposed to potential fatal injuries when they perform their activities. Ballistic protective armor has been used for protecting soldiers from lethal injuries caused by various projectiles. Two different types of ballistic protective armor are commonly used; soft armor and hard armor. Soft armor affords the soldier less protection, but more flexibility than hard armor. Soft armor usually consists in multiple layers of a textile material such as Kevlar®, Dyneema®, Spectra®, or Twaron®. Hard armor, often called SAPI (Small Arms Protective Insert) plate is worn in addition to soft armor depending on the level of protection needed. Helmets use only hard armor. A SAPI plate is usually made from a ceramic composite. The plates are typically inserted into front, back, and possibly side pockets of the ballistic vest. Similarly, the soft armor is encased in a fabric covering and the package is inserted into pockets in the vest. Figure 1 shows examples of an outer tactical vest with soft armor, and the front SAPI plate being held by a soldier.

Outer Tactical Vest with
Soft Body Armor

Soldier inserting SAPI Plate into Vest

Figure 1. Examples of Outer Tactical Vest, and Hard Body Armor
(http://www.afmo.com/Outer_Tactical_Vest_p/204-00011.htm)

The effectiveness of having a SAPI plate for reducing fatal injuries has been recognized. According to Moss (2006, January 07), a recent Pentagon study reported that at least 80 percent of the marines who have been killed in Iraq from wounds to their upper body could have survived if they had extra body armor. In this study, at least 74 of the 93 fatal torso wounds from March 2003 through June 2005 were analyzed, and findings indicated that bullets and shrapnel struck the marines' shoulders, sides or areas of the torso unprotected by the plates (*Figure* 2). According to Moss (2006, January 07) wounds at the arm muscle and shoulder represent 15% among total lethal torso injuries. Body areas around the front and back SAPI plates accounted for 65%.

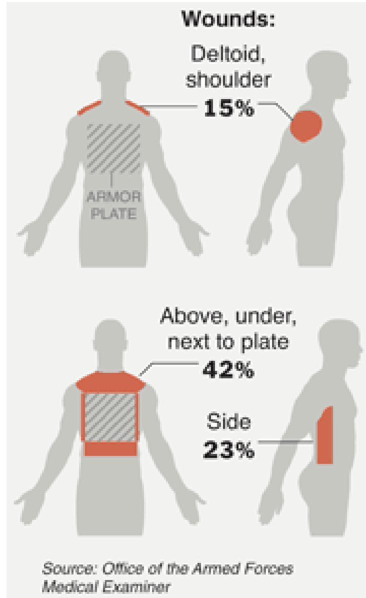


Figure 2. Armor Analysis (Moss, Jan, 07, 2006)

The U.S. Federal News Service (2006, May) also reported one incident in which the optional SAPI plate strapped to the side of the soldier's body, saved the soldier's life from an insurgent sniper's shot.

However, several problems including hindering task effectiveness, increasing weight, and reducing task speed, and maneuverability have been recognized in using SAPI plates (http://www.defensetech.org/archives/002068.html). A focus group was conducted to acquire the end-users' input in development of a load bearing ballistic vest (Nam, Kumphai, Branson & Peksoz, 2007). The subjects had experience in using SAPI plates in their ballistic vests in field combat. They listed heavy weight, fit and discomfort resulting from stiffness, rigidity and shape of the SAPI plates as problems (Nam, Kumphai, Branson & Peksoz, 2007).

Typically, increased protection requires thicker rigid plates. As the thickness is increased, the weight is usually increased as well. Daanen and Reffeltrath (2007) suggested that protective clothing should be designed in such a way that a good balance exists between protection and performance. They argued that the chosen materials should be as light as possible and the clothing design should account for human performance (p.202). Maximizing human performance while reducing the wearer's impediment through appropriate garment properties such as design, size and use of materials are critical issues for the clothing designer to resolve.

In the development of limb and shoulder armor, the rigidity and stiffness of possible fabrications pose challenges for allowing the shoulder joint (glenohumeral joint) to perform various movements (shoulder flexion, shoulder extension, shoulder adduction, shoulder abduction, shoulder rotation, external rotation of arm, internal rotation of arm, circumduction). Considerable design expertise is required in order to provide ballistic protection and full mobility to the arm and shoulder. In addition, the rigid and stiff materials could exert pressure and discomfort at certain body areas.

Therefore biomechanical evaluations of performance are critical to consider. Range of motion (ROM) has been used as an effective tool to measure joint movability (Huck,1988; Adams & Keyserling, 1996). Garment fit is another critical factor influencing human performance. The importance of good fit for high performance clothing is more critical than fit for fashion clothing. Fit influences the wearer's mobility, which is critical for protective clothing, because it directly relates to the wearers' safety. In addition, improper fit could cause fatigue and potentially even chronic health conditions. Several researchers explored the effect of ease and fit on firefighters' performance while wearing protective encapsulated suits (Huck, Maganga & Kim, 1996).

Wearer's perceived comfort is another important factor. Perceived comfort and flexibility can be assessed by wearer trials, which are useful for providing subjective information for comparing types of armor. Flexibility is generally assumed to be one of the major factors in the overall wearability of a body armor system. Horsfall, Champion, and Watson (2005) found that how well the armor conforms and moves with the body, as well as the fit of armor, are primary factors in the wearability and comfort of any body armor system.

Purposes and Objectives

The purpose of this study is to compare performance effects and perceptual responses of wearing three different arm armor systems using no arm armor as a control garment treatment.

The objectives of this study are 1) to develop a protocol and/or instruments to assess selected human performance effects of wearing different arm and shoulder ballistic systems, 2) to evaluate the selected human performance of localized pressure, ROM, perceived garment impediment, wearer acceptability, and visual armor coverage.

Significance of the Study

Practical Sense:

There is a need for using ballistic armor to increase soldiers' survival and the armor should minimally restrict the wearer's performance. There is a need for achieving balance between increased ballistic protection and reduced human performance and comfort while wearing body armor. The proposed study has the potential to quantify human performance measures while wearing additional arm and shoulder armor.

Although ROM has been studied for a fire fighter's structural ensemble, no similar studies were found for body armor. No research has been found that compares the clothing properties of shoulder protective armor. This study will fill these gaps. Lastly, the results of this study could lead to improved arm and shoulder armor.

<u>Theoretical Sense:</u>

This study was guided by an existing framework, namely, the ‘Overview Model for Causes of Negative Performance Effects on Workers’ developed by Adams, Slocum and Keyserling (1994). This study operationally extended Adams, Slocum and Keyserling’s work (1994) by using variables related to fit and performance.

<u>Methodological Sense:</u>

The study has methodological significance by developing an integrated protocol to use multiple instruments simultaneously to capture various aspects of the wearer’s performance. The individual development of and use of each instrument also represents a methodological advancement in the fit and performance literature.

Definition of Terms

Biomechanics - the study of forces and their effects on living things (Hartze, 1974). Kreighbaum and Barthels (1996) defined biomechanics as an area of study wherein the knowledge and methods of mechanics are applied to the structure and function of the living human system (p.1).

Anthropometry - the study of human measurement for use in anthropological classification and comparison (Hartze, 1974).

SAPI (Small Arms Protective Inserts) - armor plates that when inserted into a protective vest will provide protection from certain high power rifle bullets. The SAPI is part of a protective system, which typically includes soft armor for fragmentation and protection within a tactical vest. The SAPI shall consist of a monolithic high performance ceramic (silicon carbide or boron carbide) joined to molded layers of SPECTRA Shield PCR layers or Dyneema layers on the back of the plate. The backing material is molded to the same curvature as the monolithic ceramic (Bhatnagar, 2006, p.156).

Anatomical position - the standard reference position for the body when describing locations, positions, or movements of limbs or other anatomical structure (McGinnis, 1999, p.24). The body is in the anatomical position when it is standing erect, facing forward, both feet aligned parallel to each other, toes forward, arms and hands hanging straight from the shoulders at the sides, fingers extended, and palms facing forward (McGinnis, 1999, p.24).

Ball and socket joint - the ball-like head of one bone fits into the socket-like head of another, permitting all movements. Shoulder and hip joints are both ball and socket joints (McGinnis, 1999).

CHAPTER II

REVIEW OF LITERATURE

This chapter will review the overview model for causes of negative performance effects on workers developed by Adams, Slocum, and Kerseling (1994) as a framework. Studies in garment properties and human performance including physiological, physical, and psychological aspects were reviewed. The chapter will conclude with an examination of modern body armor materials including textile products, rigid materials and ballistic protection, NIJ body armor classification scheme, and anatomy of the shoulder and arm region for understanding movement and position at the shoulder area.

Framework

Summary of Overview Model for Causes of Negative Performance Effects on Workers (Adams, Slocum & Keyserling, 1994)

An "Overview model for causes of negative performance effects on workers" developed by Adams, Slocum and Keyserling (1994, given as *Figure* 3) was developed based on literature reviews to systematically study the relationships among the identified garment properties and immediate effects. This model was expanded from Nunneley (1986)'s tripod model that identified three factors that influence heat stress associated with protective clothing. Nunneley (1986) argued that heat stress may result from one or more of three factors including work rate, clothing, and environment.

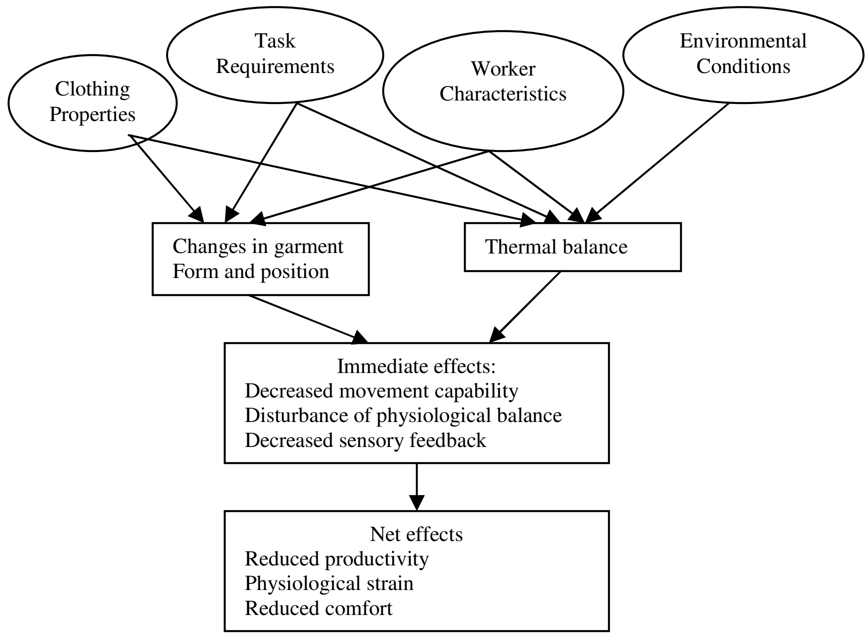


Figure 3. Overview Model for Causes of Negative Performance Effects on Workers Wearing Protective Clothing (Adams, Slocum & Keyserling, 1994, p.7)

The overall model explains the relationships between four causal factors, functional events, immediate effects, and net effects. Clothing properties, task requirements, environmental conditions and worker characteristics represent the four causal factors in this overview model. These four causal factors result in functional events such as changes in garment form and position, and thermal balance. Functional events are posited to result in immediate effects, and immediate effects to result in net effects.

Clothing properties include stiffness, hand, coefficient of friction, vapor permeability, insulation, bulk/compression, weight, ventilation, stretch, and ease. Garment properties can be determined by garment subcomponents, and garment components. The relationships among garment subcomponents, garment components and garment properties are shown in *Figure* 4.

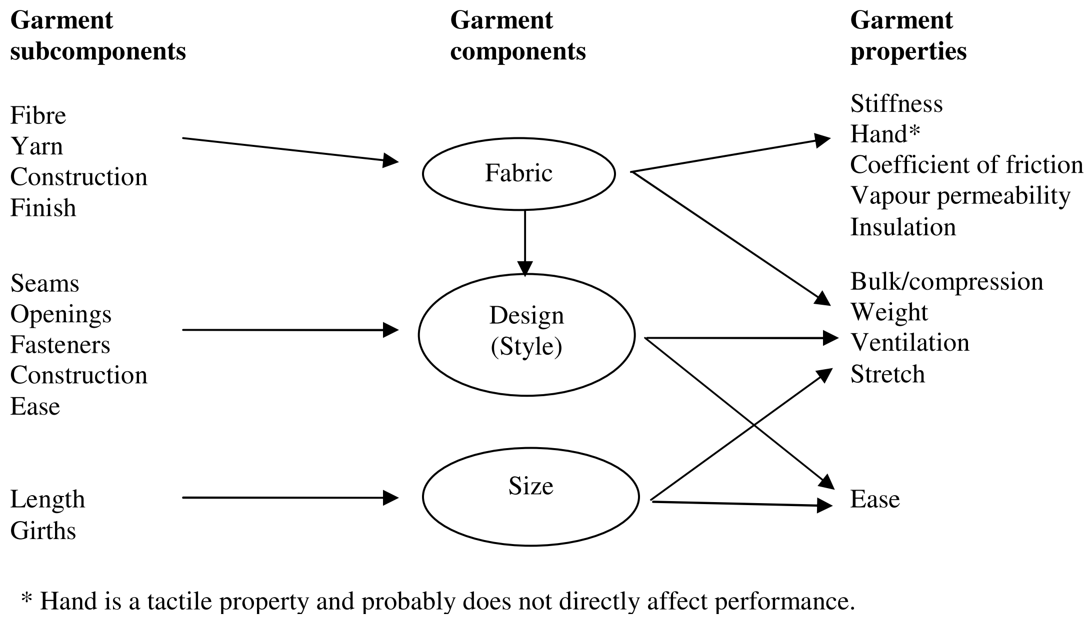


Figure 4. Relationship Among Garment Subcomponents and Garment Properties (Adams, Slocum & Keyserling, 1994, p.8)

Task requirements determine what movements must be made, as well as the characteristics of those movements. Movement involves the contraction of muscles and the subsequent generation of metabolic heat. Worker movement also causes clothing to move and change form (p.8). Worker characteristics that may influence performance can be grouped into three categories: namely, anthropometry, physiology, and motivation. Environmental conditions such as air temperature, RH, etc. also may affect the wearer's performance.

The four causal factors above result in functional events such as changes in garment form and position, and thermal balance. These functional events may result in immediate effects including decreased movement capability, disturbance of physiological balance, and decreased sensory feedback. These immediate effects may produce the net effects of reduced productivity, increased physiological strain, and reduced comfort.

Garment Properties and Human Performance Research

Since increasing the wearer' performance through garment design is of interest to clothing designers, researchers and developers, there has been considerable amount of research conducted in the areas of human performance and associated garment properties under controlled environment conditions assigning identical task requirements among comparison groups.

Adams (1994) developed a matrix summarizing the protective clothing studies contained in a data base of approximately 300 papers for the period 1957 to 1992 pertaining to the ergonomic effects of protective clothing and equipment to identify how clothing properties and performance are associated with each other. The survey was conducted of 118 protective clothing and equipment studies found in refereed journals, conference proceedings, and government technical reports. Heat stress was excluded in this survey. The dependent and independent variables were noted for the studies surveyed and the matrix was developed as a summary table. Each cell of the matrix was then coded to indicate the number of studies that utilized a particular measure to assess effects of the corresponding garment parameter as shown in *Figure* 5 (Adams, Slocum & Kerserling, 1994, p.9).

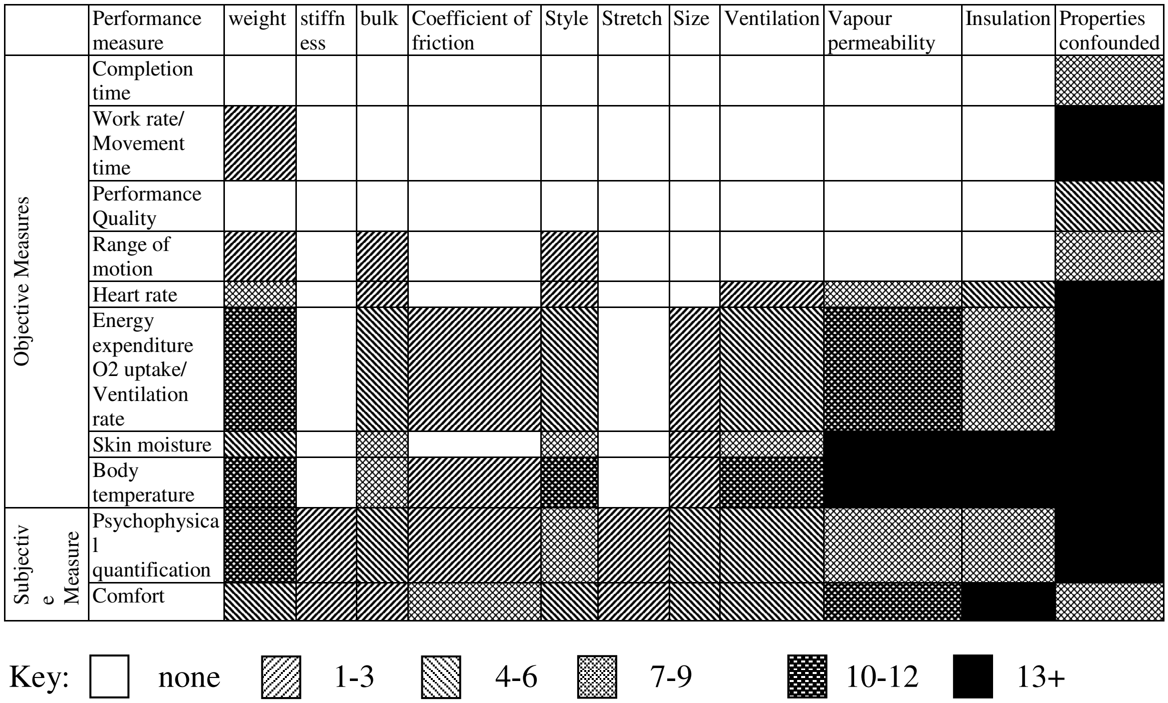


Figure 5. Number of Studies out of 118 Reviewed that Isolated or Defined a Given Garment Property and Corresponding Dependent Measure (Adams, Slocum & Keyserling, 1994, p.10)

The above matrix shows that the dependent variables cover a wide range of measures including both objective and subjective measures such as completion time, work rate/movement, performance quality, range of motion, heart rate, energy expenditure, skin temperature, body temperature, psychological quantification, and comfort. The independent variables for the associated clothing properties, found from the existing literature were: weight, stiffness, bulk, coefficient of friction, style, stretch, size, ventilation, vapor permeability, and insulation. The properties "confounded" on the right half of the table column on the top half scored high frequency, which indicated that many studies did not isolate or quantify specific garment components and properties. The bottom half of the matrix shows that a good amount of research has been done looking at fabric and garment properties as related to thermoregulation issues and comfort. The top half of the matrix shows that relatively few studies have been conducted looking factors including completion time, work rate/ movement time, performance quality, and range of motion. These factors are physical issues related to human performance. Examination of this matrix suggests that further studies need to be done regarding the ergonomic aspects of clothing with specified garment properties.

Studies in Garment Properties and Human Performance Area

There have been many studies that investigated the relationship between clothing properties and human performance. In most cases, multiple competing prototypes were compared and evaluated in terms of the wearers' performance in each prototype.

Garment Properties

Garment properties might affect the wearer's performance. Materials with high levels of stiffness and rigidity could interfere with the wearer's mobility, while materials with high stretch properties could increase the wearer's comfort. Adams (1994) listed stiffness, hand, coefficient of friction, vapor permeability, insulation, bulk/ compression, weight, ventilation, stretch, and ease as garment properties that could influence the wearer's performance. These garment properties could be derived from the garment components, including fabric, design (style), and size (ease) (Adams, 1994).

There have been studies to evaluate performance depending on the use of fabrics. Barker and Scruggs (1996) compared multiple gloves made of different fabrics to assess the comfort performance of fabrics for nuclear protective apparel. Different fabric compositions including 100% nylon, 100% polyester, 100% cotton fabrics, and polyester/cotton blended fabrics were compared, and their mechanical and surface properties were measured using the Kawabata Evaluation System that provides highly sensitive fabric measure. Chang and Shih (2007) investigated the effects of glove thickness on hand performance and fatigue during an infrequent high-intensity gripping task using a grip gauge with load cell. They compared four-gloved conditions including bare hand, Cotton-1, Cotton-2, and Covered-2. When subjects wore one or two layers of cotton gloves, the conditions were specified as Cotton-1 or Cotton-2, accordingly. Covering the handle of the grip gauge with a cotton 1 glove but not wearing it during exertion by the bare hand was specified as Covered-2, which was considered to be comparable with cotton-2 in thickness, but could be considered as a different wearing style. The cotton-2 condition, that was covered handle of the grip gauge, was selected for its common application in workplaces in Taiwan while workers are handling materials or operating hand tools manually. The hand performance was evaluated by maximum volitional contraction (MVC) and its associated time needed to reach the MVC (Tmvc), and the total force generation (TFG) during the sustained task. The hand fatigue was assessed by MVC degeneration (ΔMVC), the shift in time needed to reach the MVC, and the MEY (maximal endurance time) associated with the sustained task. The result indicates that wearing gloves decreased the grip MTC, and the thicker the gloves, the less the grip MVC, but the wearing style did not change the MVC (Cotton-2 MVC was indifferent from Covered -2 MVC). As to muscular fatigue, on the other hand, wearing gloves did not affect ΔMVC, MET, Tmvc. Due to the greater bare-hand MTV and indifferent MET, bare-hand TFG was better than those conditions with gloves.

Li, Barker, and Deaton (2007) studied the effects of material components including moisture barrier, and thermal liner, and design features including design/style, accessory, and size/fit on the heat and moisture transfer performance of firefighter turnout clothing using a sweating manikin in a climate chamber. Size/fit was considered a design feature for this study.

Huck, Maganga, and Kim (1997) investigated the influence of amount and location of ease in protective garments on fit and mobility aspects of wearer's performance. Specifically, the location of added crotch ease in protective coveralls was an independent variable for their study, with two levels: 1) the total needed crotch ease was added to the coverall back torso, and 2) half of the total needed crotch ease was added to the front torso and half of the total needed crotch ease was added to the a torso. ROM at appropriate body positions was measured as an objective measurement and wearer acceptability was evaluated after performing an exercise protocol for a subjective measurement.

Fit and Ease

In general, a well fitting garment contributes to the confidence, comfort, performance, and even safety of the wearer (Branson & Nam, 2007). Various criteria have been used to evaluate the appropriateness of fit of the clothing. Watkins (1995) specified that garments can be tested by expert raters, subject responses, and physical tests. Branson and Nam (2007) argued that fit could be judged from three different perspectives including from the industry producer, the individual, and the researcher perspectives using objective and subjective methods at multiple steps of the garment production and use cycle (Branson & Nam, 2007).

Rasband (1994) described a well-fitting garment as a garment that hangs smoothly and evenly on the body with straight seams, no fabric distortion nor pulling, and no gaping (Rasband, 1994) as a fit criteria for conventional clothing from the standpoint of the observer. Ashdown and DeLong (1995) focused on the wearer's perception, and noted that perception of fit as judged by the wearer involves several major issues, namely appearance or how the wearer perceives that the garment looks on themselves, and perception of comfort based on both tactile and visual responses. Often, wearing comfort is best ascertained by asking open-ended subjective questions such as "Is this prototype comfortable?" to the wearer. Physical tests can be conducted in a laboratory for a wide range of functions depending on the purpose of the garments. Watkins (1995) listed time to don and doff, range of motion, range of vision, grip strength, and ability to manipulate objects as examples of physical tests (Watkins, 1995).

In the functional apparel area, garment fit is considered to be a critical factor that could affect the wearer's performance. Improper fit of the garment could threaten the wearer's safety by interfering with the wearer's performance and exposing the wearer to a hazardous situation. Several researchers proposed guidelines to determine appropriate fit for target user groups (McConville, 1974). McConville (1974) developed a guideline for personal-protective clothing and equipment for the U.S. Air Force. He proposed hiring two investigators to observe preliminary fit in terms of protective capability, loss of functional capability by subject (mobility, agility, visibility, etc.), areas of stress on the item, integration with associated garments, fit, and comfort (McConville, 1974, p.21-22). He also suggested photographs taken of test items with an emphasis on photographing problem areas. McConville (1974, p.30) also listed fit judgment criterion as follows.

- When an item is designed to protect the wearer from a life-threatening hazard, it must achieve this protection for at least 98% of the user population.

- For all other garments and functions, if at least 90% of the sample population achieves a functional fit, it can be considered a good result.
- At least 80% of the sample must achieve a functional fit or garment production in present form is called into question.
- 80-90% functional fit means qualified approval.
- Meaningful defects should be clearly described and recommendations should be made for needed or desirable modifications.

Tests for fit may be static (the wearer remains in one position) or dynamic (the wearer adopts a range of movements or positions usually selected to represent those relevant to the activity for which the garment and/ or product is worn) (Laing and Sleivert, 2002, p.6). Crown and Rigakis (1992) describe dynamic fit as allowing the body to perform usual tasks without garment interference and resistance. Dynamic fit is highly relevant to the study of human performance. Although this can be evaluated using rather coarse grading scales. Range of motion is one of the commonly used measures for accessing dynamic fit.

Garment ease is an important concept in a fit study. Ease is the amount of fabric in a garment beyond what is needed to fit the body exactly. The industry refers to "extra room" as *ease*. Ease could be described as 'the distance between the inner surface of a garment and the skin surface of the wearer' using more quantitative terminology. There are primarily two kinds of ease. *Wearing ease* is the amount of ease needed to be able to move and breathe comfortably in a garment. "Style ease" or "design ease" is the extra amount added to create the desired silhouette for the garment (http://explore.cornell.edu).

Branson and Nam (2007) indicated that the amount of *wearing ease* and *design ease* required by the manufacturer is influenced by choice of material, a given garment style and function, and the designer's perception of desired aesthetic choices for a given garment (p.266). The amount of ease desired in a garment by an individual is influenced by personal preference and the environmental context in which the wearer anticipates wearing the garment (Branson & Nam, 2007, p.266).

The use of ease as a quantitative indicator for evaluating fit has been spotlighted since the 3D body scanner was developed and used by the apparel industry (Meunier et al., 2000; Kim, Suh, Suk, Park & Kim, 2001). Kim et al. (2001) compared and evaluated the wearing ease of a ready-to-wear jacket using a 3D body scanner. Cross sections acquired from the 3D body scanner, of the same subjects wearing multiple jackets in identical position were layered using an AutoCAD program. The relationship between the cross section of the body and the wearer's perceived fit was investigated and evaluated.

<u>Human Performance</u>

Many researchers have conducted research with an aim to optimize garment properties to maximize wearer's performance or to compare and evaluate the performance of individuals wearing competing prototypes. The wearer's performance was determined by various means from a single measure to multiple measures covering physical, physiological, and psychological aspects of human performance depending on the required task. In most cases, the researchers used multiple performance measures to determine the results to cover multiple aspects of human performance. Human performance research in relation to garment or equipment properties were reviewed focusing on each measurement category even though most studies used multiple measures covering more than two categories of effects.

1) Physiological Measures In Human Performance

Heart rate, energy expenditure, O^2 uptake/ ventilation rate, skin moisture, sweat rate, body temperature, EMG (electromyography), fatigue, and blood pressure have been used as measures to assess physiological effects.

Niesen, Gavhed, and Nilsson (1989) measured skin temperature and time to start to sweat to evaluate how closeness of fit affects skin cooling. Ten male subjects simulated packing work under three ambient conditions wearing each of two undergarment fit simulations (tight and loose). Wearing a tight-fitting garment resulted in higher torso and arm skin temperatures. Sweating tended to begin earlier and skin wettedness tended to be higher with the tight-fitting garment than with the loose-fitting garment.

Lung function was measured when Bygrave, Legg, Myers, and Llewellyn (2004) investigated effect of fit on a backpack design. They had two independent variables, each with three levels. The first consisted in the control condition or no pack, a loose fitting pack, and a tight fitting pack fit. The second independent variable had three different backpack styles. Optimized fit was decided initially to determine the criterion of loose and tight fit. After subjects were helped to adjust the backpack that best suited their body size to achieve a ‘comfort fit’, the length of the shoulder straps, hip belt and chest strap and length of pack were measured and recorded. The shoulder and chest straps and hip belt were loosened by 3cm to achieve a ‘loose pack’ fit and tightened by 3cm from CF to achieve a ‘tight pack’ fit. Lung function measurements including forced vital capability

(FVC), expiratory volume (FEV), peak expiratory flow (PEF), and forced expiratory flow (FEF) were evaluated. In comparison with a loose pack fit, the tight pack fit was associated with a significantly lower FVC, FEV, FEF, and a fall in FEF.

Southard and Mirka (2007) used EMG (electromyograph) as an indicator for muscle exertion when they evaluated backpack harness systems in non-neutral torso postures (15^o, 30^o, 45^o, and 60^o of sagittal bend) under each harness system. This research was conducted to improve harness design in terms of reduction of trunk muscle exertion, fatigue and to improve overall comfort. The objective of their study was to evaluate the effects of non-neutral postures on biomechanical loading and then to reconsider the backpack system design recommendations. A survey also used to measure the subjective comfort of the subjects.

2) Physical Measures In Human Performance

Completion time, work rate/ movement time, performance quality, range of motion, and time of donning and doffing have been included in the physical measure category.

Adams and Keyserling (1996) developed a method for assessment of protective clothing effects on worker mobility (Accepted as ASTM F 1154-88). They used both physical and psychological scales for this study. Range of motion, and perceived freedom of movement were used to assess impediment and comfort for three different sized overalls; undersized, appropriately sized, and oversized. The subjects performed a set of gross body movements adopted from Saul and Jaffe (1955) and Huck (1988). Those nine movements included elbow flexion, shoulder flexion, shoulder extension, shoulder abduction, shoulder horizon flexion, shoulder horizon extension, hip flexion, hip abduction, and knee flexion. Appropriate size was determined from the manufacturer's recommended sizing chart, based on the subject's height and weight.

Tremblay-Lutter and Weihrer (1996) used both manual dexterity tests (time of task completion) and a subjective questionnaire to evaluate the wearer's effective functioning of hand and perception of a comfortable fit for determination of optimized ease. Four tests of manual dexterity including 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 were used for evaluating objective dexterity, and a questionnaire with 19 items was used to evaluate wearer's perception of fit.

Range of motion is one of the frequently used measures for mobility evaluation. Huck (1998) used range of motion for evaluating the mobility restriction of subjects while wearing protective clothing. She developed a technique to evaluate the restriction of protective clothing systems by measuring the gross range of motion changes for eight joint movements using the Leighton Flexometer® that represented the types of physical activity that a fire fighter might engage in during the course of performing his duty.

Starr (2005) used vertical gross displacement data recorded by videotape when she compared a prototype sports bra previously developed for large-busted women, with two commercial sports bras. Reflective markers were taped on lateral points of the Acromion Processes, Sternal Angle, and both bust points to determine the amount of motion for both the body and each breast. Breast displacement for each garment treatment was calculated subtracting the body's motion from the overall breast motion. The results showed that the garment treatment prototype, a sports bra design significantly related to the breast displacement experienced by subjects during each test session (Starr, 2005).

Amount of surface area has been used as a dependent measure for hat design. Lee, Ashdown, and Slocum (2006) measured the total body area that would be protected from UV exposure by calculating the surface area shadowed by hat brims using a 3D body scanner and accompanying software to compare different brim designs of hats for golfers to protect them from harmful UV (ultra violet) sun rays. They used three active positions including standing, driving and putting as representative positions in playing golf to apply the concept of dynamic fit.

3) Psychological Measures In Human Performance

Since results from objective measures are not always consistent with wearers' perceptions, subjective measures are usually used along with the objective measures to evaluate how the user perceives performance effects during the required task. Perceived comfort, perceived pressure, and perceived restriction have been used to examine psychological effects.

Likert-type scales are one of the most commonly used instruments to measure psychological effects imposed on the wearer. McConville (1974) indicated that good fit and comfort are best ascertained by asking open-ended subjective questions such as "Is the mask comfortable?" or "In terms of fit and comfort, which oxygen mask do you prefer?" (p.13). Huck, Maganga, and Kim (1997) developed a wearer acceptability instrument designed to be completed after a subject completed a range of body movements. The nine scales consisted of a series of descriptive adjective sets to determine how subjects felt and also how they perceived the fit and comfort of their clothing. The ISO body armor standard (ISO 14876-1, 2002) included a method to evaluate the wearer's perceived movement comfort in body armor. Wearer trials tasks includes office use, standing with arm movements, behind back reach, in front of body reach, lying down and getting up, forward bend, walking and running, and lifting and carrying, and the level of accomplishment and the perceived comfort could be measured by choosing an appropriate response description for each task completed according to protocol. For example, comfort in the standing position with arm movements can be evaluated after following the specified movement protocol by assigning one of the following five response descriptions 1) no problem, 2) some effort needed to complete the movement, 3) effort and discomfort in completing the movement, 4) the effort and discomfort slowed or disturbed the movement, 5) could not complete the movement in a reasonable time.

Nam et al. (2005) investigated wearer's perception of comfort and fit of two cooling vest prototypes through use of a ballot consisting of ten Likert-type response items along with the visual scan image comparison by expert panel ratings.

Various perception instruments were used by Peksoz (2005) along with physiological measures in her study comparing and evaluating the cooling effectiveness of two prototype cooling vests worn under level A and level B protective ensembles. Temperature and humidity perceptions, visibility perception, and subjects' perceived fit and comfort were measured using scaled ballots. Subject's skin temperature, microclimate humidity, sweat rate, heart rate, and core temperature were determined with instruments for the physiological measures. Findings indicated that the subjects' perception of cooling relief generally agreed with the physiological data

Many studies have been conducted to combine multiple aspects of human performance. Branson, Simpson, Claypool, Chari, and Ruiz (1997) used skin temperature, sweat rate, manual dexterity and perceived comfort for comparison and evaluation of three multiple-layered artificially-cooled chemical protective glove systems.

Devroey, Jonkers, Becker, Lenaerts, and Spaepen (2007) used biomechanical, physiological and subjective measures to evaluate the effect of backpack load and position during standing and walking. Thorax flexion, activity of M.erector spinae and abdominals were used as physical measures, heart rate was used for physiological measures, and Borg scores were used as a physiological measure. These findings suggest that carrying loads of 10% of body weight and above should be avoided, since these loads induce significant changes in electromyography, kinematics and subjective scores.

Modern Body Armor Materials

Cited from Scott (2006), ballistic casualties in war, including World War II, Korea, Vietnam, Israel, and the Falklands were recorded as 59% from projectile fragments, 19% from bullets, and 22% from other causes. The main ballistic threats to military personnel are not only bullets but also fragmenting projectiles including flying debris, bomb and grenade fragments (Tobin, 1994). The projectiles originate from grenades, mortars, artillery shells, mines, and improvised explosive devices (IEDs) the latter used by terrorists (Scott, 2006). The other threats are low velocity bullets from hand guns, and high velocity bullets from rifles and machine guns (Scott, 2006). To protect the wearer's body from ballistic threats, various materials have been developed and used.

Body armor is broadly classified as ‘soft’ and ‘hard’ armor (Wagner, 2006; Chen & Chaudhry, 2005). Soft body armor is made from manmade polymeric lightweight fibrous materials using high technology that exhibit great ballistic resistance performance (Chen & Chauhdry, 2005). But textiles alone cannot protect against high-velocity bullets of 5.56 mm, 7.62 mm, 12.7 mm, and sharp projectiles that cut though textiles (Shephard, 1986). Soft armor is worn by police, law enforcement and military. It is relatively flexible, can be tailored to conform to the body contours of the wearer, is designed to stop handgun bullets and to provide fragmentation protection, and it is usually inconspicuous (Wagner, 2006).

Additional rigid plates can be worn with soft armor. The hard armor is made from ceramics, plastic, or metal and textile composites. They are used to protect vital organs such as the heart (Shephard, 1986) from stabbing and slashing injuries (Chen & Chauhdry, 2005, p.532), and bullets. They are mainly used by military and peacekeepers to stop fragments from explosions and bullets (Wagner, 2006). There may be two hard armors inserted into a military vest to cover vital organs in the front and back, and in some vests as many as five inserts covering neck and groin area (Wagner, 2006, p.10).

Shephard (1986) indicated that choice of material for body armor will vary depending on the level of protection, weight, bulk, and flexibility of material and wearer’s required task. Since there always has been a dilemma between protection and comfort providing adequate ballistic protection for an individual is a complex process. Shephard (1986) listed the weight, bulk, rigidity and physiological burden imposed by wearing the armor as the related limiting factors, and argued that textile structures can offer advantages of low density, flexibility and comfort over rigid armor.

Textile Products in Ballistic Protection

Historically, woven silk fabrics were used for ballistic protection. More recently high modulus aliphatic nylon 6.6 with a high degree of crystallinity and low elongation was developed and is widely used in body armor, and as the textile reinforcement in composite helmets (Marsden, 1994). Since the 1970s a range of aromatic polyamide fibres (p-aramids) have been developed. These are based upon poly-parabenzamide or poly-paraphenylene terephthalamide (PPTA) with trade names Kevelar ® (Du Pont) and Twaron ® (Akzo Nobel, now Teijin). Another fiber which is a copolymer of >85% PPTA is Technora ® (Teijin), although it does not appear to be used at this time.

The recognition of lightweight fibrous material-based armor as a superior system for personal protection compared to metallic armor occurred during the Second World War, and was confirmed during the Korean war (Laible, 1980; Temple, 1945; Anonymous, 1953; Vanderbie, 1957; Herget, Coe, & Beyer, 1962).

Jacobs and Dingenen (2001) indicated that high performance fibers used in ballistic products have characteristics including low density, high strength, and high energy absorption capability. Song and Lee (2006) listed flexibility, high modulus and strength at least in the axial direction, being an excellent reinforcing material for polymers as the reasons for the emergence of the fibrous armor for personal protection.

There are several representative ballistic fiber products available in the current market including aramid fibers, highly-extended ultra high-molecular-weight polyethylene (UHMWPE) fibers, and Poly(p-phenylenebenzobisoxazole) (PBO).

The first successful example of rigid-rod type liquid-crystalline-polyester fibers, was introduced by DuPont, and its various derivations are currently used in many different applications. Following the Kevlar fibers in the US market, a Dutch firm, Alzo Nobel Inc., introduced the same family of fibers under the trade name of Twaron ® in the European market (p.211).

In addition to aramid fibers, highly-extended ultra high-molecular-weight polyethylene (UHMWPE) fibers were introduced in the early 1980s. Currently, there are three companies including Allied Signal Inc. (now Honeywell), DSM Inc, a Dutch firm, and Mistui Petrochemical Inc., a Japanese firm that manufactures this polymer with similar processing techniques. Allied-Signal Inc. marketed Specta ® fiber in the US, and DSM Inc. introduced Dyneema ® fiber in the European market. Mistui Petrochemical Inc. produced Tekmilon ® fiber for the Asian market.

Recently, Poly (Poly(p-phenylenebenzobisoxazole) (PBO) was introduced as a high-strength, high modulus polymer of the rigid-rod type that has high potential for armor applications (p.231). PBO fibers have moduli and strength twice that of para aramids, but unfortunately the fiber degrades by hydrolysis in warm, moist conditions (Moryer et al., 1996). A Japanese firm, Toyobo Inc., commercialized this fiber under the trade name of Zylon ® (p.231).

<u>Rigid Materials in Ballistic Protection</u>

To increase the level of protection, ceramic composites and other fiber composites have been mainly used as a rigid material for current body armor.

Ceramic Component- Ceramics have been used since the 1960's achieving weight reduction while improving ballistic protection dramatically (Carothers, 1988). According to Carothers (1988) the first ceramic armor developed in the 1960's was a composite of a ceramic, aluminum oxide with a fiberglass laminate. According to

Carothers (1988) there are four categorizations in ceramic composites including aluminum oxide, silicon carbide, modified boron carbide and boron carbide.

Fiber Composites- Some ballistic fibers can be made into a rigid form. The Spectra Shield PCR plies can be layered to form the thickness required to resist a bullet. The layered structure may be heated in an autoclave or die press to form a semi-rigid or rigid plate (DeGaspari, 2002). Another application for a SAPI plate is to combine or fuse together ceramic (metal) plates with ballistic fabrics.

Ballistic Protection and NIJ Body Armor Classifications

The material selected such as metals, ceramics, transparent glazing, fabrics, felts and fiber-reinforced composites can vary depending on the required level of protection (Bhatnagar, 2006). NIJ Standard 0101.04 is the latest test standard issued by the U.S. Department of Justice. It is developed to establish minimum performance requirements and test methods for determining ballistic resistance of personal body armor (Crime Control Digest, 2000). The level of desired protection will be determined by the threat, that is, the kinds, caliber, and speed of the bullet. Ballistic resistance body armor in this standard is classified into seven levels including Level I, IIA, II and IIIA which provide increasing levels of protection from handgun threats. Levels II and IV, which protect against high powered rifle rounds, are for use only in tactical situations (Bhatnagor, 2006). The detailed descriptions for each protection level classification is summarized and presented in Table 1.

Table 1
NIJ Body Armor Classification and Ballistic Performance (Bhatnagar, 2006. p.9)

Classification	Ballistic Performance
Type I (22LR; 380 ACP)	Protects against .22 caliber Long Rifle Lead Round Nose (LR LRN) bullets, with nominal masses of 2.6 g (40 gr) impacting at a minimum velocity of 320 m/s (1050 ft/s) or less, and 380 ACP Full Metal Jacketed Round Nose (FMJ RN) bullets, with nominal masses of 6.2 g (95 gr) impacting at a minimum velocity of 312 m/s (1025 ft/s) or less.
Type IIA (9 mm; 40 S&W)	Protects against 9 mm Full Metal Jacketed Round Nose (FMJ RN) bullets, with nominal masses of 8.0 g (124 gr) impacting at a minimum velocity of 332 m/s (1090 ft/s) or less, and 40 S&W caliber Full Metal Jacketed (FMJ) bullets, with nominal masses of 11.7 g (180 gr) impacting at a minimum velocity of 312 m/s (1025 ft/s) or less. It also provides protection against the threats mentioned for Type I.
Type II (9 mm; 357 Magnum)	Protects against 9 mm Full Metal Jacketed Round Nose (FMJ RN) bullets, with nominal masses of 8.0 g (124 gr) impacting at a minimum velocity of 358 m/s (1175 ft/s) or less, and 357 Magnum Jacketed Soft Point (JSP) bullets, with nominal masses of 10.2 g (158 gr) impacting at a minimum velocity of 427 m/s (1400 ft/s) or less. It also provides protection against the threats mentioned for Type I and IIA.
Type IIIA (High Velocity 9mm; 44 Magnum)	Protects against 9 mm Full Metal Jacketed Round Nose (FMJ RN) bullets, with nominal masses of 8.0 g (124 gr) impacting at a minimum velocity of 427 m/s (1400 ft/s) or less, and 44 Magnum Semi Jacketed Hollow Point (SJHP) bullets, with nominal masses of 15.6g (240 gr) impacting at a minimum velocity of 427 m/s (1400 ft/s) or less. It also provides protection against most handgun threats, as well as the threats mentioned for Type I, Type IIA, and Type II.
Type III (Rifles)	Protects against 7.62 mm Full Metal Jacketed (FMJ) bullets (U.S. Military designation M80), with nominal masses of 9.6 g (148 gr) impacting at a minimum velocity of 838 m/s (2750 ft/s) or less. It also provides protection against the threats mentioned for Type I, Type IIA, Type II, and Type IIIA.
Type IV (Armor Piercing Rifle)	Protects against .30 caliber armor piercing (AP) bullets (U.S. Military designation M2 AP), with nominal masses of 10.8 g (166 gr) impacting at a minimum velocity of 869 m/s (2850 ft/s) or less. It provides at least single hit protection against the threats mentioned in sections for mentioned for Type I, Type IIA, Type II, and Type IIIA, and Type 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 minimum reference impact velocities to be used, and indicate that this standard shall govern in all other aspects.

Hard armor can be worn with level IIIA soft armor to achieve level III and IV protection. The main difference between the level III and IV inserts is that the level IV inserts also protect against armor piercing bullets. This armor is highly desirable for machine gun threats (http://www.ukbodyarmor.com/faq.htm).

Anatomy of Shoulder and Arm Regions

The shoulder and arm complex is an integrated skeletal system consisting of bones, joints, muscles, nerves, blood vessels, other tissues and the motor unit. A motor unit is a single α motor neuron (large lower motor neurons of the brainstem and spinal cord) and all of the corresponding muscle fibers it innervates (Norkin & Levangie, 1983). The components closely associated with movement are bones, joints, muscles, tendons, and ligaments. Bones perform the mechanical functions of support, protection, and leverage for the body (Graaff, 1998). According to their mechanical functions, the shapes of bones differ. The component where two bones meet or join is called a joint. The primary function of a joint is to connect bones together while controlling the motion allowed between them (McGinnis, 1999). Muscles serve a mobility function by producing or controlling the rotation of a bony lever around a joint axis; they serve a stability function by helping joint structures maintain the integrity of a joint through joint compression (Norkin & Levangie, 1983, p.87). In addition, one of the important parts of the complex system of levers formed by the various bones and joints are the tendons and ligaments. Tendons are tough, fibrous bands of tissue that join muscles to bones. Ligaments are strong cords of fibrous tissue that support and hold articulating surfaces together at the joints (McGinnis, 1999, p.34).

Structural Components of the Shoulder and Arm Complex

The bones associated with the shoulder and arm complex are the humerus, clavicle, scapula for the shoulder area, and the humerus for the upper arm, and the radius and ulna for the lower arm area (illustrated in Glenohumeral (shoulder) and elbow joints (illustrated in Glenohumeral (shoulder) and elbow joints (illustrated in).

Glenohumeral (shoulder) and elbow joints (illustrated in *Figure* 6) are the joints associated with the shoulder and arm complex. The shoulder joint is a ball and socket joint that is the ball-like head where one bone fits into the socket-like head of another, permitting all movement including flexion, extension, adduction, abduction, and circumduction. The elbow joint is a hinge joint with the surface of one bone being concave, and the other surface convex, thus permitting movement in only one plane (Graaff, 1998). The movement is limited to flexion/extension.

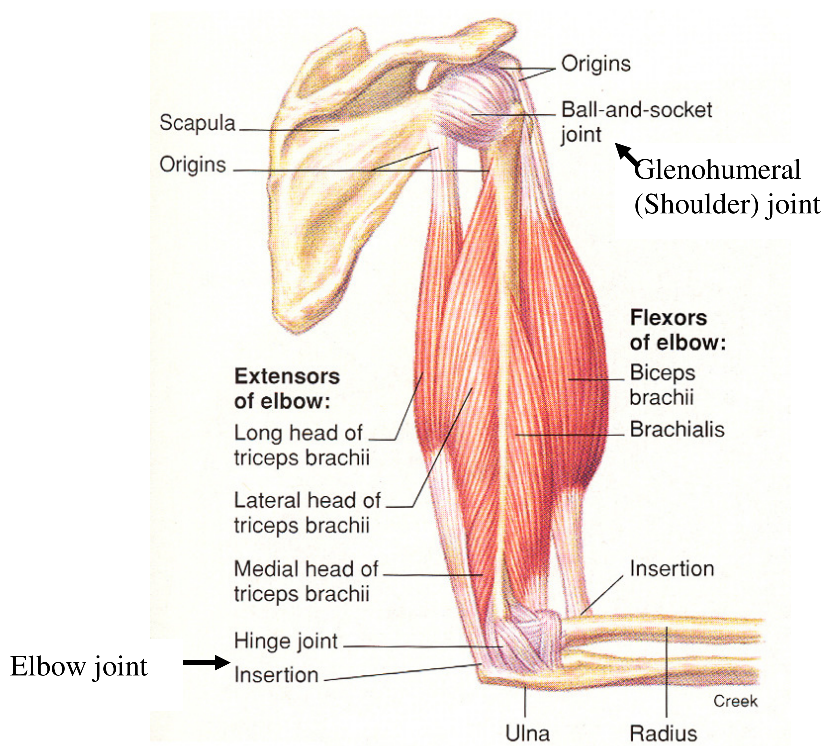


Figure 6. The Major Bones, Joints, and Muscles of Shoulder and Arm Complex (skeletal, muscular, and joint system, Graaff, 1998, p.142)

<u>Human Body Movement</u>

Bones, joints, and muscles working together form a system of levers and forces that produce mechanical movement. Anatomical planes and axes of motion are used to describe relative motions of body segments. The three principle anatomical planes are the sagittal, frontal, and transverse planes. These planes are at right angles to each other. The three principal anatomical axes that correspond to each of these planes are the transverse, AP (Anatomical Plane), and longitudinal axes (presented in *Figure* 7).

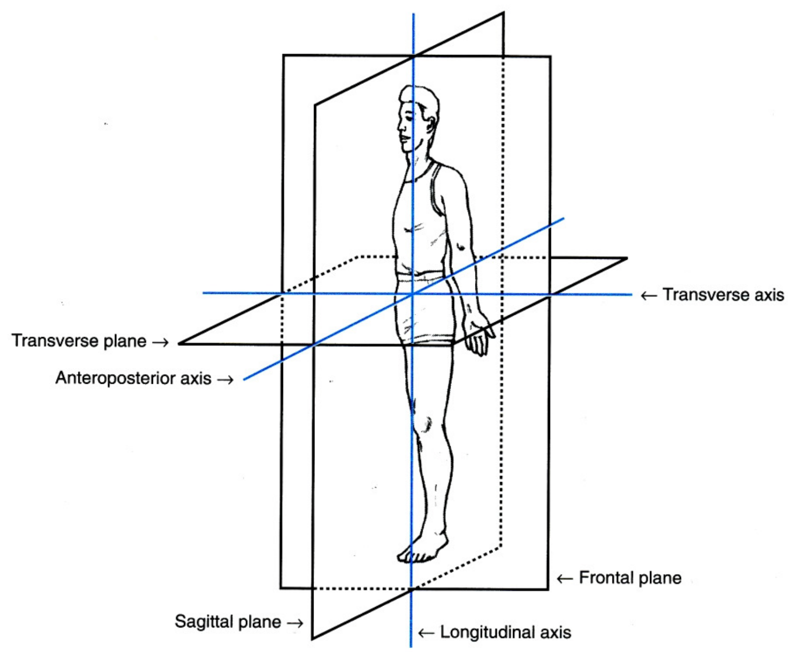


Figure 7. Cardinal Anatomical Planes and Axes of Motion (McGinnis, 1999. p.26).

Body movement occurs with a change in position from the anatomical position, and takes place in one of several planes. Joint movements are broadly categorized as angular and circular movements. Angular movements increase or decrease the joint angle produced by the articulating bones including four types of angular movements, those are flexion, extension, abduction, and adduction (Graaff, 1998, p.201). Flexion is movement that decreases the joint angle on an anterior-posterior plane. The reverse of flexion is called extension. Abduction is movement of a body part away from the main axis of the body, or away from the midsagittal plane, in a lateral dimension (Graaff, 1998, p.201). Adduction is the opposite of abduction, is movement of a body part toward the main axis of the body (Graaff, 1998, p.201). In joints that permit circular movement, a bone with a rounded or oval surface articulates with a corresponding depression on another plane. The two basic types of circular movements are rotation and circumduction. Rotation is movement of a body part around its own axis while circumduction is the circular movement of a body part so that a cone-shaped airspace is traced (Graaff, 1998, p.201).

The movements associated with the shoulder and arm are: shoulder flexion, shoulder extension, shoulder adduction, shoulder abduction, shoulder rotation, elbow flexion and extension, external rotation of arm, and internal rotation of arm, shoulder circumduction. Each movement is illustrated in Figure 8.

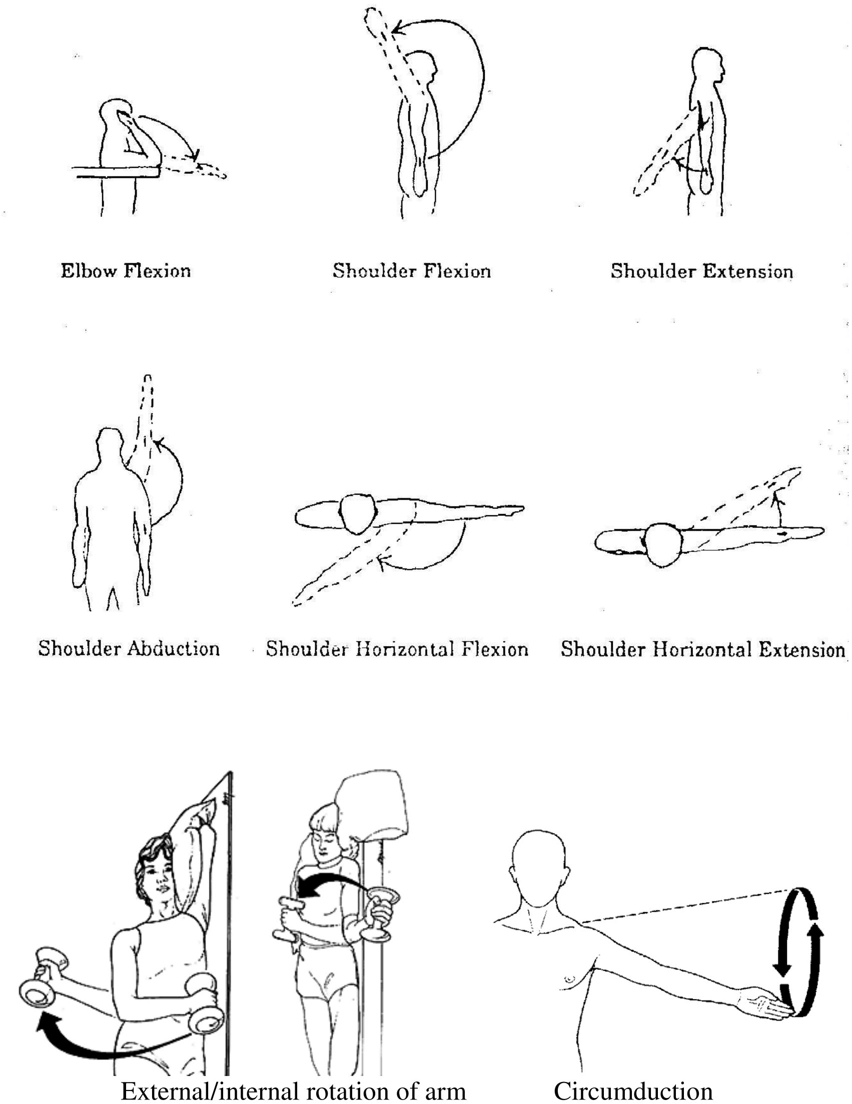


Figure 8. Movements at Shoulder and Arm Regions
(Source: Saul & Jaffe, 1955 :Huck, 1988)

CHAPTER III: METHODOLOGY

Soft limb protective body armor was developed to provide primarily shrapnel protection from improvised explosive devices during the early phases of the Afghanistan/ Iraq war. Subsequently, provision for inclusion of a rigid plate in the QuadGard™ arm armor system was added. The shoulder joint is a ball and socket joint which permits movements in three planes including flexion, extension, adduction abduction, and circumduction. Armor for the arm and shoulder ideally should maximize wearer's coverage and comfort while minimizing restriction of mobility.

The overall purpose of this research is to obtain human subject data for subjects wearing no arm and shoulder ballistic protection and for subjects wearing three protective arm and shoulder armor systems, in order to compare subjects' ROM, localized pressure, armor coverage and perceptual responses.

Proposed Framework

This study was guided by a model developed by Adams, Slocum and Keyserling (1994) as shown on page 1, Chapter II. Their model was developed based on an extensive literature review to systematically study the relationships among identified garment properties and the immediate effects and net effects. The modified model to cover the scope of the proposed research (Adams, Slocum, and Kerserling (1994)'s Model), is presented in *Figure* 9. Environmental conditions and thermal aspects are not considered in this study.

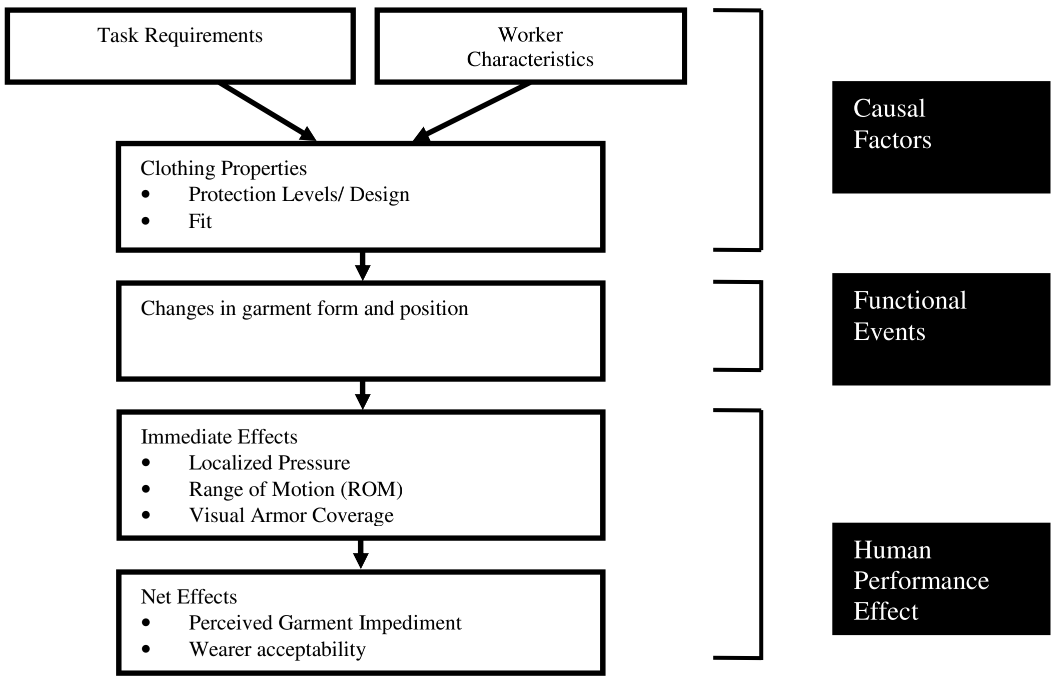


Figure 9. Framework Examining Effects on Solders wearing Selected Arm Armor Systems

<u>Overview of the Proposed Model</u>

The Adam's et al. model (1994) suggested that four factors affect human performance including environmental conditions, task requirements, worker characteristics, and clothing properties. As a functional clothing designer and researcher, we try to enhance the wearer's performance by designing clothing with appropriate fabric and clothing properties. Environmental conditions, task requirements, and worker characteristics were controlled for this laboratory evaluation study.

Subjects and Sampling

Ten volunteer healthy males, ranging in age from 19 to 30 years (mean 24.2 ± 1.90 yrs old), who wear size medium battle dress uniform (BDU), who have recent experience serving in the military or in ROTC (Reserve Officers' Training Corps) were selected as participants in order to increase the homogeneity of the sample group and to receive valid feedback from the subjects derived from their actual experiences. Three current ROTC and seven personnel with previous military experience participated in this study. There were three Americans, three Koreans, three Venezuelans, and one Greek. The subjects' height and weight were obtained through self-reported ballot. Their average reported height was 175.76 ± 2.75 cm (69.19" ± 1.08"), and the average reported weight was 77.18 ± 3.70 Kg (170.15 ± 8.16 lbs). Chest circumference and arm circumference were obtained from the scan images from a 3D body scanner using Polyworks. Basic demographic and body measurement data and descriptive statisticsof the subjects are presented in Table 2.

Table 2
Demographic Information

Subject	Nationality	Age (year)	Height (cm)	Weight (kg)	Arm Circumference (cm)	Chest Circumference (cm)
1	American	22	170.18	80.91	39.13	102.11
2	Korean	24	179	83.18	35.22	96.45
3	Greek	27	175	84.09	35.94	103.46
4	American	21	177.8	72.73	31.01	91.5
5	Korean	26	172.72	66.82	33.56	93.5
6	American	27	184.5	84.09	30.75	92.65
7	Venezuelan	19	168	70.45	32.96	99.76
8	Venezuelan	23	172.7	79.55	35.22	94.77
9	Korean	30	175	72.73	38.23	102.45
10	Venezuelan	23	172.7	77.27	33.29	104.25

Descriptive Statistics

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Age	10	11.00	19.00	30.00	24.20	3.29
Height	10	16.50	168.00	184.50	174.76	4.73
Weight	10	17.27	66.82	84.09	77.18	6.18
Arm circumference	10	8.38	30.75	39.13	34.53	2.78
Chest circumference	10	12.75	91.50	104.25	98.09	4.86

Note. Unit for height, chest circumference, arm circumference: cm/ Unit for weight: Kg

A flyer with information about this study (Appendix A) was prepared and distributed to Oklahoma State University's ROTC. Fifty dollars were presented to each participant upon completion of their participation as compensation. Each subject's scan image file was converted to a 3D animated avi. file which allows each subject's image to be viewed using Window Media Player. This was also given to each subject. Consent form was acquired (Appendix B). Approval for all experimental procedures was obtained from the Oklahoma State University Institutional Review Board (OSU IRB) for human subjects before the experiment was initiated (Appendix C).

Independent Variables

Armor treatment and *movement treatment* were the independent variables. A control, and three arm armor systems constituted the *armor treatment*. Five movements including shoulder flexion, extension, abduction, horizontal flexion, and horizontal extension constituted the *movement treatment*.

Armor Treatment

The armor treatment had four levels including control, and arm armor systems A, B, and C.

Control Garment Treatment

Since the protective arm armor system can not be worn by itself and is worn over the BDU and OTV, wearing the OTV over the BDU was regarded as the control for this study (presented as *Figure* 10).

Front Back

Figure 10. Control Garment Treatment (Wearing OTV over BDU)

The BDU in the United States is the standard military uniform worn in combat, and it is either a solid color or a camouflage pattern. Size medium BDU was used for this study. The size label on the BDU defined the medium as: height: from 170.18 cm to 180.34 cm (67 to 71 in.), and chest from 93.98 cm to 104.14 cm (37 to 41 in.). All subjects' chest sizes were in this size range, but two of the subjects' heights were out of this size specification. One subject was 4.16 cm taller, and one subject was 2.18 cm shorter than specification. However, all of them reported that they wore size medium during their military experience and height was not considered to be a critical factor since this study focused on arm armor. The weight of the BDU shirts and pants was 1.37 kg (3.02 lbs) in total. The OTV is worn over the BDU, and it is usually made of nylon with pockets for insertion of soft and hard protective inserts. The weight of the medium OTV was 3.83 kg (8.44 lbs) with only soft armor.

<u>Arm Armor System A</u>

Arm Armor System A includes the control plus the arm and shoulder portion of the Phase V QuadGard™ arm armor system (shown as Figure 11). This patent pending system consists in an outer shell of Cordura ® nylon, Ripstop nylon lining, and an insertable soft ballistic pack of multiple layers of Dyneema® . Dyneema® is a trade name for an ultra-high-stength gel-spun polyethylene with an extremely high strength-to-weight ratio and is light enough to float on water. It has high-energy absorption characteristics and dissipates shock waves faster than earlier ballistic materials (Chen & Chaudhry, 2005, p.535). The Dyneema multi-layers are all encased in Ripstop nylon. The arm armor system consists of three separate components including a shoulder component, upper arm component, and a lower arm component (shown in Figure 11). Webbing and snaps attach the shoulder and arm components to the OTV. Arm armor system A with an inserted ballistic pack weighs 0.96 kg (2.12 lbs), and with the control, the whole system weighs 6.16 kg (13.58 lbs).

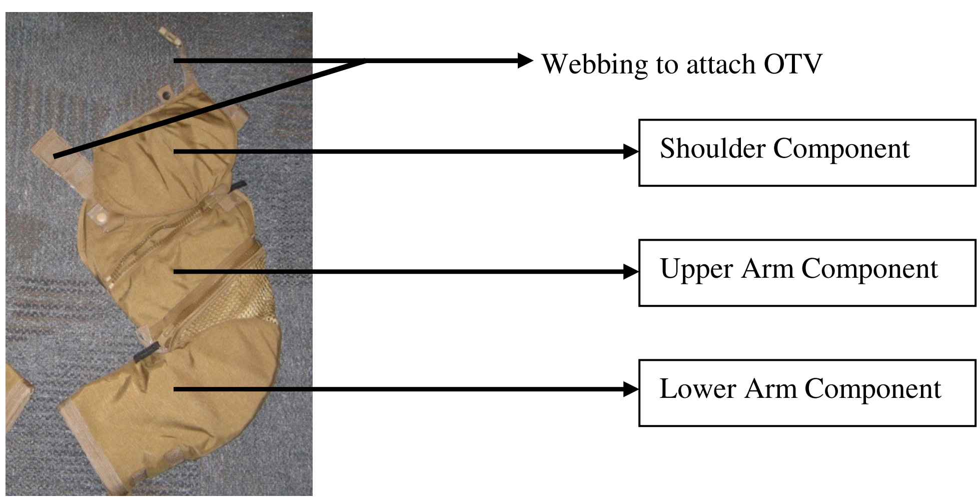


Figure 11. Arm Armor System A

Arm Armor System B

The arm armor system B includes system A plus a commercially available conventional hard armor plate (plate 1). The dimensions of the hard plate are 7” x11” x 5/8” (presented as Figure 12). The plate has a slight curvature, and weighs 1.15kg (2.54 lbs). Thus system B weighs 7.31 kg (16.11 lbs).

Figure 12. Conventional Hard Armor Plate (Plate 1)

<u>Arm Armor System C</u>

Arm armor system C includes system A plus a prototype proprietary hard arm plate which is available through FSTechnology, LLC (presented as Figure 13, plate 2). The dimensions of the developed hard plate are 7” (width of outer curvature) x 11” with 3/4” thickness (presented as *Figure* 13). The plate weighs 0.96 Kg (2.11 lbs). Thus, system C weighs 7.11 kg (15.67 lbs).

Figure 13. Prototype Hard Armor Plate (Plate 2)

In summary, components worn for each armor system and the control are presented in Table 3.

Table 3
Components of Armor Treatment

Armor Treatment Components	Control	A	B	C
BDU	X	X	X	X
OTV	X	X	X	X
Soft Armor		X	X	X
Conventional (Plate 1)			X	
Prototype (Plate 2)				X
Weight	3.84 kg (8.44 lbs)	6.16 kg (13.58 lbs)	7.31 kg (16.11 lbs)	7.11 kg (15.67 lbs)

Movement Treatment

Five Shoulder and Arm Movements

Five shoulder and arm movements representing extreme movements were performed for obtaining data on localized pressure, range of motion, perceived garment impediment, wearer acceptability, and visual armor coverage. The five movements include: shoulder flexion, shoulder extension, shoulder abduction, shoulder horizontal flexion, and shoulder horizontal extension (Figure 14). They were selected as relevant movements for assessing the influence of wearing an arm armor system on shoulder and arm movement based on previous studies conducted by Saul and Jaffe (1955) and Huck (1988).

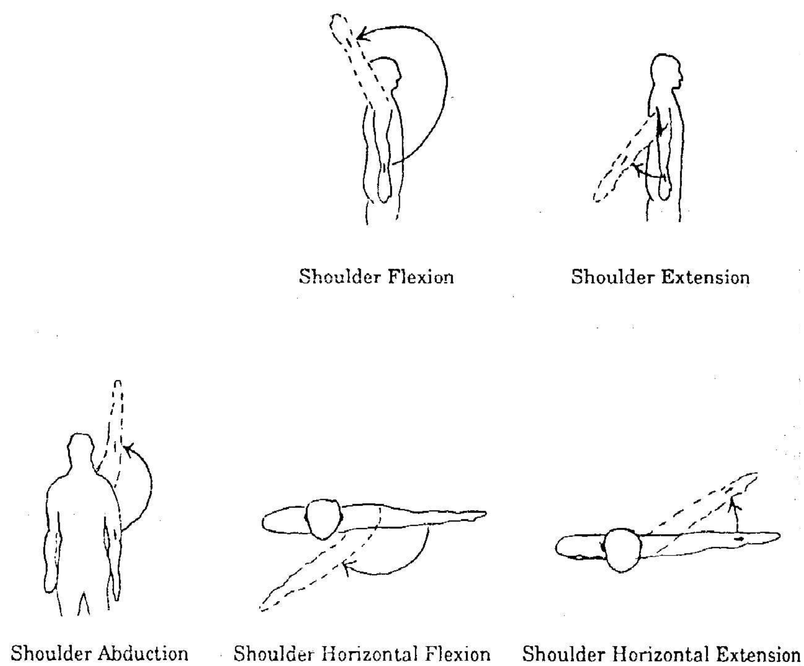


Figure 14. Selected Five Representative Shoulder and Arm Movements (Modified from Saul & Jaffe (1955) and Huck (1988))

An explanation of the selected five representative shoulder and arm movements are given below.

- Shoulder Flexion

Start from starting position with arms at side (middle of the thigh), perform shoulder flexion and return to starting position with arms at side.

- Shoulder Extension

Start from starting position with arms at side, perform shoulder extension as far as possible and return to starting position with arms at side.

- Shoulder Abduction

Start from starting position with arms at side, and perform shoulder abduction as far as possible, and return to starting position with arms at side.

- Shoulder Horizontal Flexion

Start from the starting position with arms open 180 degree, perform shoulder horizontal flexion as far as possible, and return to the starting position with arms open 180 degree.

- Shoulder Horizontal Extension

Start from the starting position with arms open 180 degree, perform the shoulder horizontal extension as far as possible, and return to the standing position with arms open 180 degree.

For each movement, subjects were asked to straighten their elbow as much as possible, and roll their fingers as shown in Figure 15. This was done in order to have a straight line from the hand to the shoulder for ROM measurements as recommended in the handbook from Human Solutions Inc.

Figure 15. Straightened Elbow and Hand Pose

Additional Reference Shoulder Scans

Subjects were scanned in two additional shoulder positions including a standing position and a 90 degree at side position Figure 16) for use as reference poses to aid in the measurement of ROM. For the standing position, the elbow was straightened as much as possible, and the hand was rolled up as for the other five movements. For the 90 degree at side position, the subject raised his arm to create a 90 degree angle with his side. A landmark was attached to the shoulder point (*Figure* 16) for the control treatment as shown in Figure 16, and it was further used to find a pivot point to measure ROM. This point was used as the origin of two axes for determination of ROM (see Figure 22).

Retake picture without OTV

Standing Position

90° at Side Position

Figure 16. Additional Shoulder Positions and Landmark for Shoulder Point

Experimental Design

A four by five complete block design with 10 subjects repeated measures was used for this study. Each subject performed five movements while wearing four arm armor system treatments ie. one control treatment plus three arm armor treatments, to measure five dependent variables to determine the effects of armor and movement treatments. The order of wearing the arm armor treatments (armor system A, B, and C) was randomized. The control garment was the first garment worn followed by the randomized arm armor treatments.

Dependent Variables

The dependent variables included: 1) localized pressure, 2) ROM, 3) perceived garment impediment, 4) wearer acceptability, and 5) visual armor coverage. Localized pressure was measured at two locations in the upper arm armor. ROM was measured in degrees at the maximum exertion point for each of the five movements. Wearer acceptability was determined with a ballot completed at the conclusion of each armor treatment. Instrumentation information for each dependent variable is provided in the next section. Visual armor coverage was determined by a panel of three fit judges' evaluation of 3D scan images. Perceived garment impediment was assessed by completing a ballot at the conclusion of each movement.

Instrumentation and Data Preparations

Localized Pressure

Localized pressure was measured at two locations on the inside of the upper arm armor using two sensors. The data exerted on the sensors from wearing an armor treatment was collected using a telemetry system. The data were analyzed using MyoResearch XP software.

Sensors

FlexiForce force sensors produced by Tekscan were used to measure localized pressure exerted by the armor system using resistive principle. The pressure sensor is an ultrathin (0.208 mm), flexible printed circuit that senses a contact force. Its thinness and flexibility allow it to conform to curved surfaces. Its width and full length are 14 mm and 203 mm, respectively. The force sensors are constructed of two layers of substrate (polyester/polyimide) film. On each layer, a conductive material (silver) is applied, followed by a layer of pressure-sensitive ink. An adhesive is used to laminate the two layers of substrate together to form the force sensor. The active sensing area is defined by the silver circle on top of the pressure-sensitive ink, and it is a circular probe with a 9.53

mm diameter (see Figure 17) (www.tekscan.com/flexiforce.html).

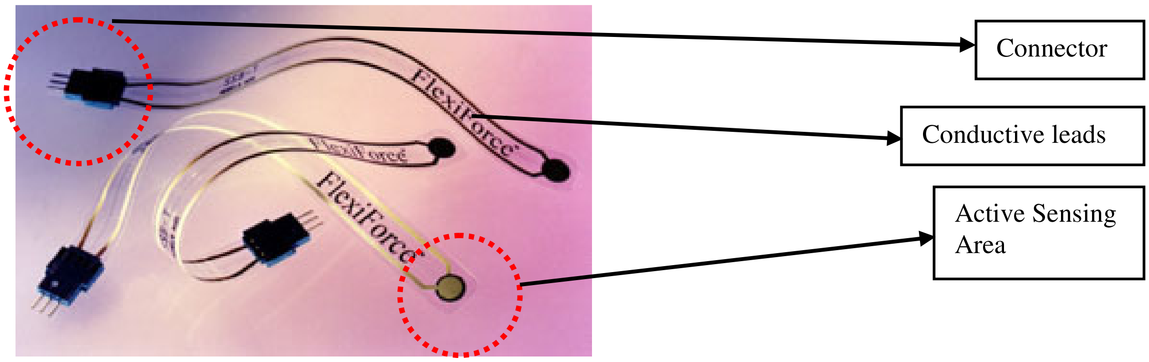


Figure 17. Localized Pressure Sensors (www.noraxon.com)

Silver extends from the sensing area to the connectors at the other end of the sensor, forming the conductive leads. The *FlexiForce* single element force sensor acts as a force sensing resistor in an electrical circuit. When the force sensor is unloaded, its resistance is very high. When a force is applied to the sensor, this resistance decreases. The 0-1 lb sensor 5000 mV /lb (1135 mV/N) was selected for this study. The pressure signals produced by an arm armor system were recorded with a 1000 Hz sampling frequency (www.tekscan.com/flexiforce.html).

Sensor Placement

Two localized pressure sensors were attached to the inner side of the upper arm armor component for the dominant hand. One sensor was mounted on the upper area (Area 1) and the other sensor was mounted on the lower area of the upper arm component (Area 2) as shown in Figure 18. The sensor was attached using medical tape.

Figure 18. Placement of Localized Pressure Sensor

Data Logger and Transmitter

The MyoTrace™ 400 is the portable, handheld measurement instrument from Noraxon. The physical dimension of the MyoTrace™ 400 is 16.98 cm x 11.11 cm x 2.73 cm for height, and it weighs 382.70g. Two channels for measuring localized pressure at the two areas specified above were used. Two sensors were connected to the amplifier and plugged into the MyoTrace™ 400 (Figure 19). MyoTrace™ 400 was attached to subject's belt using a clip provided by Noraxon. The MyoTrace™ 400 was connected to personal computer using a PC Interface (a device for telemetry), and a bluetooth module was inserted into the PC Interface. Bluetooth data transmission on the MyoTrace allows free motion up to 20 meters and sent data in real time to the computer. The systematic diagram of the pressure sensing system is shown in Figure 20 (www.noraxon.com).

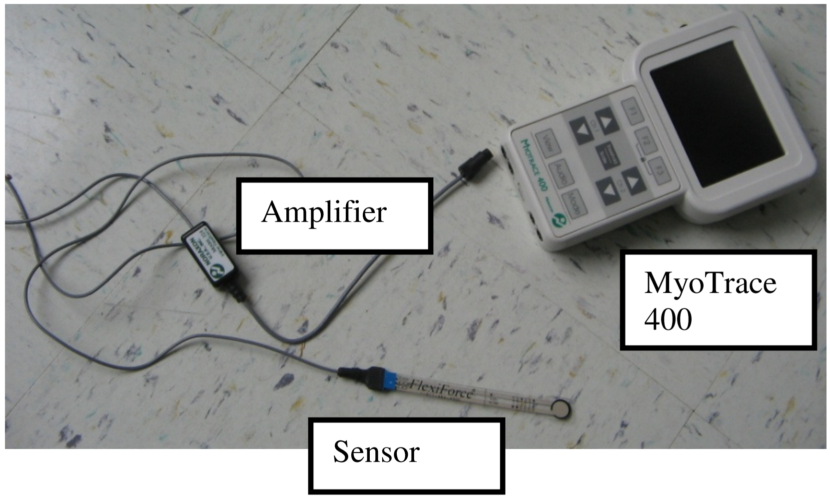


Figure 19. Connecting Sensors to the MyoTrace 400

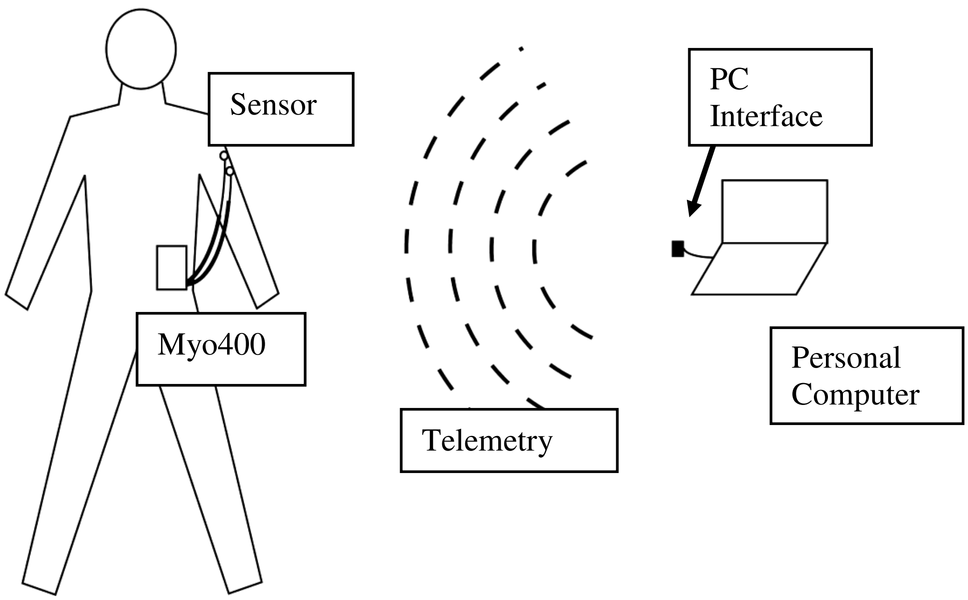


Figure 20. The Schematic Diagram of the Pressure Sensing System

Once the data were collected, MyoResearch XP software with Clinical Applications was used for data analysis. It created average curves of the force record while the subject was performing all movements. The starting and ending time was marked by the researcher, and it is shown in Figure 21. The localized pressure when the subject reached their maximum point was selected and calculated, because we were focusing on the localized pressure for each subject's maximum point of movement. After the subject reached his maximum point, the subject was asked to hold the position for 10-15 seconds for both body scanning and for acquiring enough data for the localized pressure. The starting and ending times were marked and recorded by the researcher for further analysis.

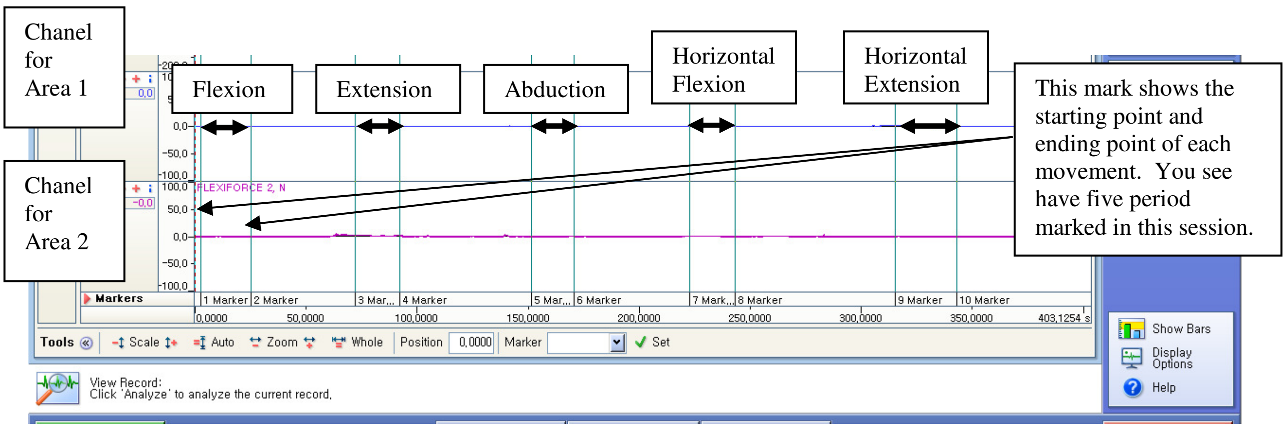


Figure 21. Graphical Presentation of Exerted Force and Sub-Period Curves

The localized pressure during all five movements was recorded using MyoResearch XP software from Noraxon Inc. *Figure* 21 shows the graphical presentation of exerted force in two body areas during all movements in certain arm armor treatment (Armor Systems A, B, and C). The parallel lines on the graph shows the starting and ending points of pausing at maximum movement in each movement marked by the researchers. The mean force of five subdivided period (that represents five movements) was calculated respectively using this software to have a mean force for each movement. The data were measured as N (Newton, unit for force) using Flexiforce, then it was transferred into Pa (=1 N/m^2, Unit for pressure) dividing the force with the area of active sensing area in Flexiforce force sensor. In total, 300 localized pressure data (10 subjects x 3 arm armor treatments x 5 movements x 2 upper arm areas) were analyzed for this study.

Range of Motion (ROM)

ROM was used to evaluate the restriction in arm and shoulder movement while wearing each armor system treatment. Subjects' body pose in each maximum point of movement was scanned using the 3D body scanner, and the scan images were used to measure the ROM. Subjects were scanned in the control arm armor treatment (OTV) plus three arm armor system treatments. Thus, each subject was scanned 22 times (4 armor treatments x 5 movements, plus the additional two reference positions to assist in ROM measurements).

Reference images acquired from the two additional positions, and other images at each movement while wearing the control and three arm armor treatments were superimposed to identify origin of axes for ROM measurement. The standing reference position was used for measuring flexion, extension, and abduction. The ninety degree at side reference position was used for measuring horizontal flexion, and horizontal extension. The angle between the origin and the location each movement location was measured (as shown in Figure 14) and used to calculate ROM.

Two images (one reference scan image taken from one of the additional reference positions, and the other scan images from the five movements were brought onto one screen and superimposed on each other to identify the pivot and origin for ROM (Figure 22). The light colored image on the left indicates the standing position and the right indicates the 90 degree at side position. The left image shows a side view, and the right image shows a top view. The dark image indicates a subject wearing a certain arm armor treatment in one of the five movement treatments. The image on the left side shows a subject in extension, and the right image indicates a subject in horizontal flexion movement.

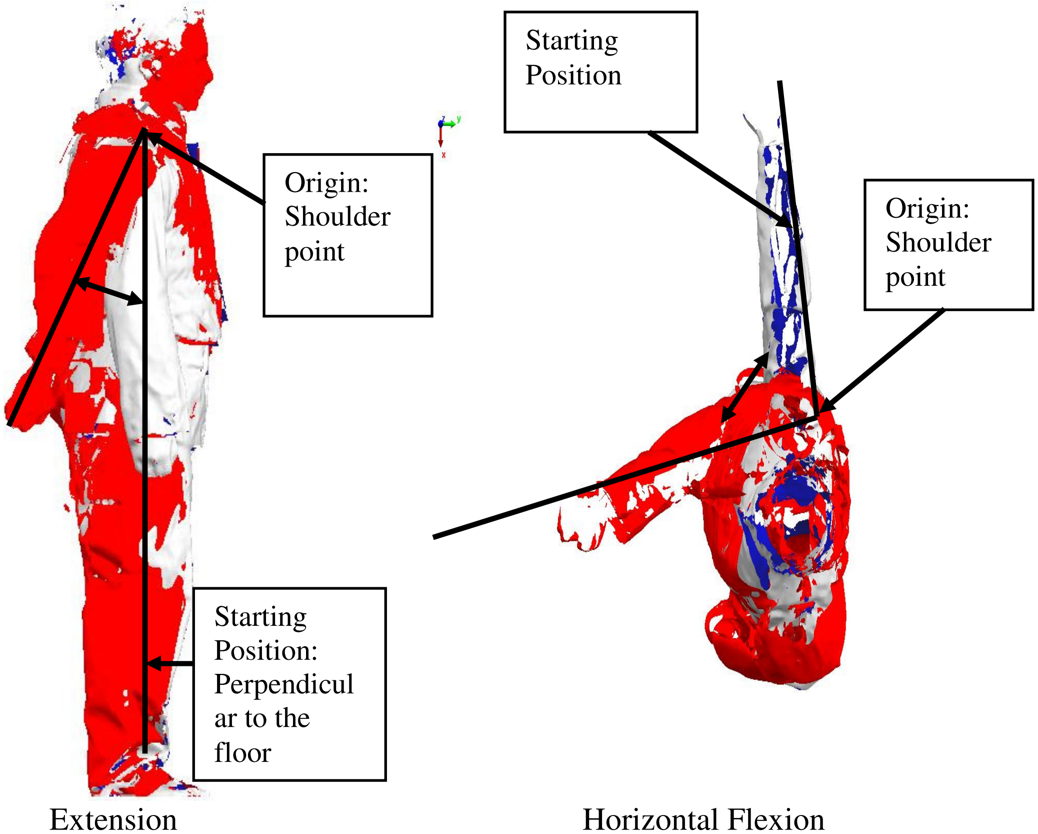


Figure 22. Superimposing Images and Measuring ROM

After printing out the images at front, side, and top views, two straight lines were drawn manually linking the pivot point with the middle finger of the arm in the movement with the origin shoulder point. The angle between the origin and the moved location was measured using a manual goniometer. ROM was measured for each subject wearing every arm armor treatment in each movement. In total, ROM of 200 scan image sets (10 subjects x 4 garment treatments x 5 movements) were measured using a manual goniometer and compared.

<u>Vitus^{Smart}XXL 3D Body Scanner</u>

The Vitus^Smart XXL from Human Solutions was used to acquire 3D scan images for determining ROM and visual surface coverage of the arm for each arm armor system. It uses optical triangulation eye-safe laser technology. It has four pillars and eight sensor heads. Scanning time takes approximately 12 seconds, and the point density is 27 dots/ cm^3. Its' measuring volume is 1200mm x 1200mm x 2100mm, and the height of the scanning is 2900 mm (http://www.vitronic.de/en). Identical scan images were used to generate a scan image set for determination of visual armor coverage for each garment and movement.

Scanworx

Scanworx provided by Human Solutions was used to operate the scanner to acquire subjects' body measurement data. Scanworx software operates the Vitus line of scanners and generates body measurements automatically.

Polyworks

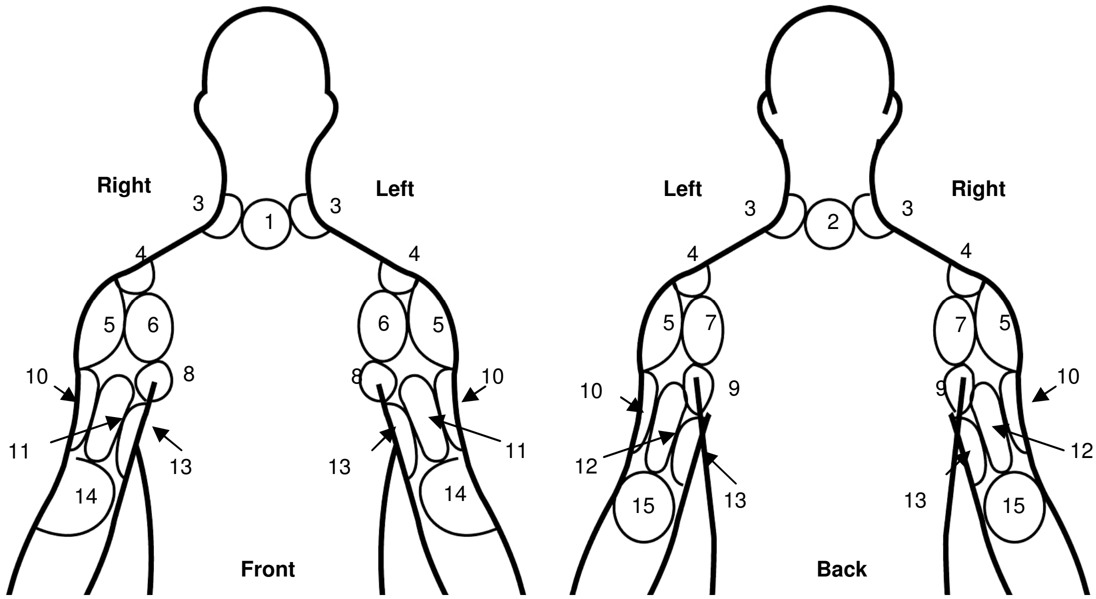
The Polyworks software merges, aligns, and compresses scanner data and takes various types of measurements including circumference, slice area, surface area, and volume. After obtaining scan images using the Vitus^Smart XXL and Scanworx, the PolyWorks software suite by Innovmetrics was used. For ROM measurement, it was used to superimpose two images for measuring ROM. For visual armor coverage, Polyworks was used to align and merge multiple images to present multiple images onto one screen, and marking images for case of identification for visual coverage evaluation session. ImView software was used by the fit judge panel to see the scan images for evaluating the coverage of the arm by the arm armor. The system allowed the judges to rotate and enlarge images for evaluating arm coverage by the armor.

Perceived Garment Impediment

Perceived garment impediment was obtained from each subject after completing each movement while wearing each armor treatment using the perceived garment impediment ballot.

Perceived Garment Impediment Ballot

Perceived garment impediment was assessed using a garment impediment ballot that was adapted from previous studies conducted by Adams and Keyserling (1996) and Corlett and Bishop (1976). Adams and Keyserling (1996) used a rating of perceived impediment scale (RPI), and a comfort ballot adapted from instruments developed by Corlett and Bishop (1976). Adams and Keyserling (1996) asked subjects to identify those regions of the body where discomfort was experienced, and then to specify the type of discomfort. The questions and body areas relevant for the arm armor system (shoulder and upper arm area) were selected for this study. To have more accurate data, the selected body areas were divided into smaller areas than the original version. While the body area associated with shoulder movement was segmented into 18 areas for the *whole body* in the original version, the *torso and upper limb body* area was divided into 15 segments for this study (Figure 23).



1) N_F: Neck Front
2) N_B: Neck Back
3) N_S: Neck Side
4) S_T: Shoulder Top
5) S_U: Shoulder Upper Arm
6) A_F: Armscye Front
7) A_B: Armscye Back
8) A_{UF}: Armscye Under Front
9) A_{UB}: Armscye Under Back
10) UA: Upper Arm
11) UA_F: Under Arm Front
12) UA_B: Under Arm Back
13) IUA: Inner Under Arm
14) IE: Inner Elbow
15) OE: Outer Elbow

Figure 23. Body Areas Diagram for Perceived Garment Impediment Ballot

After defining the areas of discomfort/ impediment, the types of discomfort/impediment were asked. Adams and Keyserling's (1996) type of discomfort ballot was modified for this study to have more relevant evaluation criteria for the protective armor. The revised impediment discomfort types included: 1) resistance to movement, mechanical pulling, 2) bulky, compression, 3) rubbing, friction, or chafing, 4) too tight, 5) too loose, floppy, 6) localized pressure, and 7) other. The perceived verall restriction in movement was also evaluated using a 5-point scale (no effect =1, severely limited movement =5). The revised perceived garment impediment ballot is given in Appendix D.

In addition to the modification of the questions in the ballot, the procedure of obtaining feedback from the subject, and the ballot were revised. In Adams and Keyserling (1996)'s study, subjects filled out the garment perceived impediment ballot by themselves. In this study, the body area diagram and the list of impediments were placed on the wall, and the perceived garment impediment ballot was filled out by the researcher as specified by the subject. This process reduced time and subjects' fatigue. This feedback was collected immediately following performance of each movement in each arm armor treatment. In total, 200 ballots (10 subjects x 4 arm armor treatments x 5 movements) were gathered and further analyzed.

Wearer Acceptability

Perceived wearer acceptability for each armor treatment and all movements was assessed using the wearer acceptability ballot that was revised from Huck, Maganga and Kim (1996)'s wearer acceptability scale for evaluation of fit of protective ensembles. It was modified into a 5-point response scale from a 9-point response scale, and the questions were modified to reflect wearing conditions of protective armor. The total numbers of questions was reduced from 16 to 8. Each question used adjective pairs that were opposite in meaning. Higher ratings indicated greater wearer acceptability. The modified wearer acceptability ballot is given in Appendix E.

This data were collected after finishing all movements in each garment treatment. Thus, four ballots per subject were generated. In total, 40 ballots (10 subjects x 4 garment treatments) were gathered and further analyzed.

Visual Armor Coverage

The major purpose of wearing protective armor is to cover the body from impact from bullets, shrapnel and other projectiles. Thus, examining the area covered by the armor when the arm and shoulder are in multiple active poses would be helpful to examine. Scan images of the shoulder and arm areas with the various arm armor systems in five movements including flexion, extension, abduction, horizontal flexion, and horizontal extension were obtained using the 3D body scanner. Since the control armor treatment (OTV wearing over BDU) did have arm armor, data on control treatment coverage were not obtained. Scan images were obtained minimizing the data loss caused from the object's shadow and location of off- scanning boundary. Subjects were positioned on the scanner platform differently for each movement as shown in *Figure* 24. For flexion, abduction, and horizontal flexion, each subject stood in the center of the platform looking at the front wall. Each subject rotated 45° facing the scanner camera column for extension. For the horizontal extension movement, each subject moved to the left front corner of the platform to enable acquiring full data image inside of the scanning boundary for their movement.

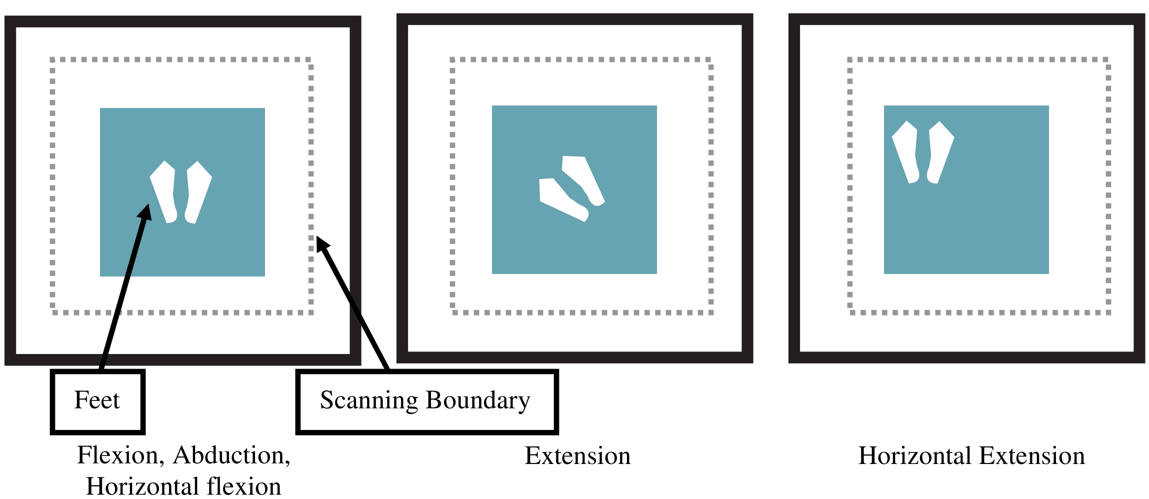
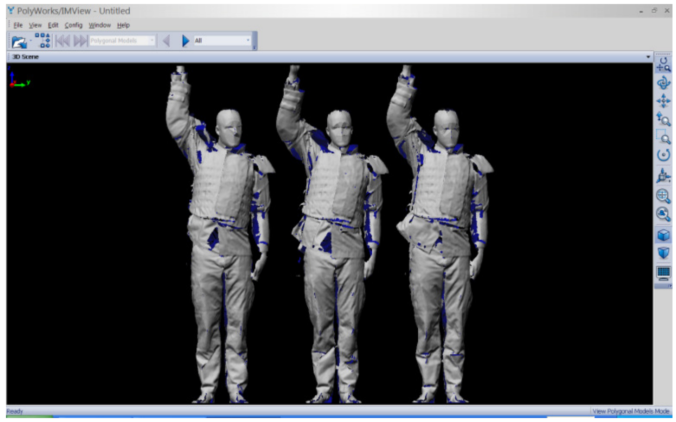


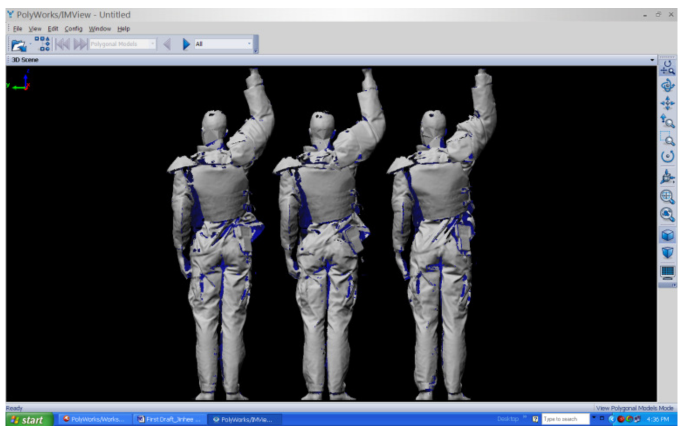
Figure 24. Feet Location for Each Movement

To make the comparison easier, three images of each subject in the three different garment treatments were brought onto the same computer screen for the independent review by the three fit judges. PolyWorks was used to bring images onto one screen that allowed the judges to view the images from all possible angels to aid in better evaluation of fit (*Figure* 25).

- Front View



- Back View



- Side View

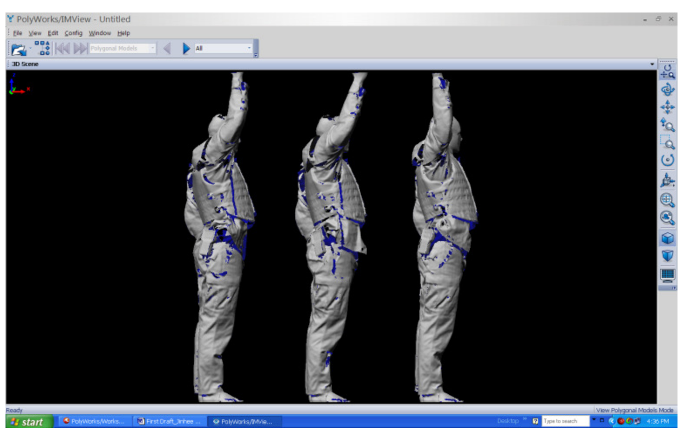
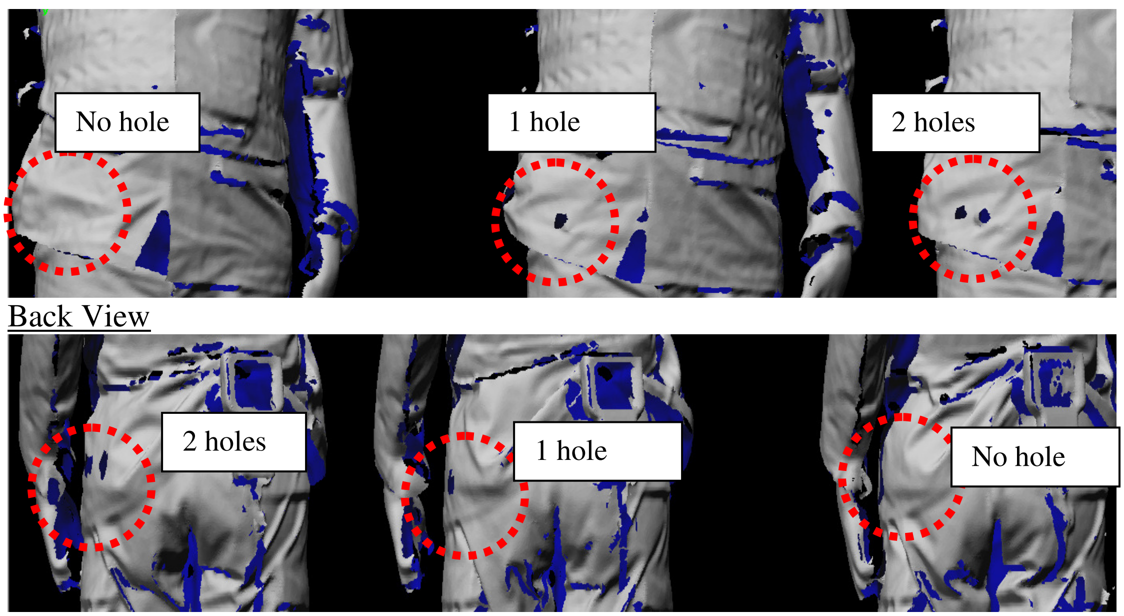


Figure 25. Screen Capture of Three Images of One Subject from in One Pose

Since the only difference among garment treatments B and C was the existence of two types of hard plates, the appearance of the garment treatments in the 3D scan images were very difficult to tell from each other. To distinguish the scan images easily, shiny black buttons were attached to the front right and left rear area of the BDU jacket. No button indicated garment system A, one button indicated garment system B (the conventional hard plate), and two buttons indicated system C (the prototype hard plate). Since the scanner can not scan the shiny black surface, it created holes in the scan images (*Figure* 26).



(**Armor System A**: no hole **Armor System B**: 1 hole **Armor System C**: 2 holes)

Figure 26. Button Holes to Distinguish Each Arm Armor Treatment

Visual Armor Coverage Ballot

The area that easily became uncovered due to movement was the focus for the evaluation for this study. Scan images were evaluated by judges using a visual armor coverage evaluation ballot developed by the researcher (Appendix F). Each area to be evaluated by the judges was circled with a dotted line (Appendix G). Fifty scan image files (10 subject x 5 movements), ImView (free viewer software downloaded from Polyworks), and the visual armor coverage ballot (Appendix F) were given to each judge. An individual explanation session was given by the researcher to explain how to use the software and how to fill in the ballot. Fit judges read instructions, opened the images using the free viewer, then rated the coverage and recorded it into the visual armor coverage ballot using a 7-point scale (1= Fully Uncovered, 7= Full Covered). Coverage at the front, underarm, and back areas (for each garment treatment) was evaluated. Horizontal flexion among the five movements was not rated in the front area due to serious missing data caused by the shadow of the dominant arm (*Figure* 27).

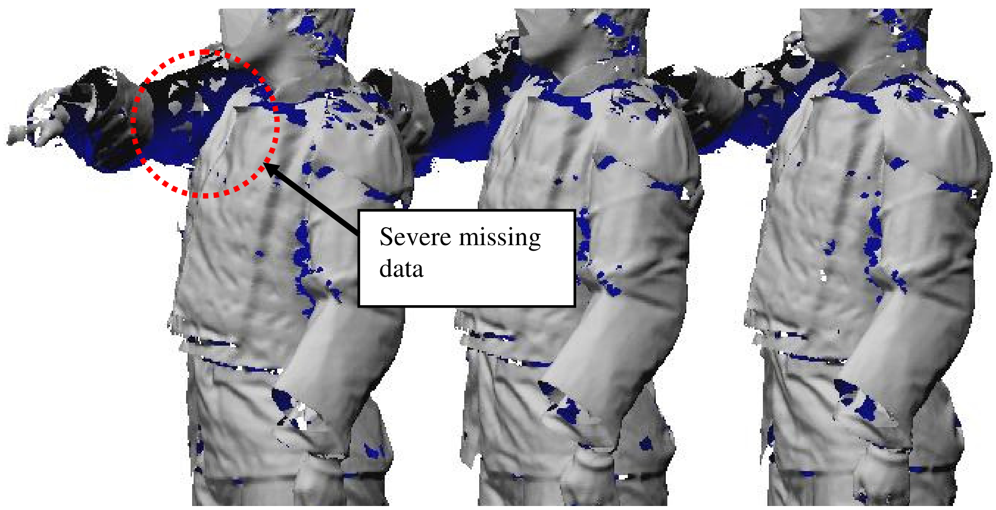


Figure 27. Missing Image Data in Horizontal Flexion at Front

Thus, there were 420 items (10 subjects x 5 movements x 3 arm armor treatments x 3 body areas -10 subjects x 3 arm armor treatments x 1 movement x 1 body areas) to rate for each judge. Three judges were selected among Oklahoma State University faculty from the department of Design, Housing, and Merchandising. Two judges had previous experience in fit evaluations using the identical software (viewer).

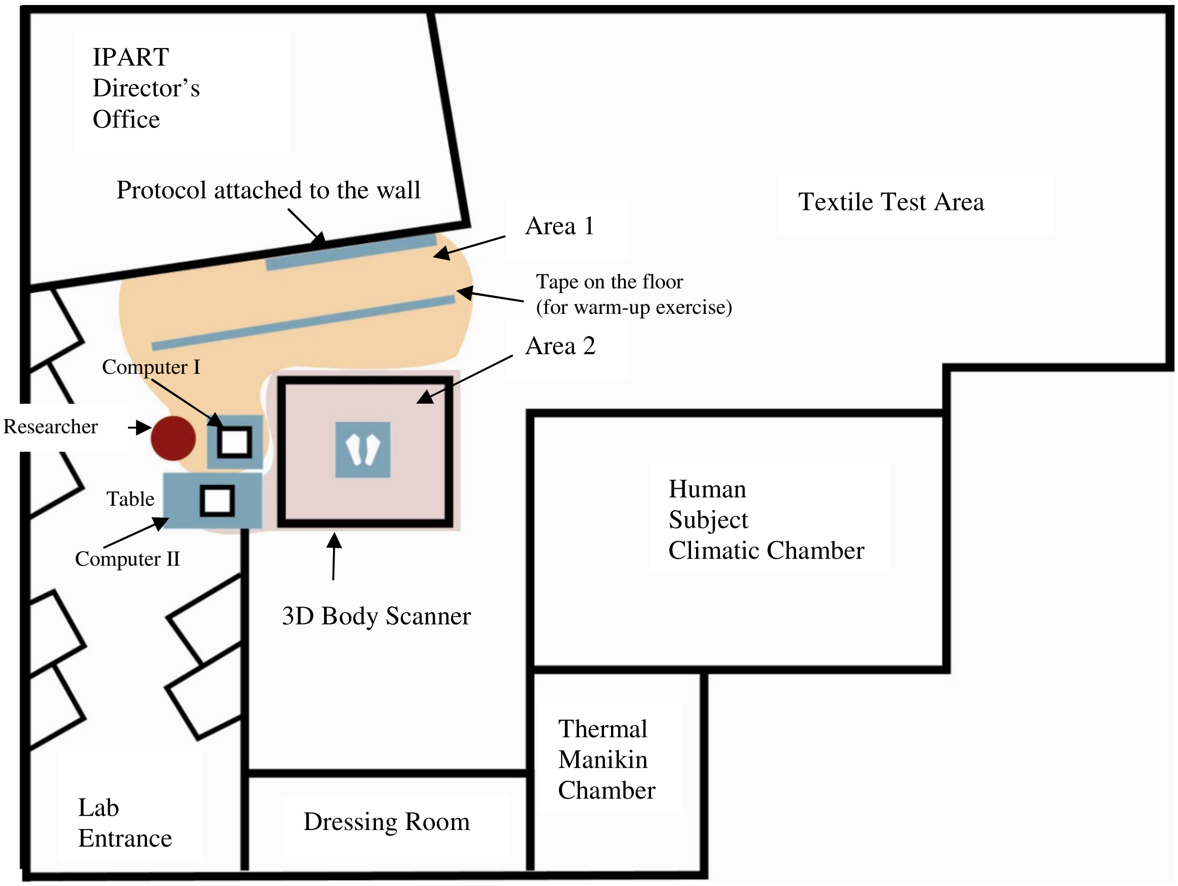
Procedures

This experimental study was conducted in two major sessions: 1) a one-hour **Pre-test procedure**, and 2) a two-hour **Test procedure**. Phone calls or brief meetings with the subjects were made by the researcher before starting these two major sessions to explain the research goal, test procedure, and location of the laboratory, as well as to verify fit of armor treatments. The meetings for the pre-test and/or test were then scheduled.

1) Pre-test Procedure

Both the pre-test procedure and test procedure were conducted at the IPART (Institute for Protective Apparel Research and Technology) Laboratory located in the Venture I building at the Oklahoma Technology & Research Park. The IPART laboratory consists of multiple chambers and sectional areas equipped with various equipment. This study was conducted in portions of the IPART laboratory areas labeled 1 and 2, as shown in *Figure* 28. These areas are equipped with the 3D body scanner chamber, two computer systems (one for the 3D body scanner, and the other computer system for the pressure sensor), and attached map board with the experimental protocol on the wall.

The Pre-test was conducted to acquaint subjects with a given range of discomfort while wearing various armor treatments. Each subject was given a random garment treatment to wear in order to see how much and what types of impediment they would experience during the actual test. Since the pre-test session was provided for training purposes, localized pressure sensors were not used.



A subject is performing a movement on the platform inside of the chamber facing the the protocol map attached on the wall.
A researcher is sitting in front of the computer to direct the subject and operate the computers.

Figure 28. IPART (The Institute of Protective Apparel Research and Technology) Laboratory

In area 1, the subjects performed a warm-up exercise. After finishing the warm-up exercise, the subject moved to area 2, the 3D body scanner chamber, to perform the arm and shoulder movements for data collection including localized pressure, ROM, and to complete two ballots to assess perceived garment impediment and wearer acceptability and visual armor coverage. A map board with the experimental protocol was placed on the wall of the laboratory before starting the pre-test, so subjects could easily follow the protocol by observing the movement protocol while performing the experiments.

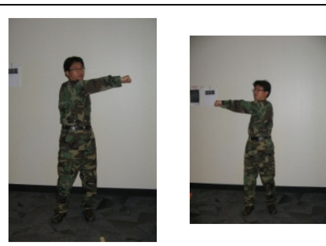
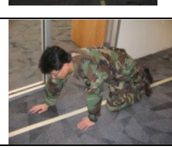
Pre-test procedure was conducted as follows;

1.1) The subject was introduced to the primary researcher and given a tour of the laboratory. The purpose of the study was then explained to the test subject, as well as information about the equipment to be used, and the experimental protocol.

1.2) Consent form and demographic information were completed.

1.3) The subject changed their clothes in the laboratory dressing room to prepare for obtaining basic body measurement data using the 3D body scanner. The test clothing consisted of the BDU pants without the jacket to acquire upper body measurements. The subject entered the 3D body scanner chamber, and posed in specific positions to acquire body measurements, especially chest and arm circumferences, as guided by Gordon (1988, need to check this). Scanning took about 10 to 15 seconds.

1.4) The subject then donned a BDU jacket, and was instructed to perform warm-up exercises as suggested in ROM studies (Huck, Maganga & Kim, 1996) as shown in *Figure* 29. The warm-up exercise protocol was modified from ASTM F1154-88 by selecting all exercises for the arm and upper arm areas. It was displayed on the wall to allow subjects to follow along easily (See *Figure* 28). The primary researcher presented each exercise protocol, and the subject followed the protocol.

Order	Procedure	
1	Raise arms Put your arms down	
2	Stand erect. With arms at sides, bend body to left and return, bend body forward and return, bend body to right, and return	
3	Stand erect. Extend arms overhead, then bend elbows	
4	Stand erect. Extend arms perpendicular to sides of torso. Twist torso left and return, twist torso right and return	
5	Stand erect. Reach arms across chest completely to opposite sides.	
6	Crawl along the tape on the floor	

- *Repeat exercise a total of three times*

Source: ASTM F1154-88
Note: [a]A strip of masking tape was placed on the floor as a guide

Figure 29. Warm-up Exercise (modified from ASTM F1154-88)

1.5) After completing the warm-up exercise protocol, subjects then donned a garment treatment and completed a full experimental test, minus the instrumentation such as localized pressure sensor and gathering actual scan image. This practice test was offered to familiarize the subjects with the complicated protocols and various test procedures and instruments. This was conducted to obtain more reliable data for the actual experimental test. Upon completion of the pre-test procedure, the subject was scheduled for another day to complete the test procedure.

<u>2) Test Procedure</u>

The test procedure was conducted as follows.

2.1) The subject changed into the test clothing consisting of the BDU jacket and pants in the dressing room. The MayoTrace handheld device was attached to the belt using the provided clip.

2.2) The subject performed the warm-up exercise in area 1 while wearing the BDU.

2.3) After completing the warm-up exercise, the subject entered the 3D body scanner chamber and stood on the platform in the middle of the scanner chamber. The OTV over the BDU (control) was always worn as the first among four arm armor treatments. For the two reference scans, the shoulder landmark was made by attaching foam to the BDU jacket.

2.4) After completing the scan of the control, the remaining garment treatments were worn in a randomized order. The soft arm armor was attached to the OTV using webbing. The shoulder landmark made was not used. Either no plate, conventional hard plate, or prototype hard plate were then inserted according to the randomized order.

After donning the garment treatment, the pressure sensors were connected to the Myo400 on the waist belt. The device and software (MyoResearch XP) installed on a computer were turned on, and data collection started.

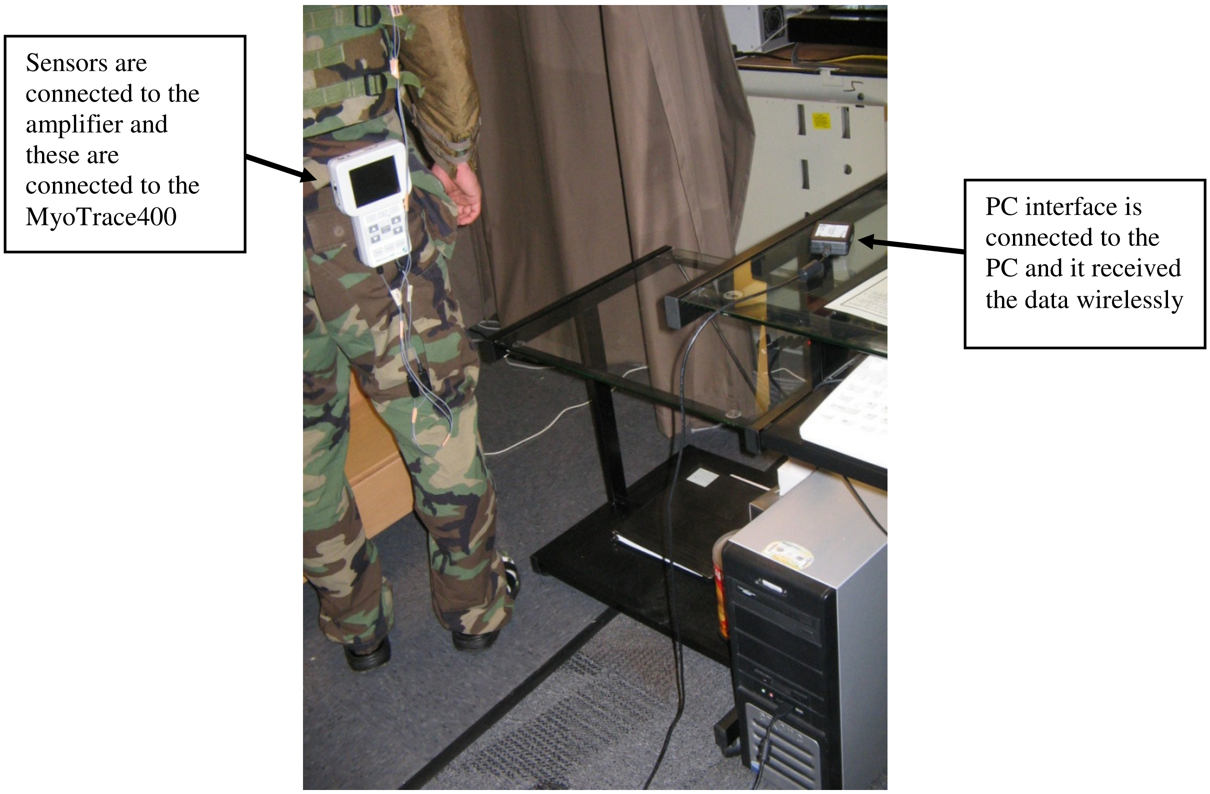


Figure 30. Subject with Myo400 Device and Sensor

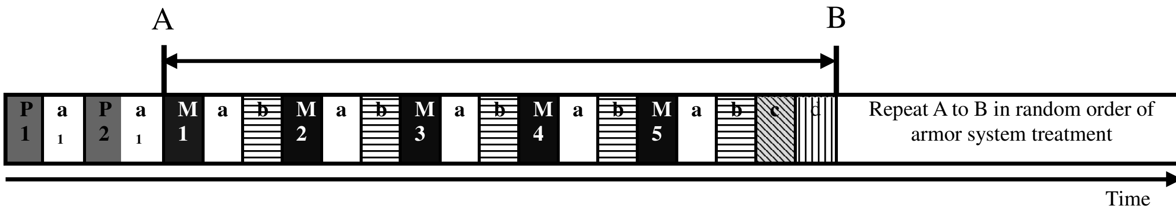
2.5) The subject entered the 3D body scanner, and stepped onto the platform located in the middle of the scanner chamber. Since there was a protocol map attached to the wall, the subject faced the wall when they began performing the shoulder movements. Five shoulder movements were performed in turn to acquire localized pressure data, scans for determination of ROM and visual armor coverage, perceived garment impediment, and wearer acceptability. Since the ROM is a measure of the full extent of the movement that a person has at a given joint, each subject was asked to move his arm as far as he could for each body movement (Adams and Kerserlying, 1996). After reaching the maximum point of movement, the researcher scanned the subject's body using the 3D body scanner. The subject held that movement position until the scan was completed. It took 12-15 seconds to scan the subject's body. The subject's torso remained straight during each movement and the palm faced the body for shoulder flexion, shoulder extension, and shoulder abduction. For shoulder horizontal flexion and shoulder horizontal extension, the subject was asked to face their palm down toward the floor. After scanning, the researcher asked each subject to look at the map on the wall and identifies body areas for which the subject perceived discomfort. Types of discomfort for each area were also recorded. The researcher recorded the subject's perceived general movement limitation. Localized pressure was saved into a computer while the wearer performed the specified movements.

2.6) Subjects completed the wearer acceptability evaluation ballot for the garment treatment they were wearing. A 5-minute break was given to the subject between each arm armor treatment.

2.7) The subject donned the next armor treatment and repeated the identical procedure from 2.4 to 2.6. Upon completion of the entire test procedure, fifty dollars, and an animated .avi file was given to each subject as compensation.

The scanned images were organized and saved into CDs to be given to the fit judges for visual coverage evaluation.

Data collection frame was provided in Figure 31 to facilitate understanding of the entire data collection procedure. This frame shows which dependent variable data were collected during which point of the test procedure. This streamlined procedure was required to maximize efficiency for acquiring data for five dependent variables with different instruments. It also seemed to reduce subjects' fatigue.



Note.
Positions and movements:
P1= Standing in control armor treatment/ P2= 90 degree at side position in control armor treatment
M1= Flexion M2=Extension M3=Abduction M4=Horizontal Flexion M5=Horizontal Extension

Data Collections:
a_1: 3D body scanning with shoulder landmark was done to acquire reference data for measuring ROM
a: 3D body scanning was done to acquire data for ROM and visual armor coverage, Localized pressure data was collected during 3D body scanning.
b: Perceived garment impediment data was acquired using ballot.
c: Wearer acceptability data was acquired using ballot.
d: A 5-minute break was given between each treatment

Figure 31. Data Collection Frame

Data Analysis

Localized pressure was collected electronically from pressure force sensors and devices, analyzed and reported using units of Pa (=1 N/m^2, Unit for pressure). ROMs were measured in degrees. The general perceived impediment item in the perceived garment impediment ballot was assessed using a 5-point response scale with opposite adjective pairs. Wearer acceptability was obtained using a 5-point response scale. Visual coverage evaluation was assessed using a 7-point response scale.

Two-way repeated-measures ANOVA (for localized pressure, ROM, perceived garment impediment, and visual armor coverage), and one-way repeated measures ANOVA (for wearer acceptability), with appropriated post hoc analyses, and descriptive statistics, were used as statistical methods. SPSS 16.0 package was used to analyze the data. A significance level of .050 was used unless otherwise specified.

CHAPTER IV: RESULTS AND DISCUSSION

Introduction

The purpose of this study was to compare performance effects and perceptual responses of subjects of wearing three different arm armor systems and no arm armor as a control while performing specified movements. Data for five dependent variables including localized pressure, ROM, perceived garment impediment, wearer acceptability, and visual armor coverage were collected during the experimental procedure.

Results

Localized Pressure

Localized pressure data from two sensors mounted at two different locations on the backside of the upper arm armor were obtained respectively to investigate the differential effects of armor system treatment and movement treatment.

Area 1

Research question: Are there significant differences in localized pressure at area 1 for armor and movement treatments?

A two-way repeated measures ANOVA was conducted with the two independent variables being three levels of armor system treatment (armor system A, B, and C) and five levels of movement treatment (flexion, extension, abduction, horizontal flexion, horizontal extension) and the dependent variable being the localized pressure at area 1 (See *Figure* 18).

Mauchly's Test of Sphericity was conducted to examine the equality of variance for both with-in subjects variable of armor treatment and of movement treatment prior to examining the ANOVA results. For the first with-in subjects variable of armor system treatments, the Mauchly's Test of Sphericity yielded a value of .04 (Chi-square approximate value of 26.93) and the assumption of Sphericity was violated ($p < .05$). Therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of Sphericity (epsilon = .51). For the second with-in subjects variable of movement treatment, the Mauchly's Test of Sphericity yielded a value of .00 (Chi-square approximate value of 90.94) and the assumption of Sphericity was violated ($p < .05$). Consequently, degrees of freedom were corrected using Greenhouse-Geisser estimates of Sphericity (epsilon= .26).

A two-way repeated measures ANOVA (Table 4) revealed that there were no significant main effects for armor system treatment, $F(1.02, 9.16) = 2.20$, $p > .05$, and was for movement treatment, $F(1.05, 9.50) = 1.25$, $p > .05$. In addition, there was no interaction effect of the armor system treatment by movement treatment, $F(1.07, 9.60) = 1.10$, $p > .05$.

Table 4
ANOVA Table for Area 1 Localized Pressure by Armor and Movement Treatments

Source	SS	df	df_{error}	MS	F	P Value
Armor Treatment	38.81×10^9	1.02	9.16	38.14×10^9	2.20	0.17
Movement Treatment	23.76×10^9.75	1.05	9.50	22.51×10^9	1.25	0.29
Armor*Movement	41.00×10^9.28	1.07	9.60	38.45×10^9	1.10	0.33

Note. Unit: Pa (=1 N/m^2)

Means and standard deviations of the localized pressure scores for area 1 of each level for armor movement treatments are presented in Table 5 and graphically can be seen in *Figure* 32.

Table 5
Localized Pressure Means and Standard Deviations for Area 1 by Armor and Movement Treatment

	Armor A		Armor B		Armor C	
Movement	Mean	SD	Mean	SD	Mean	SD
Flexion	5958.97	5304.25	**16131.83**	17986.04	6353.43	9726.89
Extension	6062.90	6030.30	**96672.79**	266142.32	6232.07	8835.81
Abduction	**8776.05**	14880.95	5455.47	4292.13	3170.76	4166.54
H. Flexion	5083.10	3701.05	**67813.11**	117677.66	12738.08	18818.96
H. Extension	3672.27	3004.00	**14606.92**	14294.04	2115.49	1857.88

Note. Unit: Pa (=1 N/m^2)/ The localized pressure value that shows highest value among the three arm armor treatments in each movement was marked as bold.

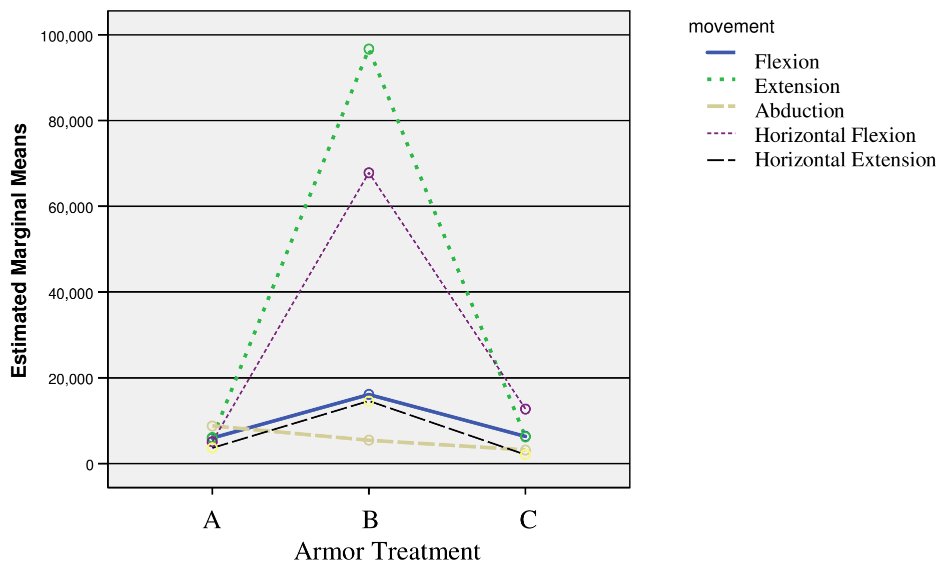
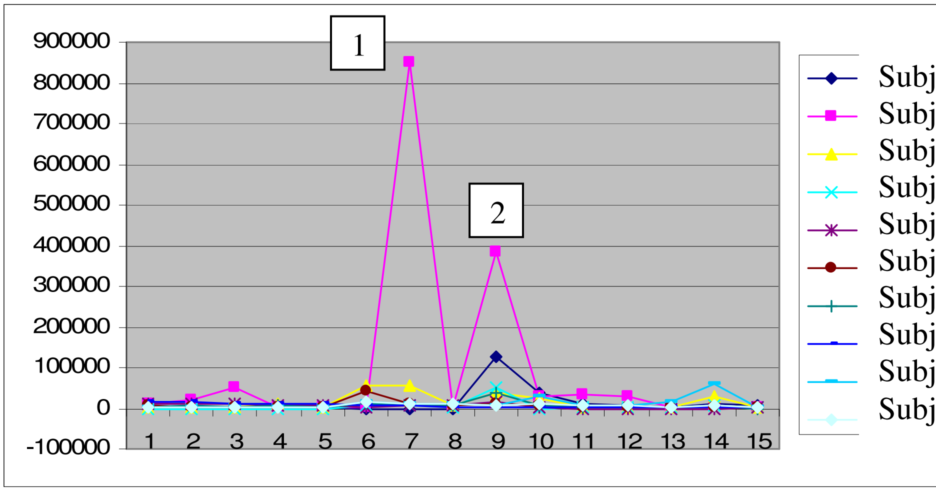


Figure 32. Estimated Marginal Means of Localized Pressure on Area 1

Examination of Table 5 shows that the standard deviations are large. The individual localized pressure data for the ten subjects were examined to explore the source of large standard deviations. Figure 33 shows the localized pressure exerted on area 1 for each subject completing each movement while wearing each garment treatment except the control garment.



Note. Unit: Pa (= 1/Nm^2)/ N=10
Numbers in row indicates the following. 1: flexion wearing armor A 2: extension wearing armor A 3. abduction wearing armor A 4: horizontal flexion wearing armor A 5: horizontal extension wearing armor A 6:flexion wearing armor B 7: extension wearing armor B 8: abduction wearing armor B 9: horizontal flexion wearing armor B 10: horizontal extension wearing armor B 11: flexion wearing armor C 12: extension wearing armor C 13. abduction wearing armor C 14: horizontal flexion wearing armor C 15: horizontal extension wearing soft armor C

Figure 33. Localized Pressure Exerted to Each Individual (Area 1)

Two clearly noticeable peaks are shown in Figure 33. The first point represents the localized pressure experienced by subject 2 in extension while wearing armor B. The second point represents the data from the identical subject completing horizontal flexion while wearing armor B.

Area 2

Research question: Are there significant differences in localized pressure at area 2 for armor and movement treatments?

Analysis of localized pressure at area 2 followed the identical method as for localized pressure area 1. A two-way repeated measures ANOVA was conducted to evaluate the effects of armor and movement treatments on the localized pressure area 2.

Mauchly’s Test of Sphericity was conducted to examine the equality of variance for both with-in subjects variable of armor system treatment and of movement treatment before examining the ANOVA results. For the first with-in subjects variable of armor system treatment, the Mauchly's Test of Sphericity yielded a value of .16 (Chi-square approximate value of 14.80) and the assumption of Sphericity was violated ($p < .05$). Therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of Sphericity (epsilon = .54). For the second with-in subjects variable of movement treatments, the Mauchly's Test of Sphericity yielded a value of .04 (Chi-square approximate value of 24.35) and the assumption of Sphericity was violated ($p < .05$). Consequently, degrees of freedom were corrected using Greenhouse-Geisser estimates of Sphericity (epsilon= .37).

A two-way repeated measures ANOVA (Table 6) revealed that there were no significant main effects for armor system treatment, $F(1.10, 9.77) = 2.31$, $p > .05$, nor for movement treatment, $F(1.46, 13.15) = 1.47$, $p > .05$. In addition, there was no significant interaction effect of the armor system treatment by movement treatment, $F(1.65, 14.90) = 1.34$, $p > .05$.

Table 6
ANOVA Table for Area 2 Localized Pressure by Armor and Movement Treatments

Source	SS	df	df_{error}	MS	F	P Value
Armor Treatment	54.22×10^{10}	1.10	9.77	49.95×10^{10}	2.30	0.16
Movement Treatment	25.62×10^{10}	1.46	13.15	17.54×10^{10}	1.50	0.26
Armor*Movement	43.00×10^{10}	1.65	14.90	25.99×10^{10}	1.33	0.29

Note. Unit: Pa (=1 N/m^2) /N=10

Means and standard deviations of the localized pressure scores on area 2 of each level based on "armor system treatments" and "movement treatment," are presented in Table 7 and graphically presented in *Figure* 34.

Table 7
Localized Pressure Means and Standard Deviations on Area 2 by Armor and Movement Treatment

	Armor A		Armor B		Armor C	
Movement	Mean	SD	Mean	SD	Mean	SD
Flexion	22531.98	36822.00	**78540.67**	144764.70	16381.35	23523.45
Extension	8143.87	7104.63	**324038.22**	747329.46	97532.47	219796.82
Abduction	**75520.23**	181983.56	15077.04	30267.41	4160.95	7544.40
H. Flexion	22038.57	62584.90	**235417.25**	210287.48	40963.43	103213.50
H. Extension	27112.48	49899.56	**149569.42**	349302.16	15971.52	32059.30

Note. Unit: Pa (=1 N/m^2) /N=10
The highlighted mean localized pressure values among the three arm armor treatments in each movement is marked as bold.

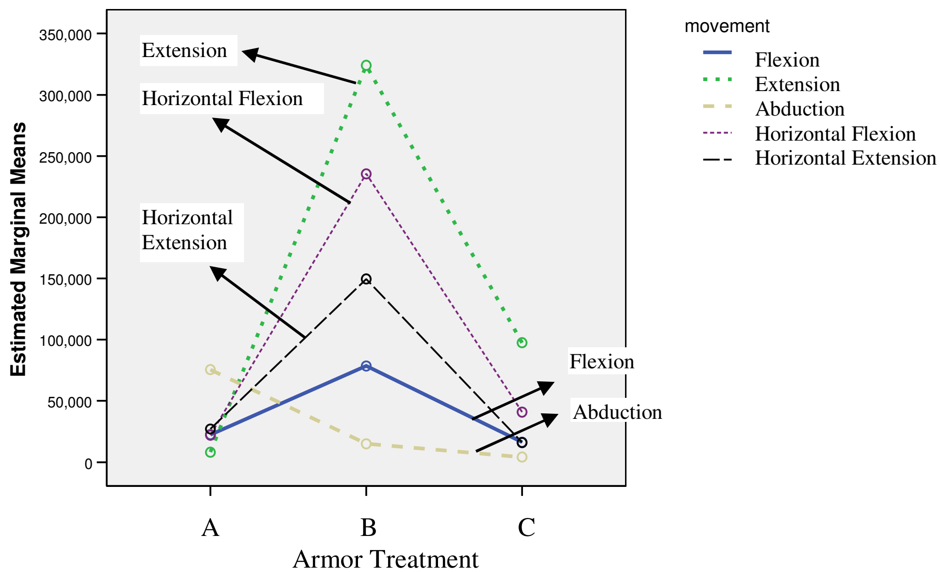
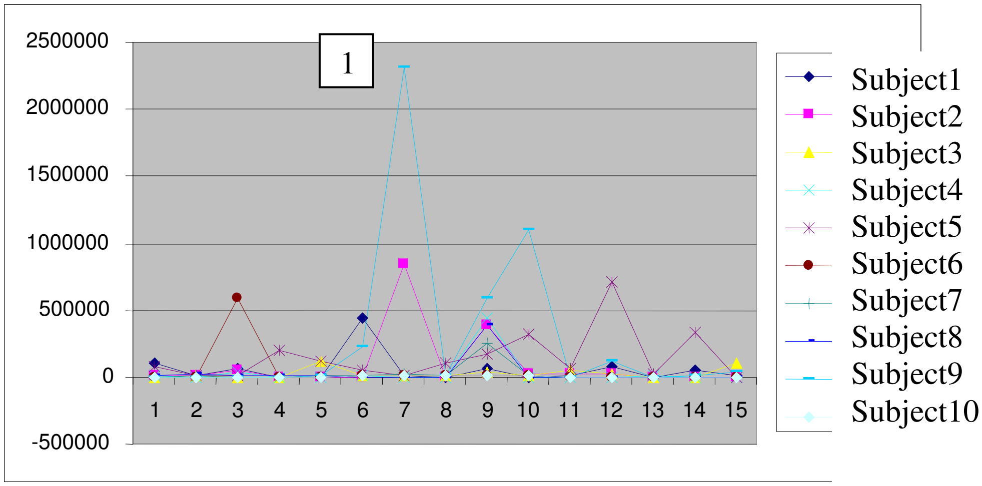


Figure 34. Estimated Marginal Means of Localized Pressure on Area 2

The overall results are similar to the results for area 1. It is noteworthy that large standard deviations were found with area 2 data as found for area 1 data (Table 7). The larger pressure was experienced by subject 4 in extension wearing armor B shown in Figure 35.



Note. Unit: Pa (= 1/Nm^2)/ N=10
Numbers in row indicates as fllows. 1:flexion wearing armor A 2: extension wearing armor A
3. abduction wearing armor A 4: horizontal flexion wearing armor A 5: horizontal extension wearing armor A 6:flexion wearing armor B 7: extension wearing armor B 8: abduction wearing armor B
9: horizontal flexion wearing armor B 10: horizontal extension wearing armor B 11:flexion wearing armor C 12: extension wearing armor C 13. abduction wearing armor C 14: horizontal flexion wearing armor C
15: horizontal extension wearing soft armor C

Figure 35. Localized Pressure Exerted by Each Individual (Area 2)

All three peaks (two for areas 1 and one for area 2) were found for subjects wearing arm armor B, but the movements and subjects with peak localized pressure data were not consistent. To further examine the source of the large standard deviations, the arm circumferences of two subjects (subjects 2 and 4) were examined. However, no differences were found between above the two subjects and the other subjects' arm circumferences (see Table 2 in Chapter 3, p.38). There could be other factors besides arm circumferences that influenced the localized pressure data. Contact area changes (material may move away from the arm due to stiffness of the plates preventing contact), and arm variations (arm size/shape/composition in terms of bone, muscle and fat tissue) may contribute to this large variation.

Because of the importance of understanding the pressure the garment may exert on the body, two Tekscan pressure sensors well played but multiple methodological issues had to be address, such as number and placement of the sensors. Although placement on skin was designed, the sensors were placed on the backside of the armor after pilot study. It showed data devised from skin surfaces yet, the resulting data needs further investigation.

Comparison of localized pressure for areas 1 and 2 indicates that showed larger localized pressure means were found for area 2. Area 1 is located in the upper arm above area 2, thus the lower area seems to have had more pressure exerted by arm armor system compared with the upper area.

Range of Motion (ROM)

Research question: Are there significant differences in ROM for armor and movement treatments?

ROM was measure by a manual goniometry from the screen shot prints of scan images taken at the front, side, and back views of the wearer performing each movement while wearing each armor treatment.

A two-way repeated measures ANOVA was conducted with the two independent variables being four levels of armor treatment (control, and armor system A, B, and C) and five levels of movement (flexion, extension, abduction, horizontal flexion, and horizontal extension) and the dependent variable being ROM. Mauchly's Test of Sphericity revealed that there was no violation ($p > .05$) of Sphericity among the two main effects and one interaction.

A two-way repeated measures ANOVA (Table 8) revealed that there were statistically significant main effects for armor treatment, $F(3, 27) = 28.49$, $p < .05$, and movement treatment, F (4, 36) = 795.00, p < .05, as well as for the interaction between the armor by movement treatments, F (12, 108) = 2.90, p < .05.

Table 8
ANOVA Table for ROM by Armor and Movement Treatments

Source	SS	df	df_{error}	MS	F	P Value
Armor Treatment	7431.80.	3	27	2477.27	28.49	0.00**
Movement Treatment	719897.41	4	36	179974.35	795.00	0.00**
Armor*Movement	1397.26	12	108	116.44	2.90	0.00**

Note. Unit: degree (°) / N=10

From *Figure* 36, it is apparent that the interaction effect was an 'ordinal interaction'. Thus, it is considered reasonable to examine the effect of armor treatment at each level of movement.

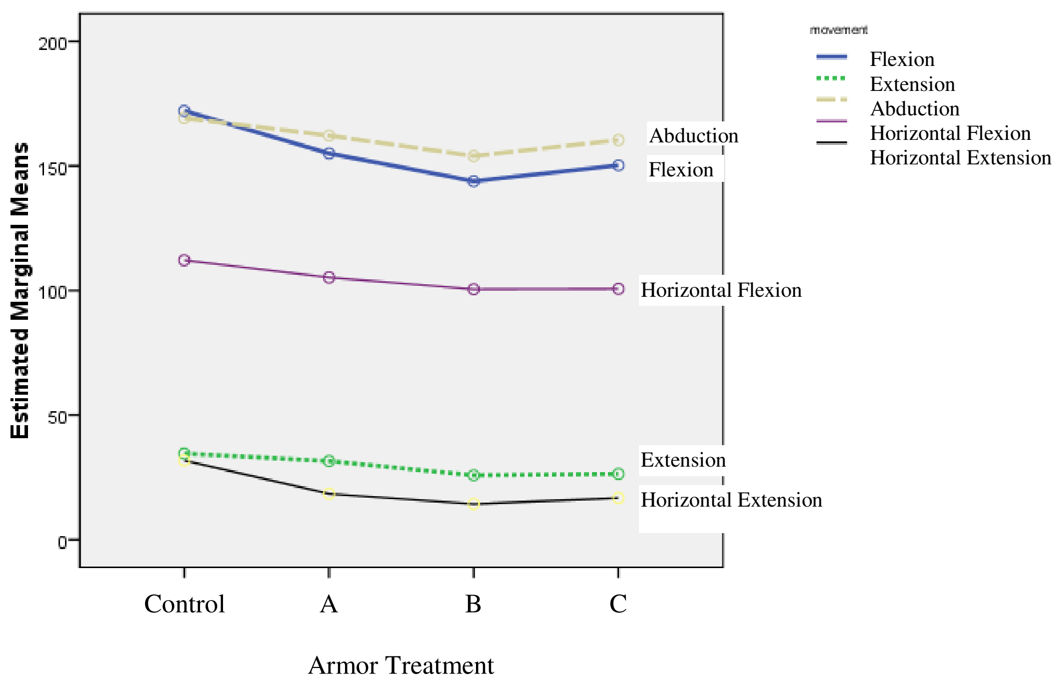


Figure 36. Estimated Marginal Means of ROM

Examination of each five movement levels in *Figure* 36 suggests that all arm armor treatments negatively affected ROM for all movements. For all five movements, armor system B showed the smallest mean ROM and therefore tended to impede movement to a greater degree than the control and other armor systems (*9*). In general, there was a trend for ROM to decrease from wearing the control armor to armor system A to armor system C to armor system B for all five movements.

Table 9

Means and Standard Deviation on the ROM by Armor and Movement Treatments

	Control		Armor A		Armor B		Armor C	
Movement	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Flexion	172.08	11.25	155.02	15.02	143.85	15.25	150.25	17.21
Extension	34.58	6.19	31.57	5.74	25.85	6.68	26.40	4.95
Abduction	169.25	8.81	162.18	14.24	154.00	15.17	160.40	13.28
H. Flexion	112.13	11.19	105.25	10.42	100.50	12.11	100.66	14.4
H. Extension	31.80	6.60	18.42	8.077	14.33	8.54	16.72	7.86

Note. Unit: degree (°) / N=10
*statistically significant at the .05 level ** statistically significant at the .01 level

Perceived Garment Impediment

Research question: 1) Which body areas did subjects experience impediment/discomfort and what types of impediment/discomfort did subjects experience? 2) Is there a significant difference in general movement limitation for armor and movement treatments?

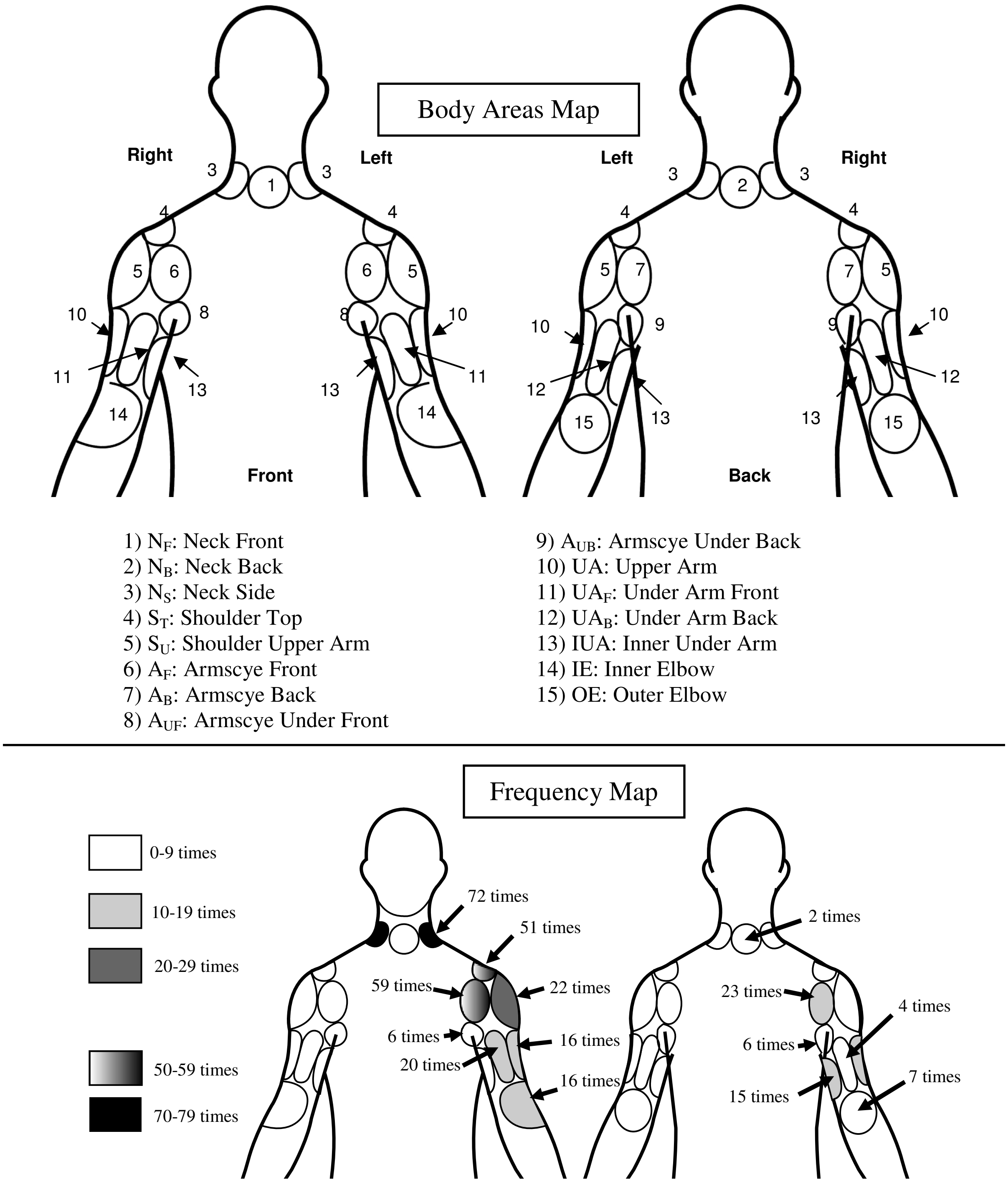
The perceived garment impediment ballot was completed 20 times (4 armor treatments x 5 movement treatments) by each of the ten subjects for a total of 200 ballots. The ballot had two major sections that were analyzed separately. The first section consists in questions 1 and 2 (see Appendix D) regarding body areas that the subject experienced discomfort during movement, and the type of discomfort experienced at each body area. Multiple choices were possible for both questions.

The second section contained one question dealing with overall perception of garment restriction during each movement in each arm armor treatment. The subjects answered using a 5-point response scale (no effect=1, severely limited movement=5).

1) <u>Body Area with Impediment and Types of Experienced Impediment</u>

Research question: 1) Which areas of the body were reported by subjects as areas of impediment/discomfort and what types of impediment/discomfort did the subjects report experiencing?

Frequency was used to examine body areas reported by the subjects as areas of discomfort/impediment and the types of impediment experienced in each area. In total, area 3 (neck side) was mentioned most frequently as a body impediment area (72 times out of 319 times). Area 6 (armscye front area) was mentioned 59 times, area 4 (shoulder top) was mentioned 51 times, area 5 (shoulder upper arm) was mentioned 22 times, area 7 (armscye back) was mentioned 23 times, area 11 (under arm front) was mentioned 20 times, area 14 (inner elbow) was mentioned 16 times, area 13 (inner underarm) was mentioned 15 times, area 10 (upper arm) was mentioned 16 times, area 15 was mentioned 7 times, areas 8 and 9 (armscye under front, armscye under back and outer elbow) were mentioned 6 times each, area 12 (under arm back) was mentioned 4 times, and area 2 (neck back) was mentioned twice out of 319 respectively. No subject reported experiencing an impediment in area 1 (neck front). Figure 33 presents the frequency of areas of impediment graphically. The first body area map indicates the areas of impediment, and the second map shows the frequency of reported impediments exerted for each body area.



Note: Each color represent the frequency range

Figure 37. Frequency of Reported Impediments Exerted for Each Body Area.

Areas 3, 4, and 6 (neck side, shoulder top, and armscye front) were reported as problematic the most frequently by the subjects. Review of *Figure* 37 and Table 10 show that these three areas were noted as problematic for all armor treatments including the control. Similarly areas 7 (armscye back) and 13 (inner underarm) although reported less frequently, were problematic for all armor treatments.

To examine the areas of impediment in relation to armor treatment, Table 10 presents the frequency data.

Table 10
Frequency for Area of Impediment by Armor Treatment

Armor Treatment	Control	A	B	C	Total
Area 1 (neck front)	0	0	0	0	0
Area 2 (neck back)	0	0	2	0	2
Area 3 (neck side)	**17**	**21**	**18**	**16**	72
Area 4 (shoulder top)	**12**	**11**	**12**	**16**	51
Area 5 (shoulder upper arm)	2	3	**10**	**7**	22
Area 6 (armscye front)	**19**	**12**	**17**	**11**	59
Area 7 (armscye back)	5	7	3	8	23
Area 8 (armscye under front)	4	2	0	0	6
Area 9 (armscye under back)	1	2	0	3	6
Area 10 (upper arm)	0	1	9	6	16
Area 11 (under arm front)	1	3	**11**	5	**20**
Area 12 (under arm back)	2	1	0	1	4
Area 13 (inner underarm)	5	5	3	2	15
Area 14 (inner elbow)	0	6	3	7	16
Area 15 (outer elbow)	0	2	3	2	7
Total	68	76	91	84	319

Note. Areas of Impediment mentioned more than 10 times were marked as bold.

While wearing the control garment treatment was unexpectedly high (68 times) areas 1-4 and 6-9 appear to pertain primary to the control garment. It is noteworthy that the areas 3, 6, 7 and 4 (side neck area, the front and back armscye, and shoulder top) represent 73 % of the complaints. Area 14, the inner elbow was noted 16 times and the outer elbow seven times, suggesting that the arm armor was problematic at the elbow for some subjects performing some movements. In shoulder areas 5, 10, 11 (shoulder upper arm, upper arm, and under arm front), the hard plate may have contributed to the expressed discomfort (Table 10). Under arm front was mentioned very frequently by subject wearing armor system B compared with armor systems A and C.

The type of impediment was also reported by subjects. Localized pressure (93 times), resistance to movement (79 times), tight (62 times), rubbing and friction (52 times), heavy (32 times), and loose (1 time) were mentioned respectively out of 319 times. In addition, the type of impediment was examined by armor system and presented in Table 11. For armor systems B and C, perception of heaviness was mentioned more frequently than armor A, and both systems B and C used hard armor plates. It is interesting that system B was reported as heavy six times more often than system C. Tight was mentioned more frequently in armor system C than armor system B.

Table 11
Frequency in Types of Impediment by Armor Treatment

Armor Treatment	Control	A	B	C	Total
1. Resistance to movement	**26**	**17**	**19**	**17**	79
2. Heavy	0	6	**16**	**10**	32
3. Rubbing and friction	**11**	**14**	**13**	**14**	52
4. tight	7	**13**	**18**	**24**	62
5. Loose	1	0	0	0	1
6. Localized Pressure	**23**	**26**	**25**	**19**	93
Total	68	76	91	84	319

Note. Areas of Impediment mentioned more than 10 times were marked as bold.

The types of impediment exerted on each body area for each movement while wearing each armor treatment were identified and are presented as matrices in Appendix H. It is important to remember that the perceived severity of discomfort/impediment is not assessed.

2) General Movement Limitation Ratings

Research question: 2) Are there any significant differences in perception of ability to perform specified movements by armor treatment?

The general movement limitation question, which used a response scale with a rating of 1 to 5 (1= no effect, 5= severely limited movement) was completed by subjects wearing each garment treatment for each movement.

A two-way repeated measures ANOVA was conducted with the two independent variables being four levels of armor treatment (control armor, armor system A, B, and C) and five levels of movement (flexion, extension, abduction, horizontal flexion, and horizontal extension) and the dependent variable being the response to the general movement limitation question (q #3 in Appendix D). Mauchly's Test of Sphericity was done prior to the ANOVA test, and the result revealed that there was no violation ($p > .05$) of Sphericity for the two main effects.

A two-way repeated measures ANOVA (Table 12) revealed that there were statistically significant main effects for armor system treatment, $F(3, 27) = 6.67$, $p < .05$, and the movement treatment, $F(4, 36) = 4.16$, $p < .05$. However, there was no statistically significant interaction effect.

Table 12
ANOVA Table for General Movement Impediment Scores by Armor and Movement Treatments

Source	SS	df	df_{error}	MS	F	P Value
Armor Treatment	12.46	3	27	4.15	6.67	0.00**
Movement Treatment	6.38	4	36	1.60	4.16	0.01*
Armor*Movement	7.62	12	108	0.64	1.45	0.16

Note. N=10
*statistically significant at the .05 level ** statistically significant at the .01 level

For the first with-in subjects variable of armor system treatment, post-hoc pairwise LSD-corrected comparisons are given in Table 13. The estimated means of each level of armor treatment were 2.52 for control garment treatment, 2.36 for armor system A, 3.02 for armor system B, and 2.76 for armor system C. The results of the LSD comparison shows that the general movement limitation scores of the control garment (mean = 2.52) were significantly less (less restrictive) than those of armor B (mean = 3.02). There were no statistically significant differences between the control and armor A (mean = 2. 36). Scores for subjects wearing armor system A were significantly less than those for subjects wearing armor systems B and C (mean=2.72). There were no statistically significant differences between B and C. Thus, subjects wearing armor system A and C experienced less movement limitation.

Table 13
Pairwise Comparisons for General Movement Limitation Scores by Armor Treatment

Armor Treatment	Armor Treatment	Mean Difference	Standard Error	P Value
Control	Armor A	0.16	0.20	0.45
Control	Armor B	-0.50	0.17	0.02*
Control	Armor C	-0.24	0.20	0.25
Armor A	Armor B	-0.66	0.10	0.00**
Armor A	Armor C	-0.40	0.13	0.01*
Armor B	Armor C	0.26	0.12	0.06

Note. N=10
*statistically significant at the .05 level ** statistically significant at the .01 level

The means and standard deviation for the general movement limitation scores for each movement by armor treatment are presented in Table 14, and graphically shown in Figure 38.

Table 14
Means and Standard Deviations for the General Movement Limitation by Armor and Movement Treatments

	Control		Armor A		Armor B		Armor C	
Movement	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Flexion	2.90	.74	2.20	.79	2.80	.92	2.50	.97
Extension	2.10	.74	2.30	.67	2.70	.48	2.50	.85
Abduction	2.70	.95	2.70	.95	3.20	.63	3.00	1.05
H. Flexion	2.90	.74	2.30	.82	3.20	.63	2.90	1.10
H. Extension	2.00	.82	2.30	1.06	3.20	.79	2.90	.88

Note. N=10
Higher score indicates higher movement limitation ((1= no effect, 5= severely limited movement).

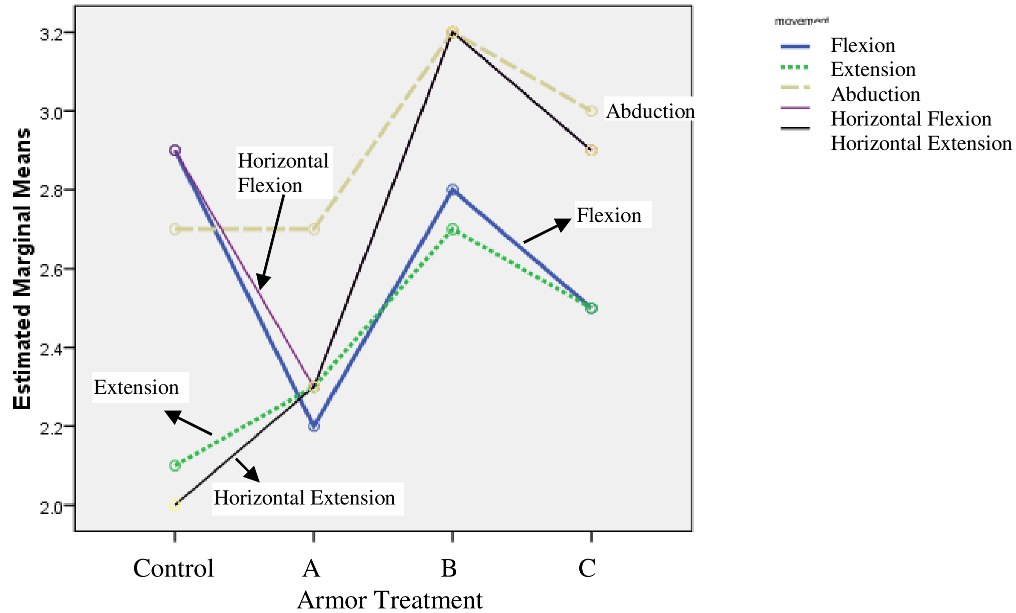


Figure 38. Estimated Marginal Means for General Movement Limitation Scores

In general, armor system B was rated as more restrictive than the control and armor system A. A similar trend was observed for armor system C.

The control garment (OTV over BDU) was rated quite highly in terms of garment movement impediment in horizontal flexion and horizontal extension (see Figure 38). During the experiment, control garment treatment was presented in the first while other arm armor treatment was presented in randomized order. The heaviness and bulkiness of the OTV could be recognized as bigger levels of impediment by the subject in the first presentation, and the impact of impediment could be reduced over time while adding other armor systems.

Wearer Acceptability

Subjects completed a wearer acceptability ballot using a 5-point response scale for a set of eight opposite adjective pairs after completing all five movements in each armor treatment. Thus, one individual completed four wearer acceptability ballots, one for each of the garment treatments. Since only armor system treatment was regarded as an independent variable for this dependent variable, one-way repeated measures ANOVA was used to analyze the data.

Eight adjective pairs were used to evaluate wearer acceptability providing information on: 1) comfort, 2) acceptability, 3) flexibility, 4) freedom of movement, 5) easiness to move in, 6) fit satisfaction, 7) preference, and 8) tightness in wearing each garment treatment. Since each item is unique, each item was individually analyzed using one-way repeated measures analysis of variance. Eight individual research questions were developed for the wearer acceptability ballot.

1) Comfort

Research Question: Is there a significant difference by armor treatment for perceived comfort?

A one-way repeated measures ANOVA was conducted with the four levels of armor system treatment as the independent variable and the dependent variable being the comfort scores (question # 1) in the wearer acceptability ballot. Mauchly's test was done prior to the ANOVA test, and it revealed that the assumption of Sphericity was not violated (chi-square = .254, $p > .05$).

Statistically significant differences in comfort were found for armor system treatment, $F(3, 27) = 6.78$, $p < .05$. Post-hoc pairwise LSD comparisons (Table 15) indicated that the comfort scores of the control armor (mean = 4.00, SD = 0.47) were statistically higher than those for armor systems B (mean = 3.00, SD= 0.81) and C (mean = 3.30). However, there was no statistical difference between the control armor and armor system A (mean = 3.70, SD = 0.82). There were statistically significant differences between armor systems A and B, and between armor systems A and C. There were no significant differences between armor systems B and C. The means and standard deviations for the comfort scores are presented in Table 16.

Table 15
Pairwise Comparisons for Perceived Wearer Comfort (q#1)

Armor Treatment	Armor Treatment	Mean Difference	Standard Error	P Value
Control	Armor A	0.16	0.20	0.28
Control	Armor B	-0.50	0.17	0.01*
Control	Armor C	-0.24	0.20	0.01*
Armor A	Armor B	-0.66	0.10	0.01*
Armor A	Armor C	-0.40	0.13	0.10
Armor B	Armor C	0.26	0.12	0.19

Note. N=10
*statistically significant at the .05 level ** statistically significant at the .01 level

Table 16
Means and Standard Deviations for Perceived Wearer Comfort (q#1)

Control		Armor A		Armor B		Armor C	
Mean	SD	Mean	SD	Mean	SD	Mean	SD
4.00	0.47	3.70	0.82	3.00	0.81	3.30	0.48

Note. N=10.
Higher ratings indicate higher wearer perceived comfort.

2) Acceptability

Research Question: Is there a significant difference by armor treatment for perceived acceptability?

A one-way repeated measures ANOVA was conducted with the independent variable being armor system treatment and the dependent variable being the acceptability scores (question # 2). Mauchly's test was conducted before the ANOVA test, and it indicated that the assumption of Sphericity was not violated (chi-square = 5.93, $p > .05$). Statistically significant differences were found for acceptability by armor system treatment, $F(3, 27) = 8.70$, $p < .05$. Post-hoc pairwise LSD comparisons (Table 17) found that the acceptability scores of the control armor (mean = 4.20, SD = 0.63) and armor system A (mean = 4.00, SD= 0.67) were significantly higher (more acceptable) than those of armor system B (mean= 3.20, SD=0.63) and armor system C (mean = 3.60, SD = 0.52). However, there were no statistically significant differences between the control and armor system A. In addition, the acceptability scores of armor system C were significantly higher that those of armor system B. The means and standard deviations for the acceptability scores are available in Table 18.

Table 17
Pairwise Comparisons for Perceived Wearer Acceptability (q#2)

Armor Treatment	Armor Treatment	Mean Difference	Standard Error	P Values
Control	Armor A	0.20	0.20	0.34
Control	Armor B	1.00	0.30	0.00**
Control	Armor C	0.60	0.22	0.02*
Armor A	Armor B	0.80	0.20	0.00**
Armor A	Armor C	0.40	0.16	0.04*
Armor B	Armor C	-0.40	0.16	0.04*

Note. N=10.
*statistically significant at the .05 level ** statistically significant at the .01 level

Table 18

Means and Standard Deviations for Perceived Wearer Acceptability (q#2)

Control		Armor A		Armor B		Armor C	
Mean	SD	Mean	SD	Mean	SD	Mean	SD
4.20	0.63	4.00	0.67	3.20	0.63	3.60	0.52

Note. N=10.
Higher ratings indicate higher perceived wearer acceptability.

3) Flexibility

Research Question: Is there a significant difference by armor treatment for perceived flexibility?

A one-way repeated measures ANOVA was conducted with armor system treatment as the independent variable and the dependent variable being the flexibility scores (question # 3). Mauchly's test indicated that the assumption of Sphericity was not violated (chi-square = 1.35, p > .05).

There were statistically significant differences in flexibility between the four levels of treatment, F (3, 27) = 5.65, p < .05. Post-hoc pairwise LSD comparisons (Table 19) indicated that the flexibility scores of the control armor (mean = 3.70), armor system A (mean= 3.70, SD= 0.82), and armor system C (mean = 3.40, SD = 0.52) were significantly higher (more flexible) than those of armor system B (mean= 2.80, SD= 0.63). There were no significant differences between the control armor and armor systems A and C; and between armor systems A and C. The means and standard deviations for the flexibility scores are available in Table 20. Note that the flexibility score for armor system B is the lowest among the four systems.

Table 19
Pairwise Comparisons for Perceived Flexibility (q#3)

Armor Treatment	Armor Treatment	Mean Difference	Standard Error	P Value
Control	Armor A	0.00	0.26	1.00
Control	Armor B	0.90	0.23	0.00**
Control	Armor C	0.30	0.26	0.28
Armor A	Armor B	0.90	0.23	0.00**
Armor A	Armor C	0.30	0.30	0.34
Armor B	Armor C	-0.6	0.22	0.02*

Note. N=10.
*statistically significant at the .05 level ** statistically significant at the .01 level

Table 20
Means and Standard Deviations for Perceived Flexibility (q#3)

Control		Armor A		Armor B		Armor C	
Mean	SD	Mean	SD	Mean	SD	Mean	SD
3.70	0.48	3.70	0.82	2.80	0.63	3.40	0.52

Note. N=10.
Higher ratings indicate higher perceived flexibility.

4) Freedom of Movement

Research Question: Is there a significant difference by armor treatment for perceived freedom of movement?

A one-way repeated measures ANOVA was conducted with armor system treatment as the independent variable and the dependent variable being the freedom of movement scores (question # 4). Mauchly's test revealed that the assumption of Sphericity was not violated (chi-square = 6.08, $p > .05$).

There were statistically significant differences in perceived freedom of movement for the armor treatment, $F(3, 27) = 7.76$, $p < .05$. Post-hoc pairwise LSD comparisons (Table 21) found that freedom of movement scores for the control armor system (M = 3.90, SD = 0.74) and armor system A (M= 3.60, SD= 0.52) were significantly higher (greater freedom of movement) than those for armor system B (M = 2.70, SD= 0.48). However, there were no statistically significant differences between the control armor and armor system A, as well as between armor systems B and C (M = 3.20, SD = 0.63).

Table 21
Pairwise Comparisons for Perceived Freedom of Movement (q#4)

Armor Treatment	Armor Treatment	Mean Difference	Standard Error	P Value
Control	Armor A	0.30	0.26	0.28
Control	Armor B	1.20	0.20	0.00**
Control	Armor C	0.70	0.37	0.09
Armor A	Armor B	0.90	0.18	0.00**
Armor A	Armor C	0.40	0.27	0.17
Armor B	Armor C	-0.50	0.27	0.10

Note. N=10.
*statistically significant at the .05 level ** statistically significant at the .01 level.

The means and standard deviations for the freedom of movement scores are presented in Table 22. Armor system C received a higher mean rating compared with armor system B even though no statistically significant differences were found.

Table 22
Means and Standard Deviations for Perceived Freedom of Movement Scores (q#4)

Control		Armor A		Armor B		Armor C	
Mean	SD	Mean	SD	Mean	SD	Mean	SD
3.90	0.74	3.60	0.52	2.70	0.48	3.20	0.63

Note. N=10.
Higher ratings indicate higher perceived freedom of movement.

5) Ease of Movement

Research Question: Is there a significant difference by armor treatment for perceived ease of movement?

A one-way repeated measures ANOVA was conducted with armor system treatment as the independent variable and the dependent variable being the easy to move-in scores (question # 11). Mauchly's test found that the assumption of Sphericity was not violated (chi-square = 3,36, p > .05). There were statistically significant differences in 'ease of movement' for armor treatment, F (3, 27) = 13.94, p < .05.

Post-hoc pairwise LSD comparisons (Table 23) revealed that 'easy to move in' scores for the control armor system were significantly different than the scores for system; system A was significantly different from armor system B and B was significantly different from armor system C. Armor system B scores (mean= 2.80, SD= 0.63) were significantly lower (less easy to move in) than those for the control armor (mean = 3.80, SD = 0.63), armor system A (mean= 3.80, SD = 0.63), and armor system C (mean= 3.50, SD= 0.53). However, there were no statistically significant differences between other pairwise comparisons. The means and standard deviations for the easy to move in scores are given in Table 24, which shows that armor system B received the lowest scores. It is noteworthy that the control and armor systems A and B scores are so similar.

Table 23
Pairwise Comparisons for Perceived Ease of Movement (q#5)

Armor Treatment	Armor Treatment	Mean Difference	Standard Error	P Value
Control	Armor A	0.00	0.26	1.00
Control	Armor B	1.00	0.21	0.00**
Control	Armor C	0.30	0.21	0.19
Armor A	Armor B	1.00	0.26	0.00**
Armor A	Armor C	0.30	0.21	0.19
Armor B	Armor C	-0.70	0.21	0.01**

Note. N=10.
*statistically significant at the .05 level ** statistically significant at the .01 level

Table 24
Means and Standard Deviations for Perceived Ease of Movement (q#5)

Control		Armor A		Armor B		Armor C	
Mean	SD	Mean	SD	Mean	SD	Mean	SD
3.80	0.63	3.80	0.63	2.80	0.63	3.50	0.53

Note. N=10.
Higher ratings indicate higher perceived ease of movement.

6) Fit Satisfaction

Research Question: Is there a significant difference by armor treatment for perceived fit satisfaction?

A one-way repeated measures ANOVA was conducted with armor system treatments as the independent variable and the dependent variable being fit satisfaction (question # 6). Mauchly's test indicated that the assumption of Sphericity was not violated (chi-square = 7.35, $p > .05$).

There were no statistically significant differences in fit satisfaction for armor treatment, $F(3, 27) = 1.70$, $p > .05$. The means and standard deviations for fit satisfaction scores are presented in Table 25. Although not statistically significant, there was a trend for the control, and armor system A and C to achieve higher scores than armor system B.

Table 25
Means and Standard Deviations for Perceived Fit Satisfaction (q#6)

Control		Armor A		Armor B		Armor C	
Mean	SD	Mean	SD	Mean	SD	Mean	SD
4.00	0.94	3.70	0.82	3.20	0.63	3.40	0.84

Note. N=10.
Higher ratings indicate higher perceived fit satisfaction.

7) Preference

Research Question: Is there a significant difference by armor treatment for perceived preference of armor?

A one-way repeated measures ANOVA was conducted with armor system treatment as the independent variable and the dependent variable being preference scores (question # 7). Mauchly's test indicated that the assumption of Sphericity was violated (chi-square = 12.48, $p < .05$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of Spericity.

There were no statistically significant differences in perceived preference between the four levels of treatment, $F (2, 18) = 2.73$, $p > .05$. The means and standard deviations for the preference scores are shown in Table 26. Although not significant, there was a trend for the control, armor system A and C to achieve higher scores than armor system B.

Table 26
Means and Standard Deviations for Perceived Preference (q#7)

Control		Armor A		Armor B		Armor C	
Mean	SD	Mean	SD	Mean	SD	Mean	SD
4.10	0.99	3.80	0.79	3.20	0.92	3.40	0.52

Note. N=10
Higher ratings indicate higher perceived preference.

8) Tightness

Research Question: Is there a significant difference by armor treatment for perceived tightness of armor?

A one-way repeated measures ANOVA was conducted with the four levels of armor system treatment as the independent variable and the dependent variable being tightness scores (question # 8). Mauchly's test revealed that the assumption of Sphericity was not violated (chi-square = 4.32, $p > .05$).

There were statistically significant differences in perceived tightness between the four levels of treatment, $F(3, 27) = 2.74$, $p < .05$. Post-hoc pairwise LSD comparisons (Table 27) indicated that the perceived tightness scores for the control garment treatment (M = 3.40, SD = 0.84) were significantly different from armor system B (M= 2.60, SD= 0.70). There were no other statistical significant differences between any other pairwise comparisons.

Table 27
Pairwise Comparisons for Perceived Tightness (q#8)

Armor Treatment	Armor Treatment	Mean Difference	Standard Error	P Value
Control	Armor A	0.30	0.34	0.39
	Armor B	0.80	0.29	0.02*
	Armor C	0.40	0.27	0.17
Armor A	Armor B	0.50	0.27	0.10
	Armor C	0.10	0.18	0.10
Armor B	Armor C	-0.40	0.22	0.10

Note. N=10.
*statistically significant at the .05 level ** statistically significant at the .01 level.

The means and standard deviations for perceived tightness are available in Table 28. Since neither loose (=5) nor tight (=1) represented a positive response for this question, a '3' might be the most positive answer. This item was different from the previous seven items in the wearer acceptability ballot. There is also the possibility that an individual might prefer a certain degree of tightness or looseness, thus it is hard to definitively interpret these mean responses.

Table 28
Means and Standard Deviations for Perceived Tightness (q#8)

Control		Armor A		Armor B		Armor C	
Mean	SD	Mean	SD	Mean	SD	Mean	SD
3.40	0.84	3.10	2.60	2.60	0.70	3.00	0.67

Note. N=10.
The neutral rating (3) would indicate neither tight nor loose.

A summary table for wearer acceptability means by armor treatment and the statistics are presented in Table 29. In all eight perceptual items, no significant differences were found between the control and armor system A. No significant differences were found between the control and armor system C for four items out of eight items, and those are flexibility, freedom of movement, ease of movement, and tightness. The control garment treatment involved wearing the OTV vest over the BDU without adding any arm armor. Armor system A is an addition of soft arm armor to the control garment treatment. These results are important in that they suggest adding soft arm armor was not perceived significantly different then subjects' perceptions for wearing only the vest. For armor systems B and C, different types of hard plates were added as inserts. System B contained a conventional hard plate. System C contained the prototype hard plate. Both hard plates had the same length and width dimensions. The conventional plate used in system B weighed 1.15 kg (2.54 lbs), and the prototype plate in system C weighed 0.96 kg (2.11 lbs), thus the additional weight is similar. However, the curvature was quite different. These results suggest that curvature of a hard plate might play an important role in subjects' perceptions.

There was a trend for subjects wearing armor system B to report less comfort, less acceptability, less flexibility, less freedom of movement, less ease of movement, less fit satisfaction, and less preference compared with other armor systems. Subjects wearing armor system A reported more positive ratings compared to armor systems B and C in eight items. Subjects wearing armor system C reported more positive ratings than subjects wearing B in all eight items.

Table 29
Summary Table- Wearer Acceptability Means by Armor Treatment and LSD Results

	Control	A	B	C	LSD Results			
Comfort	4.0	3.7	3.0	3.3	Control	A	C	B
Acceptability	4.2	4.0	3.2	3.6	Control	A	C	B
Flexibility	3.7	3.7	2.8	3.4	Control	A	C	B
Freedom of Movement	3.9	3.6	2.7	3.2	Control	A	C	B
Ease of Movement	3.8	3.8	2.8	3.5	Control	A	C	B
Fit Satisfaction	4.0	3.7	3.2	3.4	Control	A	C	B
Preferences	4.1	3.8	3.2	3.4	Control	A	C	B
Tightness	3.4	3.1	2.6	3.0	Control	A	C	B
Mean	3.86	3.68	2.94	3.35				

Visual Armor Coverage

Research question: Are there significant differences in visual armor coverage by armor treatment and/or movement treatment?

An expert fit panel consisting in three professors in the department of Design, Housing, and Merchandising at Oklahoma State University rated body coverage by arm armor. This was done for specified body areas for five movements and for three armor arm systems.

Visual armor coverage at three armscye areas (front, underarm, and back) in each movement treatment for each arm armor treatment was visually examined and independently evaluated by three judges using a 7-point response scale ranging from 1 to

7 (1=Fully Uncovered to 7=Fully Covered). The three data points for each movement and each garment were averaged for statistical analysis.

A two-way repeated measures ANOVA was conducted with the two independent variables being three levels of armor system treatment (armor system A, armor system B, and armor system C) and five levels of movement treatment (flexion, extension, abduction, horizontal flexion, and horizontal extension). The dependent variable was mean visual armor coverage scores as measured by the three fit judges. The significance values of Mauchly's Test of Sphericity indicated that for the main effects of armor system treatment (Chi-square = 1.49, $p > .05$) and movement treatment (Chi-square = 8.55, $p > .05$), the assumption of Sphericity was not violated.

Results of a two-way repeated measures ANOVA (Table 30) shows that there were significant main effects for levels of armor system treatments, $F(2, 18) = 3.88$, $p < .05$, and levels of movement treatments, $F(4, 36) = 120.56$, $p < .05$. In addition, there was a significant interaction effect of armor by movement treatment, $F(6.27, 56.42) = 5.16$, $p < .05$.

Table 30
ANOVA Table for Visual Armor Coverage Scores by Armor and Movement Treatments

Source	SS	df	df_{error}	MS	F	P value
Armor Treatment	0.34	2	18	0.17	3.88	0.04*
Movement Treatment	171.99	4	36	43.00	120.56	.00**
Armor*Movement	2.92	6.27	56.42	0.47	5.16	.00**

Note. N=10.
*statistically significant at the .05 level ** statistically significant at the .01 level.

From Figure 39, it is apparent that the interaction effect is an 'ordinal' interaction. Thus it is considered reasonable to examine the effect of garment treatment at each level of movement. For flexion and abduction, armor system A showed less coverage than armor systems B and C, and armor system C showed slightly greater coverage than armor system B (Table 31and Figure 39). For extension and horizontal extension, armor system A showed the greatest coverage.

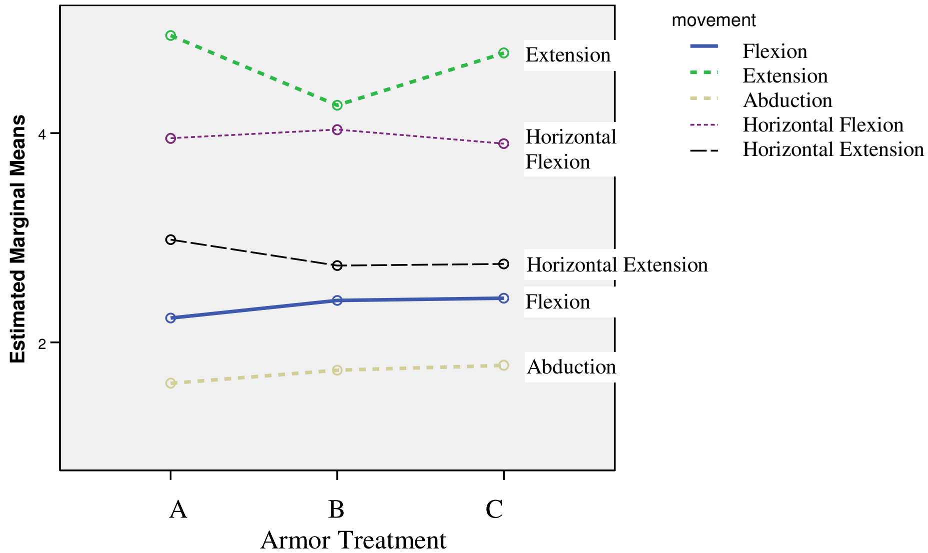


Figure 39. Estimated Marginal Means for Visual Armor Coverage

Table 31
Means and Standard Deviation for the Visual Armor Coverage Scores by Armor and Movement Treatments

	Armor A		Armor B		Armor C	
Movement	Mean	SD	Mean	SD	Mean	SD
Flexion	2.23	0.32	2.40	0.37	2.42	0.36
Extension	4.93	0.53	4.30	0.32	4.80	0.22
Abduction	1.61	0.23	1.73	0.44	1.78	0.23
H. Flexion	3.95	0.68	4.03	0.74	3.90	0.56
H. Extension	3.00	0.45	2.73	0.38	2.75	0.34

Note. N=3.
Higher ratings indicate higher visual coverage (1=Fully Uncovered, 7=Fully Covered).

Intraclass Reliability

To evaluate the reliability among the three independent judges' ratings for visual armor coverage, intraclass correlation coefficient (ICC) was analyzed using SPSS 16. The intraclass coefficient assesses the rating reliability by comparing the visual armor coverage of different ratings of the same subject to the total visual armor coverage across all ratings and all subjects. The particular model and definition of agreement selected was a two-way mixed model and absolute agreement among raters. The two-way mixed model indicates that all judges rated all targets (which is random sample) and absolute agreement compares both the consistency between trials and the agreement between ratings. For absolute agreement, if the numbers differ in value, they are considered as disagreement. This is a mixed model since the judges are a fixed effect and the targets are a random effect.

The ICC results for visual armor coverage by armor system and movements is given in Table 32. Judges were not asked to rate horizontal flexion in the front areas due to too much missing data in the body scan images. The underarm area showed the highest level of agreement among the raters having eight items out of fifteen items rated higher than 0.5 (Table 32).

Table 32
Intraclass Correlation Coefficient Results for Visual Armor Coverage by Armor and Movement Treatments

	Armor A			Armor B			Armor C		
	Front	U.Arm	Back	Front	U.Arm	Back	Front	U.Arm	Back
Flexion	**0.71**	0.47	0.33	0.20	0.46	0.30	**0.63**	-0.22	0.35
Extension	0.43	**0.52**	**0.55**	0.42	0.35	**0.63**	0.22	**0.54**	-0.23
Abduction	0.46	**0. 74**	0.38	**0.62**	0.45	0.48	0.40	**0.65**	0.33
H. Flexion	.	**0.66**	0.31	.	**0.77**	0.31	.	**0.51**	0.42
H. Extension	0.45	**0.52**	**0.76**	0.27	0.28	0.47	**0.68**	-0.12	0.35

Note. N=3.
Dots indicate value could not be calculated due to missing images (horizontal flexion)
The visual armor coverage ratings that acquired a correlation coefficient above 0.5 are marked in bold type.

Summary and Discussion

Table 33 presents a summary of significant differences determined for armor systems and movement by the five dependent variables.

Table 33
LSD Summary Plot for Armor Systems

	LSD Results			
Localized.Pressure				
Area1	No significant ANOVA result			
Area 2				
ROM	Significant Interaction Effect			
Perceived Garment Impediment				
General Movement Limitation	Control	A	C	B
Wearer Acceptability				
1 Comfort	Control	A	C	B
2 Acceptability	Control	A	C	B
3 Flexibility	Control	A	C	B
4 Freedom of Movement	Control	A	C	B
5 Ease of Movement	Control	A	C	B
6 Fit Satisfaction	Control	A	C	B
7 Preference	Control	A	C	B
8 Tightness	Control	A	C	B
Visual Armor Coverage	Significant Interaction Effect			

For localized pressure, there were no significant main effects for armor system nor for movement in areas 1 and 2. In addition, there was no interaction effect at both areas.

High standard deviations were recognized at both area 1 and 2. Subject 2 performing extension and horizontal flexion while wearing armor system B for area 1 and subject 4 performing extension while wearing armor system B for area 2 showed larger localized pressure. Understanding the reason for these results needs further investigation.

The potential source of the large standard deviations could be due to differences in arm shapes or dimensions, location of the hard plates or methodological issue. There could be an instrumentation issue. Since only two sensors with a small sensing area (9.55 mm diameter) were used for this study it would be difficult to represent the effect from the whole hard plate.

In analyzing ROM, significant main and interaction effects were found. ROM is the only dependent variable, that showed remarkable differences between control and arm armor system A. All arm armor treatments negatively affected ROM for all movements. For all five movements, armor system B showed the smallest mean ROM and therefore tended to impede movement to a greater degree than the control and other armor systems. In general, there was a trend for ROM to decrease from wearing the control armor to armor system A to armor system C to armor system B for all five movements.

For *perceived general movement limitati*on, significant differences were found for the control vs. armor system B, armor system A vs. B, and armor system A vs. C. There were no significant differences for control armor vs. armor system A, and control vs. armor system C. This result is very important as well, because it indicates that the subjects did not perceive the significant differences in terms of movement limitation after adding soft arm armor and inserting a prototype hard plate. In addition, there was trend for general movement limitation rating to increase from the wearing the control armor to armor system A to armor system C to armor system B. The reader's attention is directed to a comparison between the ROM and the general movement limitation under perceived garment limitation.

Wearer acceptability data represent important results. For all eight perceptual items, no significant differences were found between the control and armor system A. These results indicate that adding soft arm armor was not significantly different from wearing only the vest in perceptual responses. No significant differences were found between control and armor system C for four items out of eight. There was a trend for subjects wearing system B to report less acceptability ratings in all of eight items. There was a trend for wearer acceptability to decrease from wearing the control armor to armor system A to armor system C to armor system B.

In addition, the frequency analysis of the reported areas of impediment and types of impediment exerted on the areas revealed that 73% of the complaints occurred for only several areas namely, side neck, front and back armscye, and shoulder top. These area directly relate to wearing the OTV over BDU. Under arm front was mentioned more frequently by subjects while wearing armor system B. When wearing systems B and C, perception of heaviness was mentioned more frequently, which is reasonable since systems B and C contained hard plates. Armor system B was reported as heavy six times more often than arm system C, and system B was 0.43 lbs heavier. Tight was mentioned more frequently by subjects wearing armor system C than wearing armor system B.

For *visual armor coverage*, significant main effect and significant interaction effects were found. Mean differences were apparent between armor system A and armor system B with armor system A providing more coverage except for flexion. Possibly, the hard armor helped maintain the arm guard shape, or prevented the soft armor from falling.

CHAPTER V: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

Arm armor can play an important role in reducing injuries that soldiers sustain in theater. However, the bulk and stiffness of arm armor can hinder the movement of the wearer. Enveloping the arms in armor is particularly difficult due to arm contour and the elbow and shoulder joints.

A collaborative research project that included Oklahoma State University, FSTechnology, and the Naval and Army Research Laboratories, was conducted for the development of a soft limb armor system called QuadGard™. Almost 6,000 units (Phases IV and V) are being used by the U.S. Marine Corps in theater since 2005. The purpose of the present research was to examine both performance and perceptual responses of subjects wearing Phase V QuadGard ™ arm and shoulder components only. The Phase V arm unit provided an upper arm pocket to hold hard armor should that required. The four armor treatments included a control (vest only), armor system A (vest plus QuadGard ™ with soft armor), armor system B (system A plus a conventional hard plate) and, armor system C (system A plus a prototype hard plate). The two hard plates differed slightly in weight (2.54 lbs and 2.11 lbs respectively) with approximately the same dimensions. The major difference between the two plates was greater curvature in the prototype plate. The dependent variables were localized pressure, ROM, perceived garment impediment, wearer acceptability, and visual armor coverage.

In total, ten male voluntary subjects who wore size medium BDU, in age from 19 to 30 participated in this study. They all had either previous military experience or currently serve as ROTC cadets at Oklahoma State University. The subjects were instrumented with localized sensors and performed five selected shoulder and arm movements in a 3D body scanner chamber while wearing each of the armor treatments.

The specific objectives of this study were to 1) develop a protocol and/or instruments to assess selected human performance and perceptual responses associated with wearing different shoulder and arm armor systems, 2) to evaluate the selected human performance and perceptual responses including localized pressure, ROM, perceived garment impediment, wearer acceptability, and armor coverage.

Localized pressure was measured with two pressure sensors and a telemetry system, ROM was measured using the scan images acquired from the 3D body scanner, visual armor coverage was determined by fit judges looking at the 3D scan images. Perceived garment impediment and wearer acceptability of armor data were evaluated by wearers during the experimental procedure using ballots.

Descriptive statistics, two-way repeated measures ANOVA and one-way repeated measures ANOVA were used to evaluate the effects of armor system treatments and movement treatments on the five dependent variables.

Protocol Development

The experimental test procedure included a pre-test and the actual test in order to gather data for five dependent variables using different instrumentation. Data for several dependent variables was gathered simultaneously in order to reduce the subjects' fatigue. The pre-test was designed to serve educational purpose to introduce subjects to the complicated test protocol before initiating data collection. The entire test procedure ran smoothly taking only approximately one and half hours per subject. The data suggest that the approach was beneficial, so that both qualitative and quantitative data resulted from the multiple aspects of the study.

Discussion of Results

Localized Pressure

A two-way repeated measures ANOVA revealed that there were no significant interaction effect and main effects for armor nor for movement in areas 1 and 2. Examination of the means and standard deviations for both areas 1 and 2 showed a similar trend with subjects wearing armor system B to experience larger localized pressure readings compared with subjects wearing the others two armor systems. Specifically, armor system B showed larger localized pressure for most movements at both areas. High standard deviations were recognized at both areas 1 and 2. Two subjects for two movements, while wearing armor system B exhibited a larger localized pressure than other subjects. Arm circumferences did not appear to be the potential source of these data. Perhaps, arm shape or dislocation of the hard plates while performing several movements or instrumentation might explain this finding. Localized pressure for area 2 showed larger means than the area means, suggesting that more pressure maybe exerted by the arm treatments on the lower area of the upper arm.

This study found several critical issues and problems for measuring localized pressure for arm armor in terms of methodological perspective. Since mechanism of the pressure sensor is to measure and calculate the pressure on the whole sensing area it could be a problem when the force is partially exerted on the certain area of the sensors. Contact area changes caused from dynamic movement also could be a source of large variation. Specific protocol would help to resolve these issues. There was one more valuable finding during pilot study when decide the body areas to attach the sensors. Since the pressure sensors required physical contact between the backside of the arm armor and subjects' skin it was difficult to find small spot of areas that consistently maintain contact between skin and armor for every subject in movement while wearing different armor treatments. This findings and observations would be used as a valuable experience for this specific study deals with dynamic pressure on human body dimensions.

ROM

A two-way repeated measures ANOVA revealed that there were statistically significant main effects for armor, and movement treatment, as well as for the interaction effect.

Basicically, ROM decreased with the addition of soft arm armor, and further decreased when hard plates were added. In general, there was trend for ROM to decrease from the wearing control armor to armor system A to armor system C to armor system B.

Perceived Garment Impediment

Frequency analysis showed that subjects perceived impediments and/or discomfort at many upper body areas while wearing armor and performing movements. The side neck area, armscye front area, and shoulder top area together represented 73% of the complaints. Under arm front was mentioned very frequently by subjects wearing armor system B as problematic. When wearing systems B and C, perception of heaviness was mentioned by subjects more frequently than for armor A, which is reasonable since systems B and C included hard plates. Armor system B was reported as heavy six times more often than system C, and system B weighed 0.43 lbs more than system C. Tight was mentioned more frequently for armor system C than armor system B.

The second part of the perceived garment impediment ballot asked subjects to respond using a 5-point scale giving their overall perception of movement limitation after completing each movement while wearing each armor treatment. A two-way repeated measures ANOVA revealed that there were statistically significant main effects for both armor system and movement treatments, and no significant interaction effect. Post-hoc LSD test of armor treatment found significant differences for control vs. armor system B, armor system A vs. B, and armor system A and C. P value for armor system B vs. armor system C was close to 0.05 significance level that was accepted for this study. A significant difference possibly could be found with a larger sample size. There were no significant differences for control armor vs. armor system A, and control vs. armor system C. This result is noteworthy, because it indicates that the subjects did not perceive significant differences in terms of movement limitation after adding soft arm armor and inserting a curved prototype hard plate.

Examination of mean showed that control garment treatment was rated highly in horizontal flexion and horizontal extension, and it seems to be caused from the presentation order of armor treatment during the experimental procedure. However, there was a trend for general movement limitation rating to increase form the wearing control armor to armor system A to armor system C to armor system B.

Wearer Acceptability

A one way repeated measures ANOVA was used to analyze eight sub items in the wearer acceptability ballot. No significant differences were found between the control and armor system A for all eight perceptual items. This suggests that adding soft arm armor was not perceived by the subjects significantly different from wearing only the OTV. In addition, no significant differences were found between the control and armor system C for four items out of eight. This result is surprising given that system C contained a hard plate. There was a trend for subjects wearing system B which also contained a hard plate to report the lowest acceptability ratings in all eight items. These results suggest that curvature of the hard plate, which was the primary difference in the two hard plates, may have positively influenced the perceived wearer acceptability.

Visual Armor Coverage

A two-way repeated measures ANOVA revealed that there were significant main effects for levels of armor system treatment, and levels of movement treatment. In addition, there was a significant interaction effect of the armor by movement treatments.

The graph for estimated marginal means of visual armor coverage (Figure 39) shows the interaction effect. The estimated marginal means did not show parallel trends. Especially, horizontal flexion while wearing armor system B showed higher point (higher means) compared than armor system A and C. A possible source for interaction effect were recognized during experimental test. As the subject moved their shoulder and arm further, the openness of the under and side armscye areas could be larger, and this could reduce the visual armor coverage in those areas.

To increase intrass class reliability, several methods could be used. More intensive training session for faculty could increase the agreement among judges. In addition, the items that showed serious disagreement among three fit juges could be re evaluated. Three fit judges could sit together and see the problematic items and discuss to share ideas if they used identical assessment criteria.

Implications

Overall, the results from five dependent variables were quite consistent among others. In general, there was a trend for control garment treatment (when it is applied as a level of armor treatment) presented the most positive ranking among other armor treatments in all five dependent variables including localized pressure, ROM, perceived garment impediment, wearer acceptability, and visual armor coverage.

Although localized pressure is thought to be an important factor in soldier endurance and performance, measurement issues need further exploration and empirical investigation to establish meaningful protocols for their application in design perspectives. Methodology to determine ROM for this study proved workable and reliable. Methodology could be expanded to include movement germane to military action involving arm shoulder or other areas of the body. The perceived garment impediment ballot was developed for this study based on type of discomfort ballot (Adams and Keyserling, 1996). The ballot was found to be instrumented in pinpointing areas of discomfort and type of discomfort. However, it did not address severity of discomfort, which should be considered. In practical sense, separating discomfort experienced only for arm armor was not possible. Yet there appeared to be a most of number of impediment in armor directly attributable to arm armor.

The perceived garment impediment ballot also provides summary on perceived movement/ impediment limitation. Implication of the finding of no significant differences between control (OTV) and armor system A (soft arm armor) suggests that soldier did not perceive movement limitation with the addition of soft arm armor. In contract, curved arm armor was perceived to impede movement less than a conventional plate.

Limitations

1. The study was limited to a moderate number of volunteer military personnel living in the midwestern part of the United States in the spring of 2008. Military or ROTC personnel with an interest in the project goals and a willingness to participate in the study, were not chosen by a random sampling method.
2. Only two localized pressure sensors were used for this study. Having more sensors covering wider of the upper arm could provide additional data with less variation.
3. One of the task requirements that should receive special consideration is task duration. Performance effects after an extended time of use were not evaluated in this study.
4. This test was repeated one time by each subject. Multiple repetitions would be recommended to increase the reliability.

Suggestions for Future Research

1. Since this study was designed to evaluate wearers' performance and perceptual responses focusing on physical movement, the physiological aspect of human performance could be investigated in a future study. In addition, a field study using soldiers wearing armors while completing typical work activities could be conducted in the future.
2. This study was conducted to evaluate arm armor. Extended studies to investigate the performance and perceptual response data for armor for other body areas such as neck, torso, and lower limbs.

3. Investigation of the relationship between arm dimensions including arm shape and the range of motion could be a focus in a future study. Although subject size was controlled by requiring all subjects wearing size medium BDU, the size and shape of subjects' arms needs further examination.

4. The results of this study suggest that there is merit in 'shaping' hard plates to better conform to the body. A follow-up study could be done to investigate shaping of rigid plates to improve performance perceptual responses.

5. A study could be designed to determine the ballistic protection capability of the arm armor.

6. A similar investigation with a larger, more heterogeneous, subject population could be conducted.

7. A further study can be conducted to more fully investigate the pressure profile that armor represents using multiple sensors.

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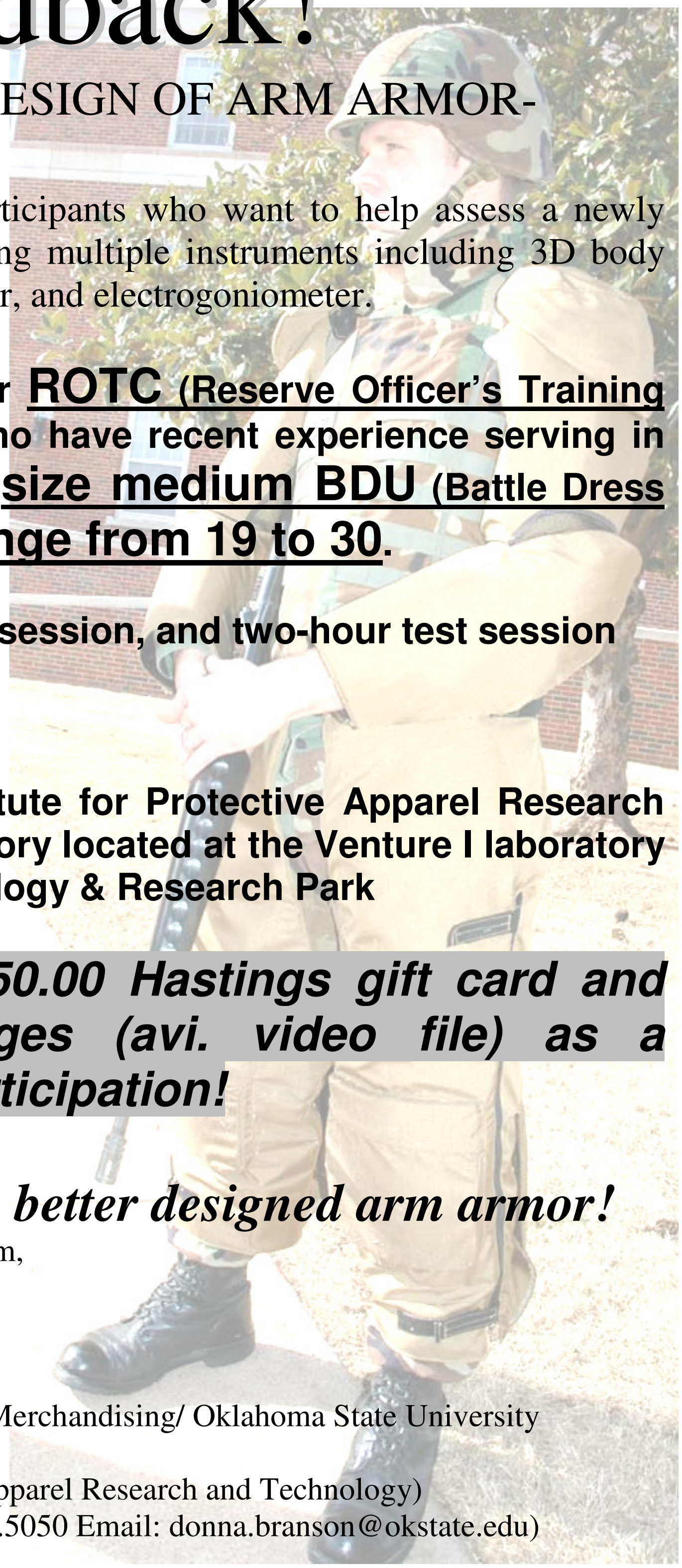
APPENDICES

APPENDIX A

ADVERTISEMENT FLYE

"Need Your Feedback!"

-To assess NEW DESIGN OF ARM ARMOR-



We are recruiting volunteer participants who want to help assess a newly designed arm armor system using multiple instruments including 3D body scanner, localized pressure sensor, and electrogoniometer.

- **Who: We are looking for ROTC (Reserve Officer's Training Corps) or individuals who have recent experience serving in the military who wear a size medium BDU (Battle Dress Uniform) and in age range from 19 to 30.**
- **What: One hour pre-test session, and two-hour test session**
- **When: April to May, 2008**
- **Where: the IPART (Institute for Protective Apparel Research and Technology) laboratory located at the Venture I laboratory in the Oklahoma Technology & Research Park**

We are offering a $50.00 Hastings gift card and your 3D scan images (avi. video file) as a compensation for participation!

Please help us make better designed arm armor!

If interested, please contact Jinhee Nam,
at **405.762.6346** or
email jinhee.nam@okstate.edu

Department of Design, Housing, and Merchandising/ Oklahoma State University

IPART (The Institute for Protective Apparel Research and Technology)
Director, Dr.Branson (Phone: 405.744.5050 Email: donna.branson@okstate.edu)

APPENDIX B

INFORMED CONSENT AND ORIENTATION STATEMENT

- **Project Title:** Armors: Fit Analysis and Performance Factors.
- **Investigators:**
  PI: Jinhee Nam, MS.
  Co-Advisor: Semra Peksoz, PhD.
  Advisor: Donna Branson, PhD.

- **Purpose:** The purpose of this study is to compare performance effects of wearing three different armor systems versus no-armor. We will assess your performance in terms of localized pressure, range of motion (ROM), perceived garment impediment, and wearer acceptability. In addition, the 3D body scanner will be used to acquire your body measurements and to evaluate armor coverage around the upper arm. This information will be used to improve the fit and performance of these armor systems.

- **Procedures**: This study will be conducted in two sessions: 1) a one-hour 'Pre-test procedure', and 2) a two-hour 'Test procedure'. Both 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. Pre-test will be conducted to establish the baseline, familiarize subjects with discomfort associated with each treatment, and provide training for movement, positioning, and warm-up exercise protocols. Consent form and basic demographic features will be obtained at the pre-test session.

  You will wear BDU pants and you will be scanned using the 3D body scanner to acquire your basic body measurements. The range of motion sensors will be placed on the arm and shoulder back. After donning the BDU and OTV as the control, you will perform five selected shoulder movements to measure range of motion and perceived garment impediment. You will be asked to provide your perceptions of impediment/discomfort at each body area after completing each body movement. The researcher will record your answers using the perceived garment impediment ballot.

  Then you will move to the 3D body scanner chamber, and pose in three selected positions. The scanning process, which will take 12 seconds, is a safe and reliable method of measuring the human body.

  After the body measurements are taken, you will don each of the armor system treatments and complete movement and position protocols as described. The full process test procedure will take maximum 2 hours. The procedure will be immediately stopped when you tell dizziness or considerable amount of fatigue. Scan images will be used for armor coverage evaluation by the expert panel.

- **Risks of Participation:** There are no known risks associated with this project which are greater than those ordinarily encountered in daily life.

- **Benefits:** This study has the potential to be used as feedback for improving armor system design. We need your input.
- **Confidentiality:** Any information obtained in this test that can identify you will remain

confidential. In any written reports or publications, no individual will be identified or identifiable. The face in the scan images will be obscured so the subject will not be identifiable. Body scan images will be saved to a dedicated computer and the files will be password protected. The data will be accessible to the researcher and co-advisors.

- **Compensation:** A fifty dollar gift card for use at multimedia entertainment retailer will be presented to you upon completion of participation in this study. Your scanned image file will be transformed to a 3D animated avi. file which you can view using Window Media Player. This will be given to you as a bonus.

- **Contacts:** If you have any questions about the research please call:
  Dr.Donna Branson at (405) 744.5050, e-mail to donna.branson@okstate.edu
  Dr.Semra Peksoz at 405.744.9520, e-mail to semra.peksoz@okstate.edu
  Jinhee Nam at (405) 762.6346, e-mail to nam_jh@yahoo.com
  If you have questions about your rights as a research volunteer, you may contact Dr. Sue C. Jacobs, IRB Chair, 219 Cordell North, Stillwater, OK 74078, 405-744-1676 or irb@okstate.edu.

- **Participant Rights:** Your decision whether or not to participate in this study will not affect your future relationships with Oklahoma State University or the Department of Design, Housing and Merchandising in any way. If you decide to participate in this study please contact:

Jinhee Nam at (405) 762.6346, email to nam_jh@yahoo.com

APPENDIX C

OSU INSTITUTION REVIEW BOARD (IRB)

Oklahoma State University Institutional Review Board

Date:	Tuesday, April 08, 2008
IRB Application No	HE089
Proposal Title:	Deltoid Armor Systems: Fit Analysis and Performance Factors
Reviewed and Processed as:	Expedited

Status Recommended by Reviewer(s): Approved   Protocol Expires: 4/7/2009

Principal Investigator(s):

Jinhee Nam	Donna Branson	Semra Peksoz
431 HES	211 HES	444 HES
Stillwater, OK 74078	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 Kennison, Chair
Institutional Review Board

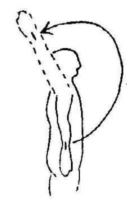
APPENDIX D

PERCEIVED GARMENT IMPEDIMENT BALLOT

Perceived Garment Impediment Ballot

Set: ____ Subject: _____ Arm Armor System Type: _______

Movement 1) Shoulder flexion



Shoulder Flexion

1. Refer to the body areas diagram (Figure 20) attached to the wall. Were these any areas of the body regions of the body that created discomfort or restriction during performing each movement you experienced discomfort or movement restriction?

1) N_F: Neck Front
2) N_B: Neck Back
3) N_S: Neck Side
4) S_T: Shoulder Top
5) S_U: Shoulder Upper Arm
6) A_F: Armscye Front
7) A_B: Armscye Back
8) A_{UF}: Armscye Under Front
9) A_{UB}: Armscye Under Back
10) UA: Upper Arm
11) UA_F: Under Arm Front
12) UA_B: Under Arm Back
13) IUA: Inner Under Arm
14) IE: Inner Elbow
15) OE: Outer Elbow

2. Explain the type of discomfort and restriction in experienced in each region.

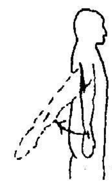
1) Resistance to movement
2) Heavy
3) Rubbing, friction
4) Tight
5) Loose
6) Localized pressure
7) Other (Describe briefly off to the side)

1) Region	2) Discomfort/ restriction type
______	________________________
______	________________________
______	________________________
______	________________________
______	________________________

3. In general, how much did garment treatment that you are wearing today affect your ability to perform shoulder flexion?

No effect	Barely effect	Slighted limited movement	Limited movement	Severely limited movement
1	2	3	4	5

Movement 2) Shoulder extension



Shoulder Extension

1. Refer to the body areas diagram (Figure 20) attached to the wall. Were these any areas of the body regions of the body that created discomfort or restriction during performing each movement you experienced discomfort or movement restriction?

1) N_F: Neck Front
2) N_B: Neck Back
3) N_S: Neck Side
4) S_T: Shoulder Top
5) S_U: Shoulder Upper Arm
6) A_F: Armscye Front
7) A_B: Armscye Back
8) A_{UF}: Armscye Under Front
9) A_{UB}: Armscye Under Back
10) UA: Upper Arm
11) UA_F: Under Arm Front
12) UA_B: Under Arm Back
13) IUA: Inner Under Arm
14) IE: Inner Elbow
15) OE: Outer Elbow

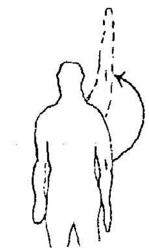
2. Explain the type of discomfort and restriction in experienced in each region.
1) Resistance to movement
2) Heavy
3) Rubbing, friction
4) Tight
5) Loose
6) Localized pressure
7) Other (Describe briefly off to the side)

1) Region	2) Discomfort/ restriction type
______	________________________
______	________________________
______	________________________
______	________________________
______	________________________

3. In general, how much did garment treatment that you are wearing today affect your ability to perform shoulder flexion?

No effect	Barely effect	Slighted limited movement	Limited movement	Severely limited movement
1	2	3	4	5

Movement 3) Shoulder abduction



Shoulder Abduction

1. Refer to the body areas diagram (Figure 20) attached to the wall. Were these any areas of the body regions of the body that created discomfort or restriction during performing each movement you experienced discomfort or movement restriction?

1) N_F: Neck Front
2) N_B: Neck Back
3) N_S: Neck Side
4) S_T: Shoulder Top
5) S_U: Shoulder Upper Arm
6) A_F: Armscye Front
7) A_B: Armscye Back
8) A_{UF}: Armscye Under Front
9) A_{UB}: Armscye Under Back
10) UA: Upper Arm
11) UA_F: Under Arm Front
12) UA_B: Under Arm Back
13) IUA: Inner Under Arm
14) IE: Inner Elbow
15) OE: Outer Elbow

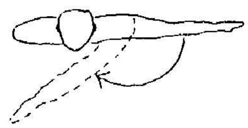
2. Explain the type of discomfort and restriction in experienced in each region.
1) Resistance to movement
2) Heavy
3) Rubbing, friction
4) Tight
5) Loose
6) Localized pressure
7) Other (Describe briefly off to the side)

1) Region	2) Discomfort/ restriction type
______	________________________
______	________________________
______	________________________
______	________________________
______	________________________

3. In general, how much did garment treatment that you are wearing today affect your ability to perform shoulder flexion?

No effect	Barely effect	Slighted limited movement	Limited movement	Severely limited movement
1	2	3	4	5

Movement 4) Shoulder horizontal flexion



Shoulder Horizontal Flexion

1. Refer to the body areas diagram (Figure 20) attached to the wall. Were these any areas of the body regions of the body that created discomfort or restriction during performing each movement you experienced discomfort or movement restriction?

1) N_F: Neck Front
2) N_B: Neck Back
3) N_S: Neck Side
4) S_T: Shoulder Top
5) S_U: Shoulder Upper Arm
6) A_F: Armscye Front
7) A_B: Armscye Back
8) A_{UF}: Armscye Under Front
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10) UA: Upper Arm
11) UA_F: Under Arm Front
12) UA_B: Under Arm Back
13) IUA: Inner Under Arm
14) IE: Inner Elbow
15) OE: Outer Elbow

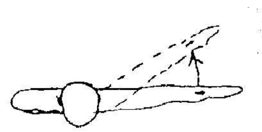
2. Explain the type of discomfort and restriction in experienced in each region.
1) Resistance to movement
2) Heavy
3) Rubbing, friction
4) Tight
5) Loose
6) Localized pressure
7) Other (Describe briefly off to the side)

1) Region	2) Discomfort/ restriction type
_______	_________________________
_______	_________________________
_______	_________________________
_______	_________________________
_______	_________________________

3. In general, how much did garment treatment that you are wearing today affect your ability to perform shoulder flexion?

No effect	Barely effect	Slighted limited movement	Limited movement	Severely limited movement
1	2	3	4	5

Movement: 5) Shoulder horizontal extension



Shoulder Horizontal Extension

1. Refer to the body areas diagram (Figure 20) attached to the wall. Were these any areas of the body regions of the body that created discomfort or restriction during performing each movement you experienced discomfort or movement restriction?

1) N_F: Neck Front
2) N_B: Neck Back
3) N_S: Neck Side
4) S_T: Shoulder Top
5) S_U: Shoulder Upper Arm
6) A_F: Armscye Front
7) A_B: Armscye Back
8) A_{UF}: Armscye Under Front
9) A_{UB}: Armscye Under Back
10) UA: Upper Arm
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12) UA_B: Under Arm Back
13) IUA: Inner Under Arm
14) IE: Inner Elbow
15) OE: Outer Elbow

2. Explain the type of discomfort and restriction in experienced in each region.
1) Resistance to movement
2) Heavy
3) Rubbing, friction
4) Tight
5) Loose
6) Localized pressure
7) Other (Describe briefly off to the side)

1) Region	2) Discomfort/ restriction type
_______	_________________________
_______	_________________________
_______	_________________________
_______	_________________________
_______	_________________________

3. In general, how much did garment treatment that you are wearing today affect your ability to perform shoulder flexion?

No effect	Barely effect	Slighted limited movement	Limited movement	Severely limited movement
1	2	3	4	5

APPEDIX E

WEARER ACCEPTABILITY BALLOT

Detoid Armor System Type: _______

For each adjective pair, circle the number that best describes how you feel.

1	Comfortable	5	4	3	2	1	Uncomfortable
2	Acceptable	5	4	3	2	1	Unacceptable

For each adjective pair, circle the number that best describes how you feel.

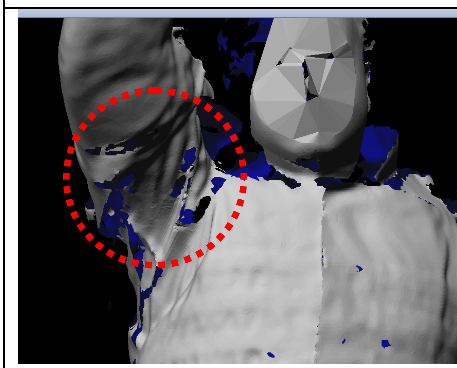
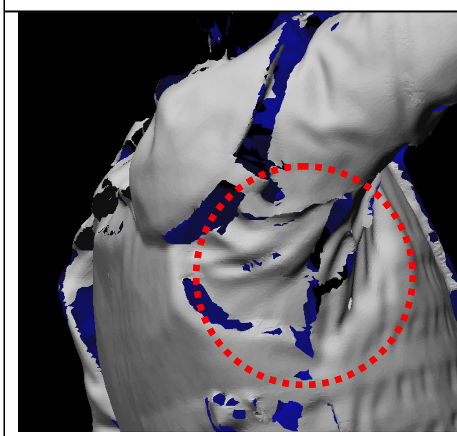
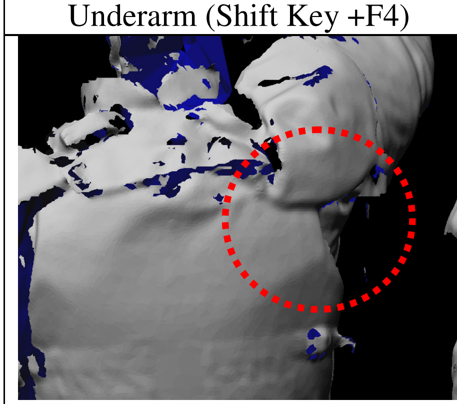
3	Flexible	5	4	3	2	1	Stiff
4	Freedom of Movement of arms	5	4	3	2	1	Restricted movement of arms
5	Easy to move in	5	4	3	2	1	Hard to move in
6	Satisfactory fit	5	4	3	2	1	Unsatisfactory fit
7	Like	5	4	3	2	1	Dislike
8	Loose	5	4	3	2	1	Tight

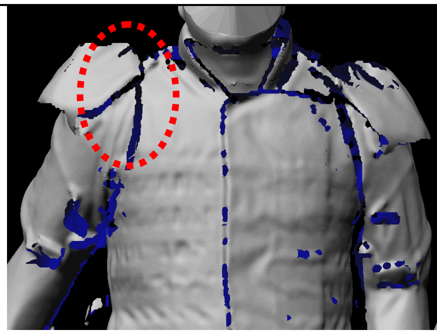
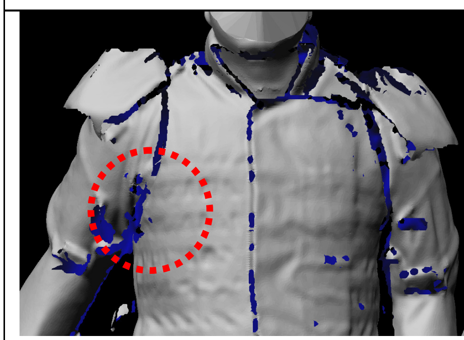
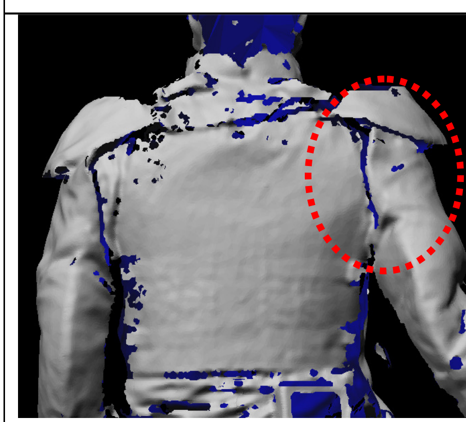
APPENDIX F

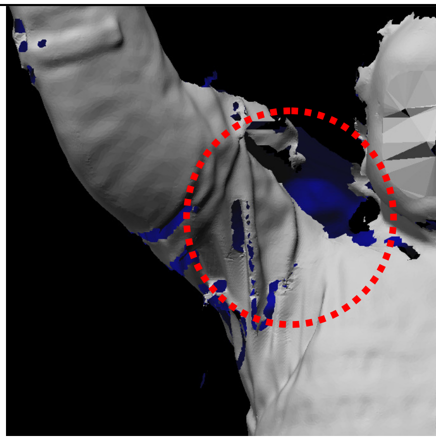
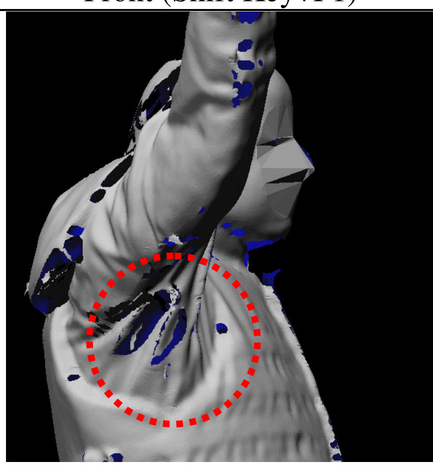
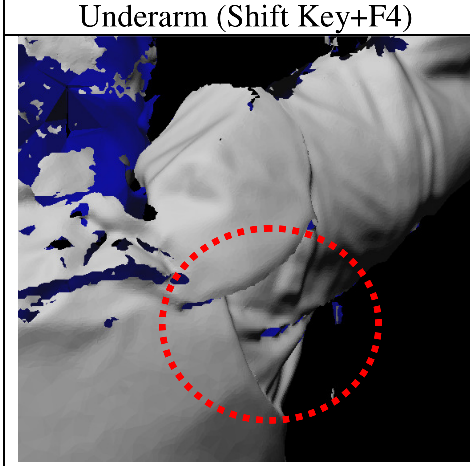
VISUAL ARMOR COVERAGE EVALUATION

Name:________________________ Date:________________________

Examine presented scan images of subject in each prototype at the circled locations. Rate the level of protection at armscye areas looking at the 3D scan images. Respond by circling the number on the 7 point scale as to coverage for each location on the attached form.

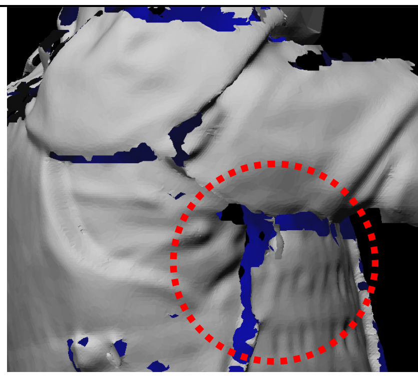
SUBJECT NO.	POSITION: Shoulder Flexion (No.1)	
		Fully Uncovered Fully Covered
 Front (Shift Key+F1)	Arm Armor System **A** (No hole)	1 2 3 4 5 6 7
	Arm Armor System **B** (1 hole)	1 2 3 4 5 6 7
	Arm Armor System **C** (2 holes)	1 2 3 4 5 6 7
	Comment:	
 Underarm (Shift Key +F4)	Arm Armor System **A** (No hole)	1 2 3 4 5 6 7
	Arm Armor System **B** (1 hole)	1 2 3 4 5 6 7
	Arm Armor System **C** (2 holes)	1 2 3 4 5 6 7
	Comment:	
 Back (Shift Key+F2)	Arm Armor System **A** (No hole)	1 2 3 4 5 6 7
	Arm Armor System **B** (1 hole)	1 2 3 4 5 6 7
	Arm Armor System **C** (2 holes)	1 2 3 4 5 6 7
	Comment:	

<table>
<tr><td colspan="3">SUBJECT NO. POSITION: Shoulder Extension (2)</td></tr>
<tr><td></td><td></td><td>Fully Uncovered Fully Covered</td></tr>
<tr><td rowspan="4">
Front (Shift Key+F1)</td><td>Arm Armor System A
(No hole)</td><td>1 2 3 4 5 6 7</td></tr>
<tr><td>Arm Armor System B
(1 hole)</td><td>1 2 3 4 5 6 7</td></tr>
<tr><td>Arm Armor System C
(2 holes)</td><td>1 2 3 4 5 6 7</td></tr>
<tr><td colspan="2">Comment:</td></tr>
<tr><td rowspan="4">
Underarm (Shift Key+F4)</td><td>Arm Armor System A
(No hole)</td><td>1 2 3 4 5 6 7</td></tr>
<tr><td>Arm Armor System B
(1 hole)</td><td>1 2 3 4 5 6 7</td></tr>
<tr><td>Arm Armor System C
(2 holes)</td><td>1 2 3 4 5 6 7</td></tr>
<tr><td colspan="2">Comment:</td></tr>
<tr><td rowspan="4">
Back (Shift Key+F2)</td><td>Arm Armor System A
(No hole)</td><td>1 2 3 4 5 6 7</td></tr>
<tr><td>Arm Armor System B
(1 hole)</td><td>1 2 3 4 5 6 7</td></tr>
<tr><td>Arm Armor System C
(2 holes)</td><td>1 2 3 4 5 6 7</td></tr>
<tr><td colspan="2">Comment:</td></tr>
</table>

<table>
<tr><td colspan="2">SUBJECT NO. POSITION: Shoulder Abduction (3)</td><td colspan="7"></td></tr>
<tr><td colspan="2"></td><td colspan="7">Fully Uncovered Fully Covered</td></tr>
<tr><td rowspan="4">
Front (Shift Key+F1)</td><td>Arm Armor System A
(No hole)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td>Arm Armor System B
(1 hole)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td>Arm Armor System C
(2 holes)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td colspan="8">Comment:</td></tr>
<tr><td rowspan="4">
Underarm (Shift Key+F4)</td><td>Arm Armor System A
(No hole)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td>Arm Armor System B
(1 hole)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td>Arm Armor System C
(2 holes)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td colspan="8">Comment:</td></tr>
<tr><td rowspan="4">
Back (Shift Key+F2)</td><td>Arm Armor System A
(No hole)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td>Arm Armor System B
(1 hole)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td>Arm Armor System C
(2 holes)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td colspan="8">Comment:</td></tr>
</table>

SUBJECT NO.	POSITION: Shoulder Horizontal Flexion (4)
	Fully Uncovered Fully Covered

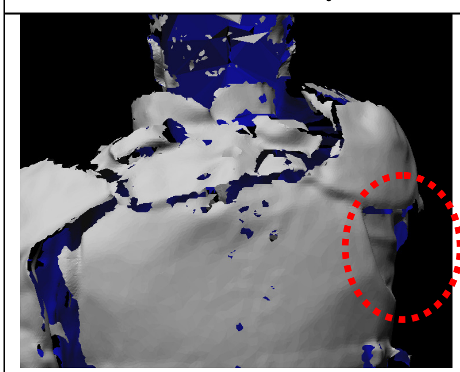
No Front



Underarm (Shift Key+F4)

Arm Armor System **A** (No hole)	1	2	3	4	5	6	7
Arm Armor System **B** (1 hole)	1	2	3	4	5	6	7
Arm Armor System **C** (2 holes)	1	2	3	4	5	6	7

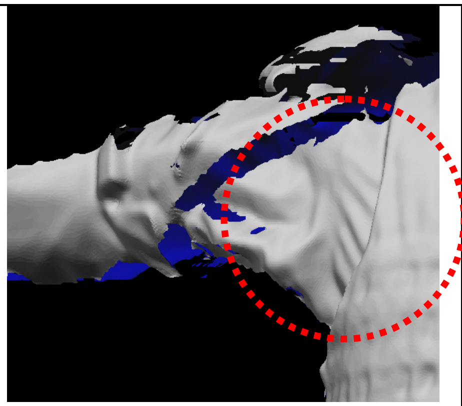
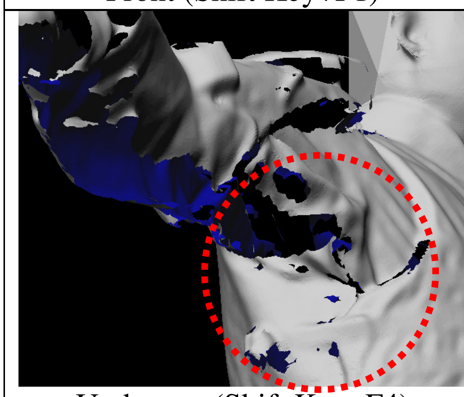
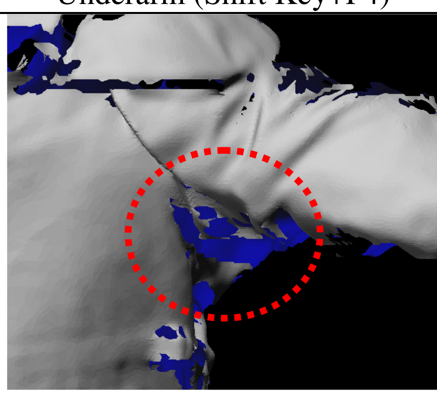
Comment:



Back (Shift Key+F2)

Arm Armor System **A** (No hole)	1	2	3	4	5	6	7
Arm Armor System **B** (1 hole)	1	2	3	4	5	6	7
Arm Armor System **C** (2 holes)	1	2	3	4	5	6	7

Comment:

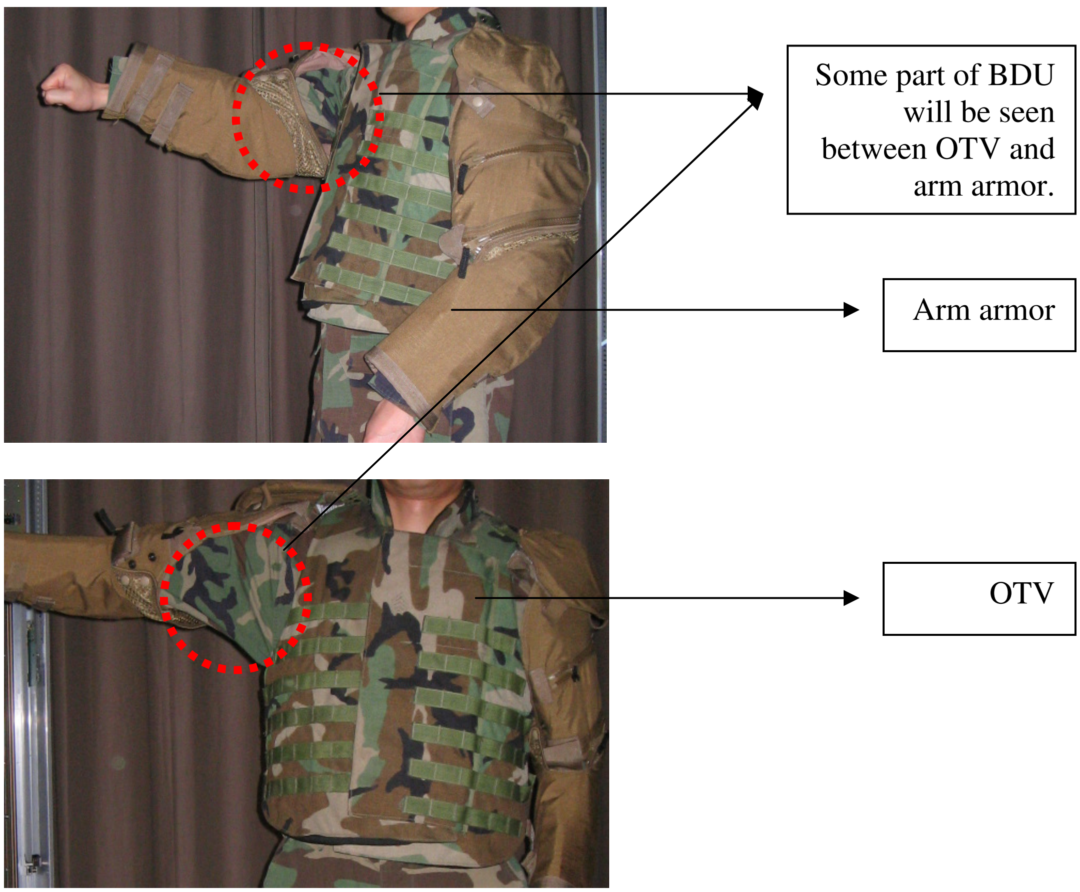
<table>
<tr><td colspan="2">SUBJECT NO. POSITION: Shoulder Horizontal Extension (5)</td><td colspan="7"></td></tr>
<tr><td colspan="2"></td><td colspan="7">Fully Uncovered Fully Covered</td></tr>
<tr><td rowspan="4">
Front (Shift Key+F1)</td><td>Arm Armor System A
(No hole)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td>Arm Armor System B
(1 hole)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td>Arm Armor System C
(2 holes)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td colspan="8">Comment:</td></tr>
<tr><td rowspan="4">
Underarm (Shift Key+F4)</td><td>Arm Armor System A
(No hole)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td>Arm Armor System B
(1 hole)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td>Arm Armor System C
(2 holes)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td colspan="8">Comment:</td></tr>
<tr><td rowspan="4">
Back (Shift Key+F2)</td><td>Arm Armor System A
(No hole)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td>Arm Armor System B
(1 hole)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td>Arm Armor System C
(2 holes)</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td></tr>
<tr><td colspan="8">Comment:</td></tr>
</table>

APPENDIX G

INSTRUCTION FOR VISUAL ARMOR COVERAGE

Instruction for Fit Evaluation (for Fit Judges)

1. Judging criteria
   a. This evaluation session is designed to visually evaluate the coverage in armscye area in active positions including flexion, extension, abduction, horizontal flexion, and horizontal extension.
   b. Keep in mind that the purpose of wearing arm armor is to provide ballistic protection for the arm area, and you are going to rate how much the arm armor covers the circled area.
   c. Following pictures show a subject with BDU, OTV, and arm armor.

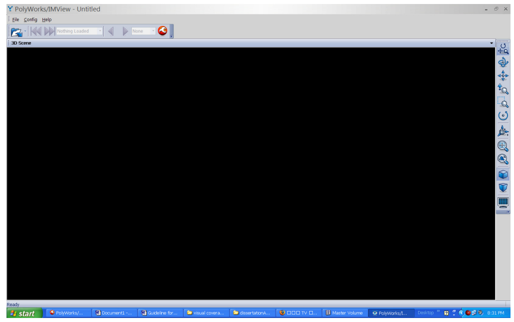


2. Once open, the scan image using Polyworks IMView software (free viewer) will show three images of identical subjects in one screen. Each image is a scan of each garment treatment on an identical subject (Detailed instruction will follow). You will examine the coverage at each armscye area and rate how much the arm armor covers the specific areas

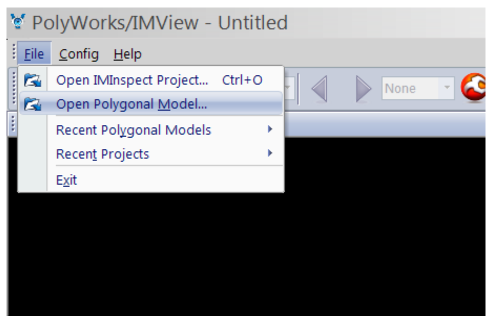
Fit evaluation Procedure using IMView

1. How to use the software and shortcut key.

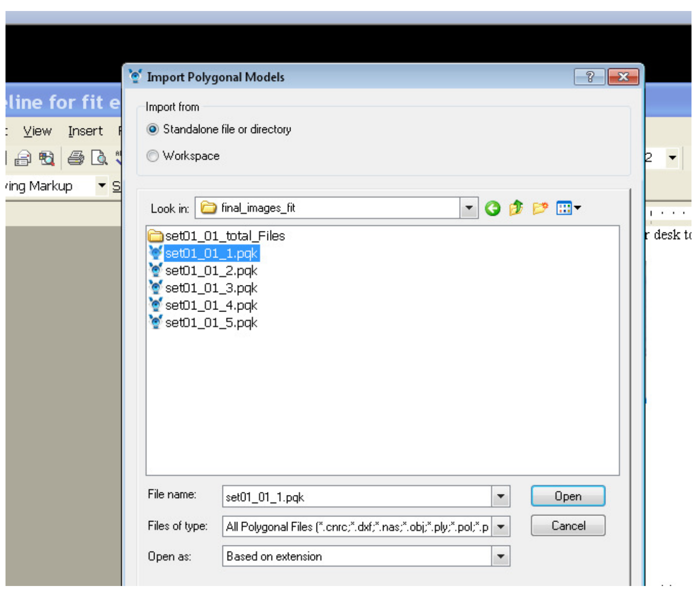
- Open IMview Software by double clicking the icon installed on your computer's desktop. You will see a screen as below.



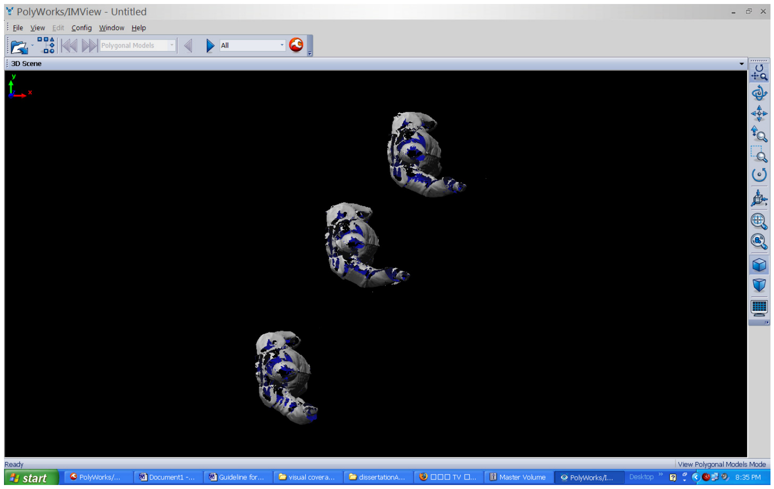
- Go to menu bar and click file and choose Open Polygonal Model.



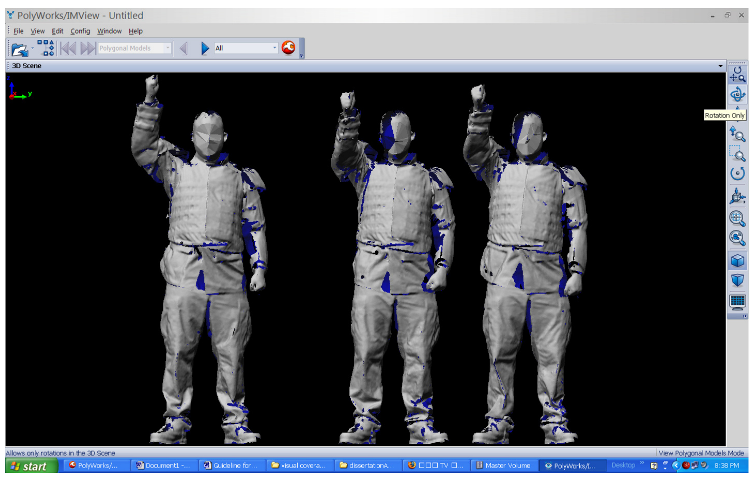
- Open file (.pqk format) from the scan image folder.



- You will see the screen with subject in three different garment treatments as below. It will be opened as a top view.

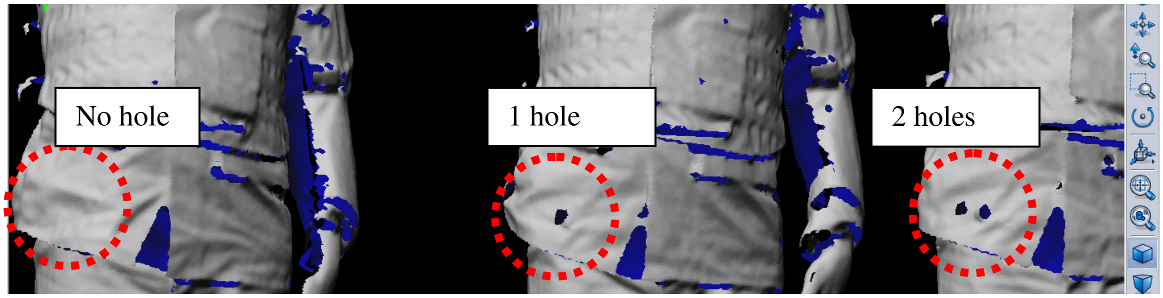


- Click Shift and F1, and you will see subjects from the front view as below.

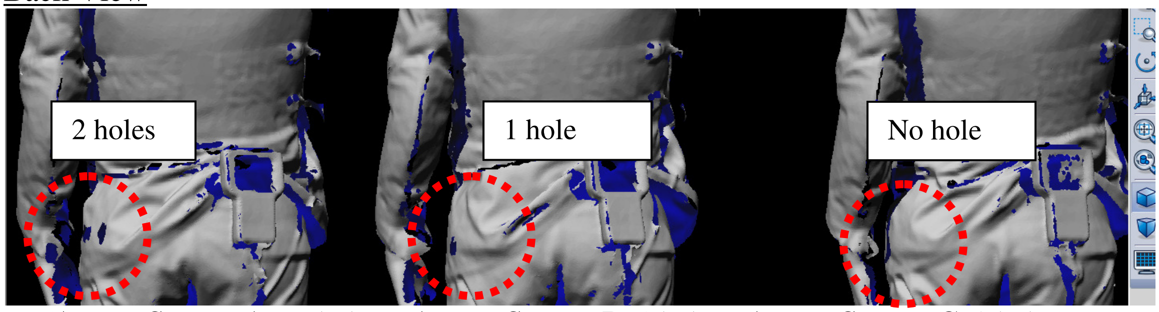


- If you do not see an identical screen alignment as above, then change the configuration. To do this, 1) go to the view-> pose -> car view and 2) go to the view -> pose-> orthogonal.
- From the left, the first armor treatment is arm armor system A (only soft armor), the second image is wearing arm armor system B (soft armor plus conventional plate), and the third image is in arm armor system C (soft armor plus prototype plate). You also can distinguish them by looking at how many holes they have in their front right bottom areas and back left bottom area of BDU as presented at below pictures. Be sure that you will see arm armor system C at your left first, B at second, and A at third when you see the subject's back.

Front View



Back View



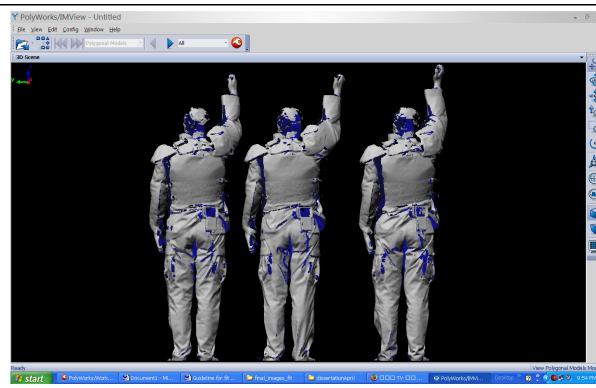
(**Armor System A**: no hole **Armor System B**: 1 hole **Armor System C**: 2 holes)

- Examine the coverage of the arm armor system focusing on armscye areas of the dominant hand rotating and moving images using short cut keys and the mouse.
- Record your evaluation rating using the visual fit evaluation ballot provided with this guideline.

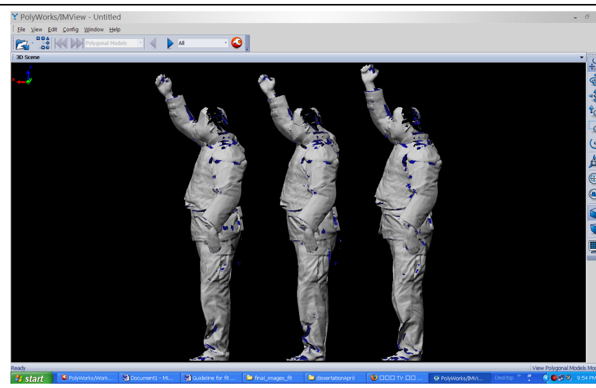
Short Cut Key

Front View:
Shift Key + F1

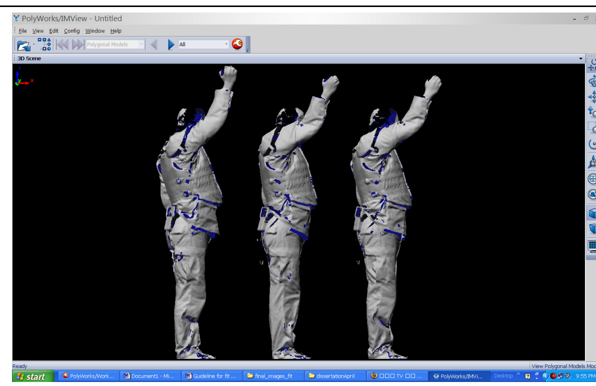
Side View:
Shift Key + F2



Back View:
Shift Key + F3



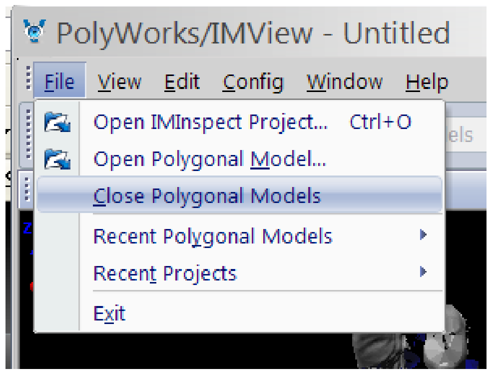
Side View2:
Shift Key + F4



Mouse Operation

To rotate image: click the left mouse button and rotate the image.
To move image: Click the middle mouse button and move the image.
To zoom in and out on the image: click the right mouse button and drag the image.
To zoom to a specific area: hold shift and the middle mouse button at the same time and then draw a box.
To rotate clockwise: hold shift and the right mouse button and then rotate the image.

- Close it (File/ Close Polygonal Models) after you finish evaluation for all three different garment treatment.



- Start evaluating another scan image using same procedure.

APPENDIX H

AREAS AND TYPES OF IMPEDIMENT FREQUENCY

Frequency Table for Control

Armor	Control																														
Types	Resistance to Movement					Heavy					Rubbing and friction					Tight					Loose					Localized Pressure					
	Flexion	Extension	Abduction	H.Flexion	H.Extension	Flexion	Extension	Abduction	H.Flexion	H.Extension	Flexion	Extension	Abduction	H.Flexion	H.Extension	Flexion	Extension	Abduction	H.Flexion	H.Extension	Flexion	Extension	Abduction	H.Flexion	H.Extension	Flexion	Extension	Abduction	H.Flexion	H.Extension	**Total**
Area 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Area 2	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Area 3	2	0	2	1	1	1	1	0	0	0	0	1	1	0	0	2	1	0	0	0	0	0	4	0	0	2	1	4	1	0	25
Area 4	1	1	1	1	2	1	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	2	1	0	1	0	2	1	0	17
Area 5	0	0	0	0	0	1	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	6
Area 6	2	0	4	3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	1	0	1	0	2	1	0	17
Area 7	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	5
Area 8	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	4
Area 9	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Area10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Area11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
Area12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	2
Area13	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	5
Area14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Area15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	6	2	7	7	4	4	3	0	0	0	0	2	5	0	2	4	4	1	0	0	0	0	8	2	1	4	6	8	4	1	85

Frequency Table for Armor A

Armor	Armor A																														
Types	Resistance to Movement					Heavy					Rubbing and friction					Tight					Loose					Localized Pressure					
	Flexion	Extension	Abduction	H.Flexion	H.Extension	Flexion	Extension	Abduction	H.Flexion	H.Extension	Flexion	Extension	Abduction	H.Flexion	H.Extension	Flexion	Extension	Abduction	H.Flexion	H.Extension	Flexion	Extension	Abduction	H.Flexion	H.Extension	Flexion	Extension	Abduction	H.Flexion	H.Extension	**Total**
Area 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2
Area 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2
Area 3	2	0	1	2	0	0	0	1	0	0	2	1	1	2	0	0	0	0	2	0	0	0	0	0	0	1	1	4	2	0	22
Area 4	0	1	0	0	0	1	0	1	0	1	1	0	2	0	0	1	0	1	0	1	0	0	0	0	0	3	0	3	0	0	16
Area 5	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Area 6	3	0	0	3	0	0	0	0	0	0	1	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0	4	0	14
Area 7	0	1	1	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	7
Area 8	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	3
Area 9	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Area10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Area11	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	4
Area12	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Area13	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	3
Area14	0	1	0	1	1	0	0	0	0	1	0	0	1	1	0	0	1	0	2	1	0	0	0	0	0	0	0	0	0	0	10
Area15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	3
Total	5	7	2	7	2	1	1	2	0	4	4	1	5	4	0	2	7	2	5	4	0	0	0	0	0	8	3	8	8	1	93

Frequency Table for Armor B

Armor Types	Armor B: Resistance to Movement					Heavy					Rubbing and friction					Tight					Loose					Localized Pressure					**Total**
	Flexion	Extension	Abduction	H.Flexion	H.Extension	Flexion	Extension	Abduction	H.Flexion	H.Extension	Flexion	Extension	Abduction	H.Flexion	H.Extension	Flexion	Extension	Abduction	H.Flexion	H.Extension	Flexion	Extension	Abduction	H.Flexion	H.Extension	Flexion	Extension	Abduction	H.Flexion	H.Extension	
Area 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Area 2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	3
Area 3	2	0	2	0	0	0	0	0	0	0	3	1	1	0	0	1	0	1	1	0	0	0	0	0	0	2	1	3	1	0	19
Area 4	0	0	1	0	0	0	0	1	0	3	1	0	1	1	0	1	1	1	1	0	0	0	0	0	0	0	1	1	0	0	14
Area 5	0	1	0	1	2	1	0	1	1	1	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	1	1	0	13
Area 6	1	0	1	1	0	1	0	0	2	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	3	0	1	3	0	15
Area 7	0	0	0	0	3	0	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
Area 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Area 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Area10	0	0	0	1	0	0	1	0	1	0	1	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	1	8
Area11	0	2	0	0	0	0	0	0	1	0	0	0	1	1	2	1	1	1	1	0	0	0	0	0	0	0	2	0	0	1	14
Area12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Area13	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	3
Area14	1	0	0	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	5
Area15	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	6
Total	4	6	4	3	6	2	1	2	5	6	6	1	4	3	5	4	6	4	5	0	0	0	0	0	0	6	8	6	6	3	106

Frequency Table for Armor C

Armor	Armor C																														
Types	Resistance to Movement					Heavy					Rubbing and friction					Tight					Loose					Localized Pressure					
	Flexion	Extension	Abduction	H.Flexion	H.Extension	Flexion	Extension	Abduction	H.Flexion	H.Extension	Flexion	Extension	Abduction	H.Flexion	H.Extension	Flexion	Extension	Abduction	H.Flexion	H.Extension	Flexion	Extension	Abduction	H.Flexion	H.Extension	Flexion	Extension	Abduction	H.Flexion	H.Extension	**Total**
Area 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Area 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Area 3	1	1	2	1	0	0	0	0	0	0	2	0	2	1	0	1	1	1	2	0	0	0	0	0	0	1	0	3	1	0	20
Area 4	0	1	2	0	0	0	2	0	0	1	1	1	3	0	0	1	2	2	0	0	1	0	0	0	0	0	1	3	0	0	21
Area 5	0	0	0	0	0	0	1	0	0	3	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	1	9
Area 6	2	1	0	1	0	0	0	0	1	0	1	0	0	1	0	1	1	0	2	0	1	0	0	0	0	1	0	0	2	0	15
Area 7	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1	2	9
Area 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Area 9	0	1	0	0	1	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	6
Area10	0	1	0	1	1	0	2	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	8
Area11	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	1	7
Area12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Area13	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3
Area14	0	0	0	0	1	0	0	0	0	0	1	0	1	1	0	1	1	1	1	2	0	0	0	0	0	0	0	0	0	1	11
Area15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2
Total	3	7	5	4	5	0	5	0	2	6	6	1	6	3	1	5	12	4	8	6	2	0	0	0	0	2	2	7	5	5	112

VITA

Jinhee Nam

Candidate for the Degree of

Doctor of Philosophy or Other

Thesis: ARM ARMOR SYSTEMS: FIT ANALYSIS AND PERFORMANCE FACTORS

Major Field: Apparel Design

Biographical:

Personal Data: Born in Seoul, Korea

Education: Completed the requirements for the Doctor of Philosophy in Design, Housing and Merchandising at Oklahoma State University, Stillwater, Oklahoma in December, 2008; Completed the requirements for the Master of Science in Design, Housing and Merchandising at Oklahoma State University, Stillwater, Oklahoma in May, 2005; Completed the requirements for the Bachelor of Home Economics in Fashion Design at SungKyunKwan University, Seoul, Oklahoma in February, 1995.

Experience: Doctoral Graduate Associate at Oklahoma State University in Stillwater, Oklahoma from August, 2008; Graduate Assistant at Oklahoma State University in Stillwater, Oklahoma from January, 2002 to May 2004; Chief Designer of Web Planning & Design Team at Cyberstone Company in Seoul, Korea from July 19998 to May 2001; Apparel Designer at Morado Inc. in Seoul. Korea from October 1995 to August 1997; Textile designer at Moazoom Textile Company in Seoul, Korea from November 1994 to March 1995; Internship at Yves Saint Laurent for Men in Seoul, Korea during August, 1994.

Professional Memberships: International Textile and Apparel Association; Alpha Omicron Nu National Honor Society

Name: Jinhee Nam Date of Degree: December, 2008

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: ARM ARMOR SYSTEMS: FIT ANALYSIS AND PERFORMANCE FACTORS

Pages in Study: 154 Candidate for the Degree of Doctor of Philosophy

Major Field: Apparel Design

Scope and Method of Study: The purpose of this study was to compare the performance effects and perceptual responses of subjects wearing three different arm armor systems versus no arm armor. Armor treatment with four levels (control garment and arm armor systems A, B and C) and shoulder/arm movement treatment with five levels (flexion, extension, abduction, horizontal flexion, and horizontal extension) constituted the independent variables. There were five dependent variables: range of motion (ROM), localized pressure, garment impediment perception, wearer acceptability, and visual armor coverage. Ten volunteer healthy males, ranging in age from 19 to 30 years, who wore size medium battle dress uniform with recent experience serving in the military or in the Reserve Officers' Training Corps served as subjects. This experimental study contained two major sessions: 1) a one-hour 'Pre-test procedure', and 2) a two-hour 'Test procedure'. Subjects were instrumented with localized sensors and performed five selected shoulder and arm movements in a 3D body scanner chamber while wearing each of the armor treatments. Data for five dependent variables were gathered simultaneously.

Findings and Conclusions: The dependent variables were analyzed primarily using one and two-way repeated measures ANOVA. *For localized pressure*, no significant main effects for armor system nor for movement in areas 1 and 2 were found, possibly due to several methodological issues. Significant main and interaction effects were found for *ROM.* There was a trend for ROM to decrease from subjects wearing the control to system A to system C to system B for all five movements. For w*earer acceptability*, no significant differences were found between the control and system A for all eight items, indicating that subjects did not perceive a difference between wearing the control and the control plus arm armor. There was a trend for wearer acceptability to decrease from wearing the control armor to system A to system C to system B. For *visual armor coverage*, significant main and significant interaction effects were found. Mean differences were apparent between system A and system B with system A providing more coverage except for flexion.

ADVISER'S APPROVAL: Dr. Donna H. Branson