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Title: Design Criteria of Type IV Body Armor for Women

Abstract approved: _____

Kathy K. Mullet

The current body armor used by the military does not provide enough fit to women. Female soldiers are ordered to wear body armor that was not built to conform to their bodies. The inadequate body armor could bring more threats than safety to the wearers.

Based on the facts that women in the military are required to wear the same type IV vest as men, and women do not have the same shape or size as men, the purpose of this study is to develop a type IV body armor which will conform to the female anatomy but also provide more comfort, fit, and mobility to females. Women's body shape demands different shaping of the materials to contour to the body. Under this concept, this research was conducted to modify the current model, *Interceptor*™, and develop a new design for women.

The *Interceptor*™ belongs to type IV body armor. It is composed of the woven ballistic fabrics and rigid plates of ballistic material, like steel, ceramic, or plastic, which meets the ballistic resistant performance requirements of the National Institute of Justice standard-0101.04.

LaBat and Sokolowski's three stage design process was applied in this research. Questionnaire was used to collect information and opinions from users. 11 female soldiers from Oregon National Guard participated in this study. Questions pertained to the user's personal information, general information between them and the vest, movements and activities, experience of wearing the *Interceptor*™ body armor, and their perceptions about the vest design were asked.

Based on the results, chest, neckline, and armhole areas were determined as the areas that need to be modified. According to users' opinions, it is important for the vest to fit female's body, give good arm mobility, and compatible with LBV. The researcher also did the market research on the *Interceptor*™ and other women's body armor, and analyzed the advantages and disadvantages of them. It helped the researcher brainstorm some design ideas for the new vest. The design criteria obtained from the research stage helped the researcher to develop the new design.

Design Criteria of Type IV Body Armor for Women

by
Tsun-Yin Tung

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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Tsun-Yin Tung, Author

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CHAPTER I
INTRODUCTION

Women's participation in the activities, which were limited only for men in the past, has increased over the years. More and more women are employed in physically rigorous jobs, like being soldiers and firefighters. According to the 2005 fiscal year report of the Office of Army Demographics, 17.4% of the active-duty soldiers are females (The Office of Army Demographics, 2005). In other words, for every five soldiers, one will be a female. These jobs are meaningful and responsible, but many of them are dangerous. Since women are not in the majority, the protective equipment they wear has not been developed for their use. Most manufacturers design the protective equipment for specific danger not for the wearer.

The comic strip (Figure 1) and the statement below it on Town Called Dobson™'s website caught my attention. It is a conversation of complaining about the current body armor from two soldiers killed in a battle. The statement below addresses that the body armor which are used in battles still have defects, especially for women. Women in the military are ordered to wear the body armors that fail to fit them. The reason for the failure is that the body armor they used, called *Interceptor*™, is only made for men's bodies (GlobalSecurity.org, 2000). This protective vest is composed of ballistic woven materials and inserted flat plates. When it is worn by a woman, a gap between breasts and the front plate is created. The gap can be big enough to stick a grenade inside and is an extra danger for the women soldiers (Town Called Dobson™, 2007). Moreover, it is difficult to breathe as a result of the pressure from the plate in the bust area. These factors raise the risk of battle injuries while women are wearing this kind of body armor.

The contribution of the protective garment is pronounced. Three thousand law enforcement officers have been saved by the body armor in past 30 years (NLECTE, 2006). Police officers don't wear their vest all the time unless they are on duty. However, soldiers in the battle are asked to wear the protective apparatus all the time. The types of ballistic vests for law enforcement officers are not the same as the army because the levels of the threats that they encounter are different. Type II vest is the one that law enforcement officers usually wear (Fowler, 2003). According to the National Institute of Justice standard-0101.04 (NIJ standard-0101.04)(2000), the type II body armor is the armor "…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."

The *Interceptor*™, the protective vests used by the United State Military, is type IV body armor which includes inserted plates in order to provide a higher level of protection (NIJ guide 100-01). The type IV body armor consisted of the woven ballistic fabrics and rigid plates of the ballistic material (NIJ Standard-0101.40). It also need to meet the NIJ Standard-0101.40, protecting wearers "…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 (1850 ft/s) or less." (NIJ Standard-0101.40, 2000, p.3).

Type II vest is also made of woven ballistic fabrics but without the plate. Comparing type IV vest, which the soldiers wear in the battle, to type II vest is much lighter than type IV vest. However, 40 percent of officers still do not wear body armor (IACP/Dupon™ Kevlar Survivors' Club, 2006). Comfort is the biggest problem. Officers' performance can be affected by the level of comfort while wearing the vests (Watkins, 1995). If the

regular ballistic vest can’t provide adequate comfort, it is not hard to imagine how uncomfortable the soldiers are when they wear the vests with additional plates.

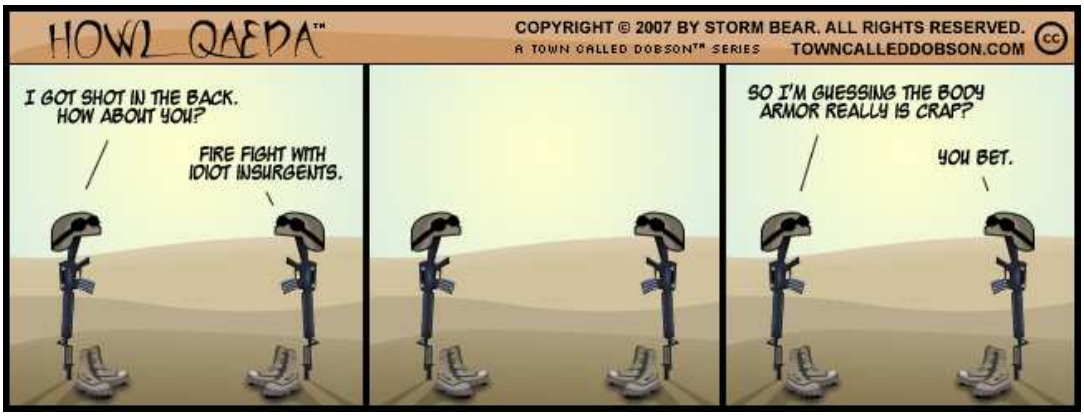


Figure 1. "Body armor? No solution for women."[1]

[1]From "Body armor? No solution for women." by Storm Bear, *Town Called Dobson*, Retrieved December 5, 2007, from Town Called Dobson Web site: "http://www.towncalleddobson.com/?p=698" Reprinted with permission of the creator.

Purpose of the Study

Based on the facts that women in the military are required to wear the same type IV vest as men, and women do not have the same shape or size as men, the purpose of this study is to develop a type IV body armor which will conform to the female anatomy but also provide more comfort, fit, and mobility to females.

The type IV vest, it is composed of the woven ballistic fabrics and a rigid plate of ballistic material, like steel, ceramic, or plastic, which meets the ballistic resistant performance requirements of the National Institute of Justice standard-0101.04 (NIJ Standard-0101.40). Women's body shape demands different shaping of the materials to contour to the body. Under this concept, this research was conducted to modify the current model, *Interceptor*™, which the U.S. military uses, and develop a new design for women.

In order to facilitate the design development, LaBat & Sokolowski's (1999) three-stage design process will be adopted in this research as the theoretical framework.

Objectives of the Study

The following research objectives will be used to guide the design research process:

1. To determine the comfort needs of the female wearers for the level IV body armor.
2. To comprehend the current *Interceptor*™ level IV vest, including materials, style, and design.
3. To identify the design criteria of the level IV body armor for women based on

Objective 1 and Objective 2.

4. To design type IV body armor for women based on the design criteria established in Objective 3.

Assumptions of the Study

1. The design specifications given will fulfill the tests required to produce a type IV body armor vest for women.
2. All the participants can understand the questions in the questionnaire.
3. All the participants answer the questions conscientiously.

Definition of Terms

Blunt Trauma: the severe bruises and even broken bones that were caused by the impact energy (US patent: 5020157).

Comfort: a garment that fits and allows for body movement.

Fit: a garment which conforms to the female body shape.

LBV: Load Bearing Vest, giving more capability for soldiers to carry the wide array equipment. “It consists of two main components: the mesh vest with numerous attachment loops and the attachable/detachable pouches of various sizes” (Militaryphotos.Net, 2008).

Type II body armor/ ballistic vest: “This armor 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." (NIJ Standard-0101.40, 2000, p.2).

Type IV body armor/ ballistic vest: "The armor 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 (1850 ft/s) or less." (NIJ Standard-0101.40, 2000, p.3).

Mobility: the ability to perform the activities of a soldier.

MOLLE: MOdular **L**ightweight **L**oad-carrying **E**quipment, "The system's modularity is derived from the use of Pounch Attachment Ladder System webbing , rows of heavy-duty nylon stitched onto the vest as to allow for attachment of various MOLLE-compatible pouches and accessories." (Wikimedia Foundation, Inc, 2008).

CHAPTER II

REVIEW OF LITERATURE

Selected background knowledge related to functional design, design processes, and body armor are presented in this chapter. The knowledge enhanced the base of the study. Each functional design study provides an integrated process for itself. Reviewing other function design studies provides the researcher a better idea of conducting a similar study. Moreover, it helped the researcher find an adequate design process and path for this particular study.

A suitable and well-designed process helps researchers organize studies systematically and reduce the possibility of failure. The process varies due to the characteristics of each study. After a broad review, LaBat & Sokolowski's (1999) three-stage design process was selected as the most adequate process for this study. It was adopted in this research as the theoretical framework.

General body armor information was reviewed as well, such as body armor styles, types, construction, and materials. Because of the characteristic of the study, it is especially important to review the relative information about body armor. The researcher needed to know what the body armor is before beginning the research and modification. For the same reasons, the researcher also reviewed the information about the *Interceptor*™ and other current body armors.

By reviewing the relative information, the researcher obtained a series of relative knowledge that integrates the study. Therefore, the review of literature information will be presented in the following order: Functional Design Research, LaBat & Sokolowski's Design Process, General Introduction of Body Armor, *Interceptor*™ Body Armor, Other

Body Armors in the Market, and Functional Needs of Wearers of Body Armor.

Functional Design Research

Scholars and designers have been emphasizing the functionality of clothing for over 60 years (Lamb and Kallal, 1992). Function design process is a process of solving problems. Functional design is described as the design that is developed for a certain cohort for their special needs, such as for soldiers, astronauts, firefighters, patients, or persons with disabilities. The purpose of clothing is no longer just to cover the human body. It is a specialized device for a certain purpose in order to protect people or make our lives easier and better.

In Cho's (2006) hospital gown redesign project, the researcher used Lamb and Kallal's FEA consumer needs model to address the design consideration for hospital gowns. They argued that the new design should satisfy the three cruxes: function, aesthetics, and expression. In the aspect of function, the new hospital gown should meet the needs, like better fit and mobility, and it should reach some level of general aesthetics. Expression should not be a kind of design that tells patients that "you are really sick, and you are different from normal people." Clothing can express a person's condition, personality, and attitude. People will seek to certain styles according to the perspectives of social identity and communicate themselves through the styles (Davies, 1985).

In Carroll and Kincade's (2007) disability apparel product development study, they created their own framework which is the most suitable development course for their study. The purposes of the study were to analyze the design possibilities of an apparel

product for working disabled women and to explore the design development for them. They had interviews with their subjects and determined the user needs and preferences. Afterward, they developed the prototype, and received evaluations and feedback from the different points of view of users and manufacturers.

In the neonate clothing study (Bergon, Capjack, McConnan, & Richards, 1996), the researchers pointed out the lack of the clothing of premature neonate. Because the neonates could not address their problems, the researchers concentrated on nurses and caregivers who were responsible for the care of the subjects. This study developed design criteria for their prototype, created a fit garment for the premature neonate according to the specification, and an evaluation tool for the prototype. The researchers addressed that an ideal infant garment should comprise the following concerns: comfort, safety, adjustability, accessibility, aesthetics, and production. These concerns can also be applied to any clothing.

LaBat & Sokolowski's Design Process

Design processes are used in many fields, such as engineering, interior design, and education, in order to aid in the "product" development processes. Table 1 shows the sorting arrangement of clothing and engineering design processes, presented by LaBat and Sokolowski (1999). The product could be a project, a design, a teaching method, or something else; it depends on the field. The product is always the goal researchers want to achieve in the end. The process of developing an apparel product is like a way of solving a problem. A well-defined design development process facilitates developers'

organization ability and allows him/her to manage the whole plan systematically (Pitimaneeyakul, LaBat, DeLong, 2004). The design processes from different areas comprise various stages and orders. These stages and orders present the best routes to achieve particular goals. Even though the stages are named differently, their principles or directions are the same. Labat and Sokolowski (1999) examined various design processes, analyzed those steps within each design process, sorted them based on their commonalities, and condensed them into three major stages. These three stages are problem definition and research, creative exploration, and implementation.

LaBat & Sokolowski's (1999) three-stage organization offers overall ideas of conducting each stage (See Table 2). This design process was used in this body armor research as the theoretical framework. This process was selected over other models, because it addresses the issue of evaluating products which are currently on the market.

Table 1. *Summary of clothing and engineering design processes. (Adapted from LaBat & Sokolowski, 1999)*

LaBat & Sokolowski (1999)		**Problem Definition and Research**	**Creative Exploration**	**Implementation**
Clothing Design Process	Watkins (1988)	1. Problem Definition 2. Variable Research	3. Definition 4. Idea Generation	5. Select Solution 6. Implementation
	Lamb & Kallal (1994)	1. Problem Identification 2. Preliminary Idea	3. Design Refinement 4. Prototype Development	5. Evaluation 6. Implementation
Engineering Design Process	Lewis & Samuel (1989)	1. Problem Recognition 2. Problem definition	3. Exploration of Problem 4. Search for Alternatives 5. Evaluation and Decisions	6. Specification of Solution 7. Communication of Solution
	Walton (1991)	1. Define Problem	2. Alternative Solutions 3. Refine Ideas	4. Analyze Ideas 5. Decision 6. Implementation

Notes: The numbers represent the sequence of taking place during the product development process.

Table 2. *LaBat & Sokolowski's Three-Stage Design Process (Adapted from LaBat & Sokolowski, 1999)*

Problem Identification	**Creative Exploration**	**Implementation**
• Initial Problem Definition - Client definition	• Preliminary Ideas - All realm of possibilities	• Production Refinement - Cost to product - Time to produce - Methods of production - Sales potential
• Research - User needs - Market	• Design Refinement - User constraints - Production constraints	• Phase 1: Immediate Production - Changes in product or production that can be accomplished immediately
• Working Problem Definition - Defined by industry client & university designer - Design criteria	• Prototype(s) Development - Meshing criteria & constraints to develop workable ideas	• Phase 2: Improvement/Refinement - Further development that may be delayed
	• Evaluation of Prototype - Preliminary: by university designer - Final: by university designer & industry client	

Problem Definition and Research

The first stage, problem definition and research, is to identify the purpose of the design. It answers the questions, what is the purpose of designing the product, and whom is it being designed for. Understanding the target market and the needs of the consumer will give the designer a clear direction of developing new designs. Even in the fashion design area, the mass apparel designers also face this stage because they need to know what season which the clothing is being designed for, and whom their target customers are (Lamb & Kallal, 1992). In LaBat & Sokolowski's (1999) industry-university textile product design project research, three activities were conducted in this stage:1) initial problem definition, 2) research, and 3)working problem definition.

Research is especially important in this stage because user needs and market condition will be determined (LaBat & Sokolowski, 1999). Identifying consumer needs helps designers develop design criteria (Lamb & Kallal, 1992). A needs assessment indicates the gap between ideal needs and real needs (Mullet, 1984). From the analysis, the designers are able to identify the problems better (Watkins, 1995). Needs assessment is especially important in the functional design process because functional design emphasizes developing special-need-related designs. In the industry, it is crucial to keep products competitive as well. Understanding current products, market environment, and economic conditions will give companies a better idea about the orientation of their products. Meanwhile, it will help the developer to assess the cost and use of materials.

Creative Exploration

There are four activities that are conducted in the creative exploration stage:

preliminary ideas, design refinement, prototype(s) development, and evaluation of prototype (LaBat & Sokolowski, 1999). The preliminary ideas step contains sketching, brainstorming, research, and question-and-answer sessions. The designers can expand their imaginations and create any possible designs visually or verbally in this stage (Lamb & Kallal, 1992).

In the design refinement step, designers revise their ideal designs from the preliminary ideas stage by detecting the design criteria in terms of user perspectives and product constraints. It is important for designers to think up creative ideas, but the creative ideas need to meet user's and company's expectations. Consumer's demands in terms of function, aesthetics, and economics as well as the time, cost, and method to produce the product will all be taken into consideration. Some conflicts may occur between the user's need and the company's perspective. Companies need to refine the design by carefully analyzing the solutions of the conflicts so that they will obtain the maximum benefit.

Prototype development and evaluation takes place after designers develop workable ideas from design criteria (LaBat & Sokolowski, 1999). Sample designs will be created. Designers will get feedback from the prototype evaluation to improve the final designs. In their research, a three-stage design process applied to an industry –university textile product design project, the prototype was evaluated through laboratory tests and a wear test. The laboratory tests consisted of tensile test, strength test, and abrasion test for the materials; the wear test was conducted to determine the product performance in actual use.

Implementation

According to LaBat & Sokolowski's (1999) industry-university textile product design project research, developers conduct production refinement, immediate production, and improvement/refinement in this stage. In the industry, companies have last design examinations that are conducted to change only immediate issues, and to assess final cost, time, and methods used to produce products. These activities are different from those in the refinement step in the creative exploration stage because companies will make their final decisions in this stage in order to mass manufacture the products. Before this final stage, it is possible to go back any stages to revise the design (Lamb and Kallal, 1992).

General Introduction of Body Armor

The function of body armor is to provide protection in terms of decreasing impact and preventing penetration from weapons. Historically, the materials have changed from animal skin and wood, to metal, to specialized fabrics. However, as weapons have advanced, it is almost impossible to use only one kind of protective apparatus to prevent injury. The body armors, today, are produced in many styles and types to more efficiently perform their functions. Thus, the Office of Law Enforcement Standards (OLES) of the National Institute of Standards and Technology (NIST) established a technical standard that specifies the equipment performance requirements and precise test methods to provide a selection and application guide for procurement officers in their equipment purchase (NIJ Standard-0101.40). This standard is widely used by the government and non-government institutions, test laboratories, manufacturers, and individuals.

Styles

In the OLES selection and application guide, it divides body armor into three different styles. One is concealable body armor; one is semi-rigid body armor; the third one is rigid body armor.

Concealable body armor is the most used type of body armor, and it is worn under the normal uniform as a protective undergarment. Because of its snug, this kind of body armor should be able to offer better comfort, lightweight, and mobility than the other two styles (NIJ guide 100-01).

Semi-rigid body armor is a body armor designed for higher threat levels. Type III and IV body armors are usually categorized in this style. It is hard to conceal in that it is always composed of articulated plates, like plastic, steel, and ceramic (NIJ guide 100-01).

Rigid body armor gives wearers the lowest mobility in that it is compound with a molded ballistic material made for protect a certain part of the body. It is worn externally and only for short time periods (NIJ guide 100-01).

Types

The Office of Law Enforcement Standards (OLES) of the National Institute of Standards and Technology (NIST) established seven formal armor classification types. Body armors were categorized by different threat levels from the weapons. In the NIJ standard-0101.40, the classification types were described clearly. The information provides the minimum requirements of performance and testing of the body armors. It included the details of bullet caliber and type, bullet mass, impact velocity, and so on (NIJ standard-0101.40). Table 3 is a summary of the ballistic-resistant armor classification.

Construction

Generally, body armors consist of two parts, the protective panel and the carrier. The protective panel is constructed by layers of the ballistic-resistant materials. These layers can be all the same sort of material or different materials and will be laminated together to achieve a certain level of protection. The carrier is made of regular garment fabrics, such as woven nylon. The protective panel can be inserted or sewn into the carrier. The performance and properties of the body armor depend on the location and number of layers of the protective panel. Comfort is mainly relative with the number of fabric layers and materials of the protective panel. It is the ultimate for the manufactures to achieve the maximum protection and comfort with the minimum weight (NIJ guide 100-01).

Materials

Scientists have been engaging in inventing new materials for body armors in order to minimize the weight and maximized the protection and comfort. In 1965, Kevlar was developed, and was the first material that was used for a modern ballistic garment because of its lightweight and flexibility (DuPont, 2008). Today, aramid, high performance polyethylene (HPPE), and polyphehylenebenzobisoxazole (PBO) are the major types of polymer fibers used in the ballistic fabrics (Fowler, 2003). The fabrics were originated to achieve better properties such as light weight, waterproof, flexibility, and impact absorbency. Table 4 is the summary of properties of the main fibers used in body armor (NIJ guide 100-01).

Table 3. *Classification for Ballistic-Resistant Armor*

Type/ Threat Level	Bullet Caliber & Type	MASS (Grains)	Velocity[a] (m/s)
I	.22 LR LRN	40	320
	.38 ACP FMJ RN	95	312
IIA	9 mm FMJ RN	124	332
	.40 S&W FMJ	180	312
II	9 mm FMJ RN	124	358
	.357 Magnum JSP	158	427
IIIA	9mm FMJ RN[b]	124	427
	.44 Magnum SJHP	240	427
III	7.62 mm FMJ[c]	148	847
IV	.30 M2 AP[d]	166	878
Special	*	*	*

Note. Abbreviations: AP─Armor Piercing bullets

FMJ─Full Metal Jacket bullets

JSP─Jacketed Soft Point bullets

LR LRN─Long Rifle Lead Round Nose bullets

RN─Round Nose bullets

SJHP─Semi-Jacketed Hollow Point bullets

*These are specified by users.

[a]The minimum velocity when impacting. [b]High velocity. [c]Rifles

Table 4. *Ballistic Fiber Names, Manufacturers, and Properties*

Name	Manufacturer	Properties
Kevlar	DuPont	First material used in modern body armor High strength Lightweight High chemical/ cut/ flame resistance Unaffected in water
Spectra	Honeywell	High strength Water penetration resistance High chemical/ cut resistance Lightweight
GoldFlex	Honeywell	Lightweight Thin Good protection against blunt trauma
Twaron	Twaron Products	High energy absorption Quicker impact dispersal
Dyneema	Netherlands	Very Lightweight High energy absorption
Zylon	Toyobo	High thermal properties Better tensile strength Lightweight

Note. Zylon is currently identified as unstable material for body armor. It increases the risk of injure when used in body armor. Case studies showed that the ballistic performance of Zylon degraded in water or over time (New Scientist, 2007; NLECTC, 2005).

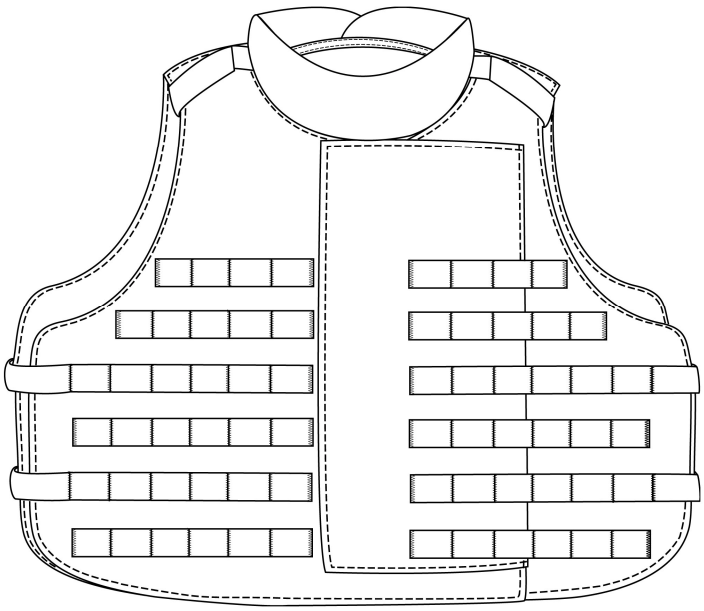
Interceptor™ Body Armor

The *Interceptor*™ body armor components included the outer tactical vest, webbing on the front and back of the vest, the Small Arms Protective Insert (SAPI), and the Armor Protection Enhancement System guards the neck, arms, and groin (GlobalSecurity.org, 2000). The outer tactical vest (carrier) is a soft armor system, and it consists of Kevlar layers that will stop 9mm pistol rounds. The webbing system allows wearers to attach other small equipments to increase the load ability. The SAPI is a trapezoid plate "…made of a boron carbide ceramic with a spectra shield backing that's an extremely hard material. It stops, shatters and catches any fragments up to a 7.62 mm round with a muzzle velocity of 2,750 feet per second. It's harder than Kevlar." (GlobalSecurity.org, 2000).

The *Interceptor*™ body armor is a unisex product with a combined 16.7 pounds. It is nine pounds lighter than the Personnel Armor System for Ground Troops (PASGT), which it replaced (Kennedy, 2005). Although the weight issue was improved, the fit issue for women soldiers still existent. "Accommodation of females in soft vest and plate female body armor systems presents a unique set of design problems. Incorporating females into male-based systems may impose disproportionate protective and functional sacrifices on females." (Bodyarmornews.com, 2008).

The core task of the study is modifying the *Interceptor*™, the current vest used in the United Stated military. Doing research on the specific vest helped the researcher identify the features of the current design in terms of the advantages and disadvantages of what is being used. The following content includes Figure 2, Figure 3, and Figure 4, which show the technical illustrations of the *Interceptor*™ and the feature statements.

The illustrations were created by the researcher from a physical inspection of an actual *Interceptor*™ vest and plate. The features, summarized from Point Blank Body Armor Inc. website, are also included is this description.



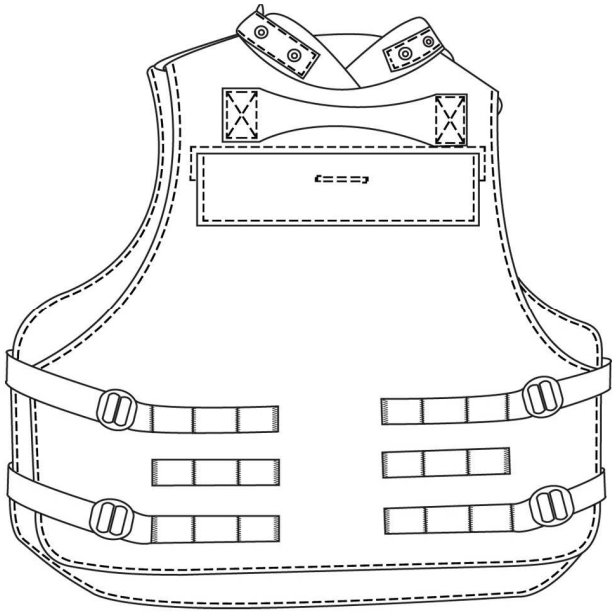
Materials

- **Hydration System Compatible:** won't be damage by hydrates.
- **Adequate for Various Ballistic Systems:** like Aramid, GoldFlex™, and Legacy™ Pro.
- **Nylon Carrier:** gives durability from abrasion.
- **Heavy-Duty Nylon:** for the modular load-bearing webbing system

Designs

- **Removable Front Collar:** to provide adequate protection.
- **Adjustable Waist:** to provide size ease.
- **Modular load-bearing webbing system:** to provide attachment of the variety of MOLLE and other accessories.
- **Front Velcro and Snaps Opening:** to provide quick and efficient "donning and doffing."
- **Front Opening Cover:** to provide intensive security of front opening.
- **Front Concealed pocket:** to carry the front ballistic plate.

Figure 2. Front View of the *Interceptor*™



Materials

- **Hydration System Compatible:** won't be damage by hydrates.
- **Adequate for Various Ballistic Systems:** like Aramid, GoldFlex™, and Legacy™ Pro.
- **Nylon Carrier:** gives durability from abrasion.
- **Heavy-Duty Nylon:** for the modular load-bearing webbing system

Designs

- **Removable Back Split Collar:** to provide adequate protection.
- **Adjustable Waist:** to provide size ease.
- **Modular load-bearing webbing system:** to provide attachment of the variety of MOLLE and other accessories.
- **Emergency Extraction Strap:** for quick take-off.
- **Back Concealed Pocket:** to carry the back ballistic plate.
- **Back Concealed Pocket Opening Cover**

Figure 3. Back View of the *Interceptor*™ [1]

Materials

- The plate was made from ballistic materials, like ceramic tiles, aramid, boron carbide, Kevlar, and Spectra, to protect against rifle rounds and some other armor piercing bullets.

Designs

- A trapezoid design with slightly curve: to provide fit to human body shape.

Figure 4. Ballistic Plate for the *Interceptor*™

Other Body Armors in the Market

The *Interceptor*™ is the sole supplier of body armor to the U.S. military. There are other body armors on the market for either for men or women. All the information could provide the researcher advanced understanding on the body armor. These body armors are comprised of different material combinations, design features, and construction technology. SAVVY Armor, LLC. is a manufacturer who produces type I to IV and customized body armors exclusively for women.

Technology Used in the Market

SAVVY Armor, LLC. addresses three technologies that make their vest the most adequate products for women: 1) thermal forming, 2) Radial offset pleating, and 3) advanced draping. The thermal forming shaping technology uses heat and pressure to create the customized bust cups to fit the women's different body shape. The advanced draping shaping technology "…consists of a uniquely shaped back panel that wraps around to the front of the body" (SAVVY, 2007). The front panel is separated from the back panel. It drapes over the bust. The overlap of the front and back panel forms the side coverage. This feature provides more protection to vulnerable internal organ areas (SAVVY, 2007).The chosen vests were presented in the research. The radial offset pleating technology is a patented technology. It uses the "…softwear to breaks the material into groups creating multi-layered pleats that lay exactly adjacent to one another" (SAVVY, 2007). Three sub groups of ballistic materials are combined into one ballistic panel. The multiple-layered pleats were exactly adjacent to one another to form a smooth surface, and there will not have bulky fabrics cluster around the underarm or

chest area. Moreover, because of this technique, customizing the bust points for different women became possible.

Rush™

This is a tactical type vest that consists of a regular bulletproof vest and plates that provide a higher level of protection. Type IV body armor is usually called tactical armor. The company states that *Rush*™ provides good fit on every kind of body, and excellent side and back coverage (SAVVY, 2007). The advanced draping shaping technology is used on the vest to fit even the most petite officers. The illustration of *Rush*™ is presented in Figure 5. The features of *Rush*™ vest are:

1. Detachable yoke system for shoulder yoke and groin.
2. Front hard armor plate pocket.
3. Front/back MOLLE attachment system.
4. Durable weapon retention system.
5. Back “officer-down” strip. (SAVVY, 2007).

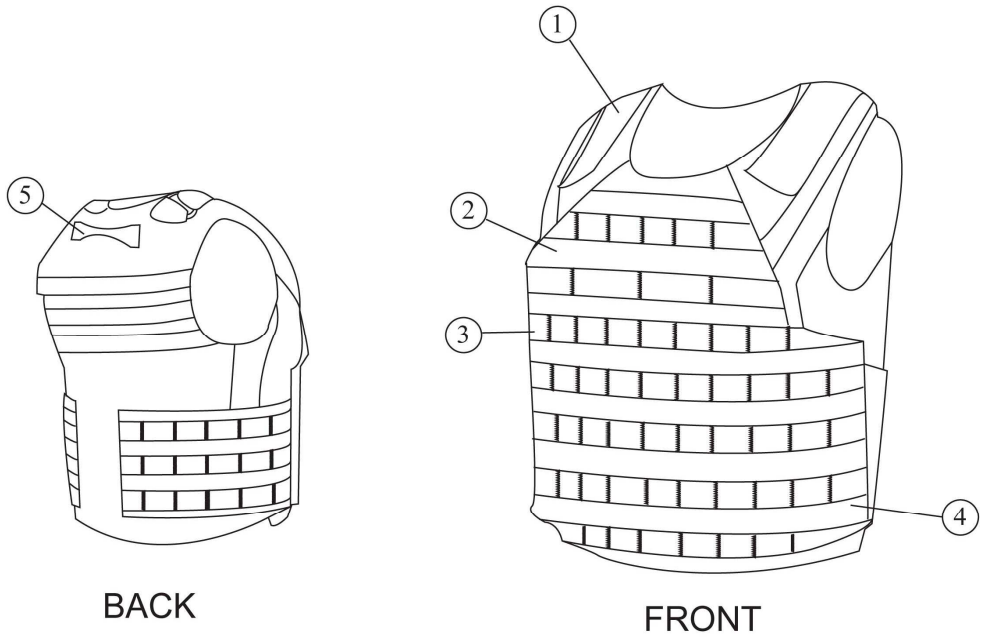


Figure 5. Tactical Armor: *Rush*™

Flair™

Like other concealable armors, *Flair*™ vest is designed to provide a perfect and snug fit for the female wearers. The thermal-forming or radial offset pleated shaping technology was used in the vest. Moreover, “increased loop on the surface of the front panel gives her more space to adjust and fit her vest to her body” (SAVVY, 2007). Figure 6 shows the illustration of *Flair*™ as well as its features. The features of *Flair*™ include:

1. Zipper garage that keeps zipper tucked away.
2. Shoulder cushion that that adds shoulder support.
3. Increased loop for enhanced adjustability.
4. Underarm cushion to reduce chaffing.

5. Standard overlap for full side coverage.
6. Mesh backstrap that helps keep vest from shifting.
7. Stretch microfiber that helps hold shape around bust line.
8. Anti-Microbial Yarn for outer carriage provides antimicrobial protection (SAVVY, 2007).

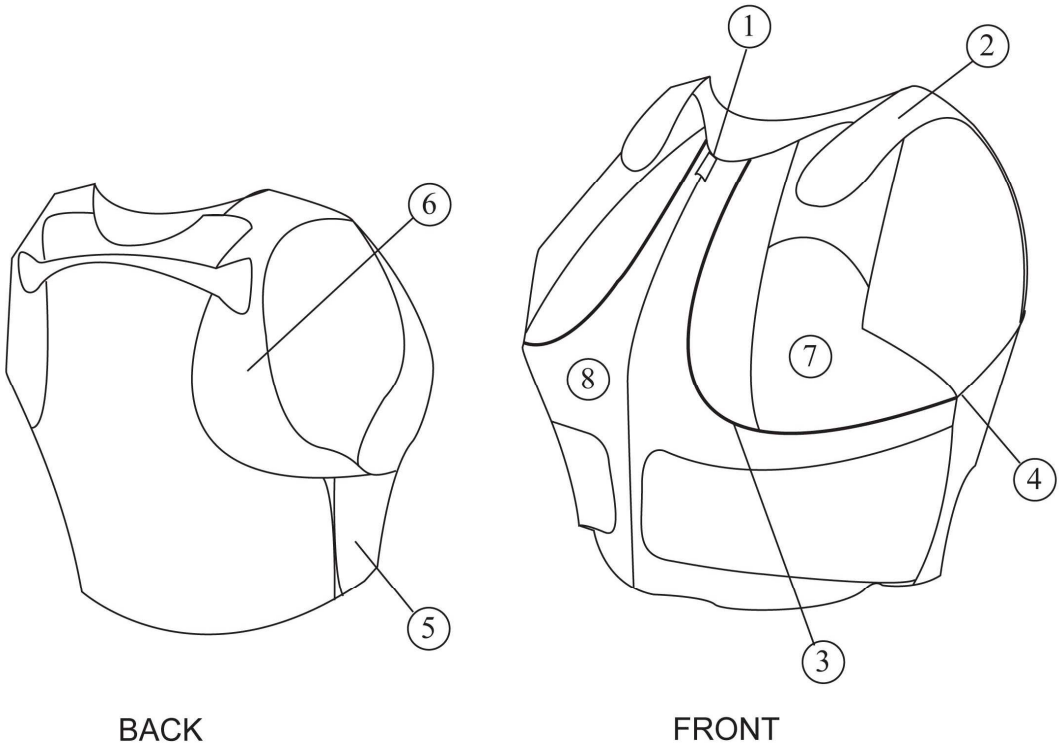


Figure 6. Concealable Armor: *Flair*™

Functional Needs of Wearers of Body Armor

From the review of literatures, it is concluded that impact and comfort, like fit and mobility, are the common and primary needs of the wearers of body armor.

Impact

To protect body from the strong impact that generated by bullet is one of the primitive ideas of inventing body armors. Generally, people think the function of the body armor is preventing bullets from penetrating the human body. However, some researches and statistics have shown that blunt trauma caused by the impact of the bullets can cause fatal injury as well (US patent: 5020157). It can cause severe internal damages or bruises and even death (NIJ guide 100-01). Body armors, especially the one with rigid material, should be able to perform at least the following three protective functions: first, spread the impact, prevent penetration, and absorb energy (Watkins, 1995). Scientists and manufacturers also engage in create new material having better and quicker manner to spread the impact and absorb the energy.

Comfort (Fit & Mobility)

Comfort is defined as a broad and abstract concept as well as a narrow and subjective one. It can represent either physical or psychological feeling. The standards that people identify their comfort level are varied. Therefore, it is always the hardest respect for designers to cope with. Although the ballistic vest has been saving thousands of police's lives, 40 percent of officers still do not wear body armor because of its discomfort (IACP/Dupon™ Kevlar Survivors' Club, 2006). The reason is that the

discomforts, like fit and dissipation problems, affect their performance while wearing the vests (NIJ guide 100-01; Watkins, 1995).

Many designers, manufacturers, and scientists are engaging in developing new designs in order to increase the comfort level. Designers focus on determining the sizing system and shape that restricts mobility. Manufacturers and scientists concentrate to invent new materials to give better water-resistance, flexibility, and breathe ability. In this research, the researcher is intending to give better fit and mobility to the wearer by using present materials. The purpose of the research is modifying current design of the type IV ballistic vest to offer more comfort to the wearers.

Fit. Fit is one of the important elements of comfort. The concept of fit is usually related to snugness. Men and women are naturally different in physique. The basic slopers that patternmakers use to create design patterns have gender and size differences. Normally, the target market is decided first, male or female, and, afterward, the sizes are decided. The American Society for Testing and Materials (ASTM) issued the standard body measurements for men and women. The standard tables of body measurements were extensively used by apparel manufacturers to develop patterns and garments that correspond with the anthropometric characteristics of their target market population (ASTM Committee, 2005). Table 5 shows the comparison of men's and women's torso measurement when the chest measurements are the same. From Table 5, it is easy to understand why the men's garment won't fit on women's body.

When the chest measurement is the key factor for law enforcement officers to select the size of their bulletproof vests, female officers would confront these following problems:

1. Waist: according to Table 5, even when the chest circumference is the same, the

waist still has two inches difference. It will reduce her mobility as a result of the bulky fabrics around the waist.

2. Armscye: this is the terminology we used in sewing construction to refer to the armhole. If the armholes are too big, this brings a safety issue. Does it conceal the body portion where the vest was designed to protect?
3. Torso length: there is no torso length measurement in the Table 5, but we can derive the torso length by subtracting the cervicale height from the waist height (cervicale height - waist height = torso length). Therefore, a man with a chest circumference of 36 inches has a torso length of 17 inches (59 - 42 = 17). A woman with a chest 36 inches has a torso length of 16 1/4 inches (561/2 - 401/4 = 16 1/4). The difference between men's and woman's torso length is 3/4 of an inch. A vest that is too long will cause a discomfort for the female officers. When she wears the vest and sits down, the hem will be pushed into the abdomen area, or the vest will be pushed upward and project into her neck.
4. Armscye depth: the depth of the armhole affects the mobility and comfort of the arms. Men's garments usually have smaller armhole depth than women's do, because women have a bust. The extra bulky fabrics around the bust and arms will reduce the mobility of arms and the comfort of the body. Moreover, in the safety aspect it might become a distraction during a mission.

Therefore, applying a vest which developed base on a man's body shape to a female soldier only increases the level of her discomfort. It is imperative to develop the protective apparatuses which can offer better fit, comfort, and maneuverability exclusively for women.

Table 5. *The Comparison of Men's and Women's Torso Measurement When the Chest Measurements are the Same*

	Men	Women	Difference
Size	36	10	
Chest/Bust	**36**	**36**	
Waist	30	28	2
Armscye	17	15 3/4	1 ¼
Cervicale height	59	56 1/2	2 ½
Waist height	42	40 1/4	1 ¾
Armscye depth	5 1/16	7 5/8	2 9/16

Note. Unit = inch.

Mobility. There are two ways to provide the mobility in clothing: fabrics and garment design (Watkins, 1995). The common problem with the ballistic material is lacking flexibility. Before a better material, which is flexible enough as well as protective, is invented, the main solution of the problem will be changing garment design. Weight and the bulky extra fabric from the oversize vest for female soldiers are the factors that restrict the wearers' mobility in body armor. In this research, the researcher will focus on modifying sizing problem which came from the failure of fitting female body shape so that female soldiers will obtain more mobility when wearing the type IV body armor.

CHAPTER III

METHODS

LaBat and Sokolowski's three stage design process (1999) was adapted in this research. Chapter II, review of literature, had introduced their concept and each stage. This chapter will indicate how each stage will be applied to the study. Moreover, the approaches that will be used to achieve each objective are identified in this chapter. A flowchart (See Figure 7) with the simple description shows the overall design process that applied in this research.

Problem Identification and Research	**Initial Problem Identification**
	Research • Questionnaire • Market Research
	Working Problem Identification • Define the problems • Design Criteria
Creative Exploration	**Design Brainstorming** • Preliminary Ideas • Design Matrix
	Design Refinement • Design Matrix
	Prototype Development • Design Specification
	Prototype Evaluation

Figure 7. Design Process of "Design Criteria of Type IV Body Armor for Women" Research

The objectives for this study provide a framework for the design process. Objectives 1, 2 and 3 are used for the fist stage of the design process. Objective 4 completes the prototype design step in creative exploration stage, but the actual prototype would not be actually constructed due to the lack of special techniques and equipments. Therefore, the implementation stage was beyond the scope of this study.

The objectives for this study are:

1. To determine the comfort needs of the female wearers for the level IV body armor.
2. To comprehend the current *Interceptor*™ level IV vest, including materials, style, and design
3. To identify the design criteria of the level IV body armor for women based on Objective 1 and Objective 2.
4. To design type IV body armor for women based on the design criteria established in Objective 3.

Objective 1: To determine the comfort needs of the female wearers for the level IV body armor.

In the first stage of the design process the initial problem needed to be identified. The initial problem is the basic reason why the researcher was interested in this study. The researcher heard from a female's complaints about the comfort of the existing vest. Comfort here would be defined as the lack of fit and mobility according her descriptions. Women's bodies have more curves than men's, but female soldiers use the same kind of vest as males do. The user needs are not satisfied. The problem turned into the purpose.

A survey was conducted in order to determine user needs. A questionnaire was used in this study as the survey tool. In the questionnaire, the questions pertained to the user's personal information, movements and activities done while wearing the vest, experience of wearing the *Interceptor*™ body armor, and their perceptions about the vest design were asked.

Objective 2: To comprehend the current Interceptor™ level IV vest, including materials, style, and design

The researcher also conducted market research in order to understand the existing products and the state-of-the-art. By doing market research, it helped the researcher analysis the advantages and disadvantages of existing vest, as well as get some design ideas for the new design.

Physical inspection and measurement of an *Inceptor*™ vest was done to determine the materials, style and materials which are currently used in the vest.

Objective 3: To identify the design criteria of the level IV body armor for women based on Objective 1 and Objective 2.

The third objective was to identify the problems and develop design criteria for a new vest design. The researcher defined the particular problems of the vest from the results of the questionnaire and market research. These problems became the main issues that the new design needs to solve. Design criteria were built up from the identified working problems and used to complete the first stage of the design process.

Objective 4: To design type IV body armor for women based on the design criteria established in Objective 3.

This stage consisted of four goals: design brainstorming, design refinement, prototype development. Design brainstorming allowed the researcher to create the blueprint of the new design and multiple combinations. This objective is done as part of the creative exploration stage of the design process.

Design refinement takes both the design criteria and preliminary ideas from brainstorming into consideration. Not all the criteria and ideas can go together. For example, people think the higher protection level the better. However, if adding too many layers of the ballistic woven fabric, the vest would become too heavy and less flexible. In this situation, the researcher needs to adjust all the needs and sometimes even has to give up some criteria. Therefore, the researcher refined the design by cross matching all the criteria and develop a new design.

After all the criteria were determined and the design blueprint created, a vest prototype design can be developed. The researcher defined the construction details, material specification, and measurements of important dimensions information for the new design in this research.

Sample and Data Collection

Any female soldier who has experience wearing the *Interceptor*™ body armor, issued by the government, could take part in this study. A written questionnaire of 26

questions that were grouped under five sections, general information, fit assessment, movement analysis, design element analysis, and personal information, was developed.

The recruitment started from Oregon Army National Guard Capt. Micah T. Goettl, who was the bridge between the researcher and the participants in Oregon Army National Guard. The plan was to develop a web based survey which Capt. Goettl would send out the web survey link by emails or give out the paper questionnaires to the participants. This is a snowball sampling. The participants who take the web survey would be asked to distribute the web survey link voluntarily to people they know and eligible to take part in this project. No one responded to the web survey.

CHAPTER IV

IMPLEMENTATION OF DESIGN PROCESS

This research followed the three stage design process by LaBat and Sokolowski (1999) and was discussed in Chapter II. In Chapter III, the individual steps from the process were introduced, and explained to achieve the objectives of this study. Individual steps under each stage were selected to provide a process for this body armor research. This chapter will present the process and data which was collected for each stage.

Stage One: Problem Identification and Research

Stage one is broken into initial problem definition, research, and working problem identification. In order to identify the user needs and clarify the problems, data was gathered through a written questionnaire. Later of this stage was conducted by physically measuring and viewing of the *Interceptor*™ vest which is the required vest used by the military.

Initial Problem Definition

The researcher became aware of problems with the body armor vest from conversations with friends who were serving in the military and a comic strip (Figure 1). Female soldiers encountered the fit problem when wearing the vest, especially when inserting the ceramic plates into the vest. Female soldiers who had bigger bust size

experienced a pressure at the bust area that makes breathing difficult when wearing the vest with plates. The researcher developed the initial problem statement and Objective 1 in order to start this research.

Research

A series of research associated with user and market were conducted. Through questionnaires the researcher collect the information related to user needs. Market research was conducted to understand the specific product, the *Interceptor*™ body armor, and other current products.

Questionnaire Data Results

A written questionnaire of 26 questions that were grouped under five sections was distributed to female Oregon National Guard soldiers during a weekend training drill. Eleven women participated in the study. The project was approved by Oregon State University's Institutional Review Board (IRB) (See Appendix A), and the questionnaire is presented in Appendix B. There were 12 open-ended questions related to the fit and activities. These questions will be discussed with the related closed-ended questions and also reviewed for correlations between the respondents and their fit requirements.

SECTION I: Questions 1 to 5 belong to section one. The researcher wanted to understand the relationship between wearers and the vest by asking the questions in section one.

Question1: What size is your most recently acquired vest?

Female soldiers were offered different choices (size) of the vest. According to the responses showed in the Table 6, most of the soldiers owned a size medium vest. 70 % of the respondents indicated that the vest they own is size medium.

Table 6. *Vest Sizes the Participants Own*

Vest Size	Reponses	Percent (%)	Accumulation (%)
Extra Small (XS)	1	10	10
Small (S)	1	10	20
Medium (M)	7	**70**	90
Large (L)	1	10	100
Extra Large (XL)	0	0	100
Total	10	100	

Question2: How long have you been serving in the military?

Most of the respondents serve in the military less than five years. Table 7 shows that 18% of the respondents served in the military less than one year; near 50% of respondents have been served in the military over one year but less than five years.

Table 7. *Years of Serving in the Military*

Service Year	Reponses	Percent (%)	Accumulation (%)
Less than 1 year	2	18	18
1~5 years	5	**46**	64
6~10 years	3	27	91
11~15 years	0	0	91
16~20 years	1	9	100
Total	11	100	

Question3: How long have you owned the vest?

Table 8 shows that most of the respondents own the vest less than three years. 37% of the respondents own the vest less than one year; 27% of the respondents own the vest more than one year but less than three years.

Table 8. *Years of Owning the Vest*

	Reponses	Percent (%)	Accumulation (%)
Less than 1 year	4	**37**	37
1~3 years	3	27	64
4~6 years	2	18	82
More than 6 years	0	0	82
Never owned one	2	18	100
Total	11	100	

Question4: How many times have you worn the vest with the plates inserted?

There are three respondents who had no experience of wearing the vest with plates in this research. However, among the people who have the experience, most of them have worn the vest with plates more than 10 times. Table 9 shows that 55% of the people have the experience of wearing the vest with plates more than 10 times.

Table 9. *Times of Wearing the Vest With Plates*

	Reponses	Percent (%)	Accumulation (%)
Less than 5 times	2	18	18
5~10 times	0	0	18
More than 10 times	6	**55**	73
Never	3	27	100
Total	11	100	

Question5: On occasions when you wear the plates, what is the average length of time that you wear the plates?

Base on the results, the average length of time that respondents wear the plates is within 12 hours. Table 10 shows that 46% respondents indicated that the average length of time wearing the plates is more than one hour but less than six hours.

Table 10. *Average Length of Time of Wearing the Vest*

	Reponses	Percent (%)	Accumulation (%)
Less than 1 hour	0	0	0
1~6 hours	5	**46**	46
7~12 hours	3	27	73
More than 12 hours	0	0	73
N/A	3	27	100
Total	11	100	

SECTION II: Questions in section II, from question 6 to question 15, are related to fit assessment. The researcher wanted to evaluate how well the vest conforms to the female body shape. The questions were asked under two situations, wearing the vest without plates and with plates.

Question 6: Evaluate the fit of each area when wearing the vest <u>without plates</u>.

Question 7: If you've answered "1" (Does Not Fit) in the previous question, use the space below to write down the specific area/areas and elaborate on why each area does not fit.

Question 8: Are there any other areas that do not fit and are not on the list above?

Question 9: If you answered "Yes" in Question 8, use the space below to write down the specific area/areas and elaborate on why each area does not fit.

Question 10: Based on your responses to Question 6 & Question 9, indicate which one specific area of the vest (without plates inserted) has the poorest fit.

Question 11: Evaluate the fit of each area when wearing the vest <u>with</u> plates.

Question 12: If you've answered "1" (Does Not Fit) in the previous question, use the space below to write down the specific area/areas and elaborate on why each area does not fit.

Question 13: Are there any other areas that do not fit and are not on the list above?

Question 14: If you answered "Yes" in Question 13, use the space below to write down the specific area/areas and elaborate on why each area does not fit.

Question 15: Based on your responses to Question 11 & Question 14, indicate which one specific area of the vest (without plates inserted) has the poorest fit.

Table 11 shows the fit comparison when wearing the vest without and with plates. Generally speaking, the degree of fit decreased when wearing the vest with plates. At the neckline area only 9% of the respondents chose "1", the fit is very bad. However, when evaluating the fit of the vest with plates, respondents who chose "1" increased to 37%. Question 7 allowed respondents to write down the specific reasons of not fit. The specific complaints about the neckline can be categorized into two trends: the neck area is too tight and the neckline area chokes the neck.

At the chest area 73% of the respondents responded "3", the fit is neutral, when wearing the vest without plates. However, when adding plates into the vest, all the responses centralized at "1" and "2", which imply the degree of fit is low (Three respondents didn't have experience of wearing the vest with plate. So, when talking about the responses, the researcher refers to those answered "1" to "5".). All the respondents who had the experience, wearing the vest with plates, indicated the fit is bad at chest area, because no one rated the chest fit higher than "2". 0% of the respondents thought the

chest fit is good when wearing the vest without or with plates. Specific complaints about the chest area from question 7 shows that most of the respondents felt "…chest tends to be tight…", "…squishes my breast…", "…difficult to breathe…."

At the waist area 55% of the respondents felt the fit is neutral ("3") when wearing the vest without plates. In the "with plates" category, the responses were not as concentrated as those in "without plates" category. 18% of respondents chose "1"; 28% of respondents chose "2"; 9% of respondents chose "3"; 9% of respondents chose "4". The complaint obtained from question 7 addressed that the waist area of the vest did not fit. One of the respondents complained the vest is "…wrong shape for my body…."

At the bottom edge of the vest - "hem" area, the response pattern was similar with the one in the waist area. 55% of the respondents felt the fit is neutral when wearing the vest without plates. The responses for the "with plates" evaluation are also dispersive: 18% of the responses are "1"; 37% of the responses are "2"; 9% of the responses are "3"; 9% of the responses are "4".

The responses for vest length is not quiet consistent in both "without plates" and "with plates" categories, although most of the respondents thought the fit of the vest length was neutral. 46% of the respondent thought the fit of the vest length was neutral when wearing the vest without plates; so does the 30% of the respondents in "with plates" category. The complaints from question 7 about the vest length are either "…vest too short…" or "… vest length too long…." The responses are dispersive and even opposite.

Table 11. *Fit Evaluation With and Without Plates*

		Does not fit.				Fit is good.
		1	2	3	4	5
1) Neckline	without plates (N=11)	9%	27%	**46%**	9%	9%
	with plates (N=9)	**37%**	18%	18%	0%	0%
2) Chest	without plates (N=11)	9%	9%	**73%**	9%	0%
	with plates (N=9)	**46%**	27%	0%	0%	0%
3) Waist	without plates (N=11)	18%	9%	**55%**	9 %	9%
	with plates (N=9)	18%	28%	9%	9 %	0%
4) Bottom edge of the vest-“Hem”	without plates (N=11)	18%	18%	**55 %**	0%	9 %
	with plates (N=9)	18%	**37%**	9 %	9%	0%
5) Armholes	without plates (N=11)	27%	0%	**37%**	18%	18%
	with plates (N=9)	28%	18%	9%	9%	9%
6) Vest length	without plates (N=11)	18%	18%	**46%**	18%	0%
	with plates (N=9)	30%	0%	30%	10%	0 %

SECTION III: From question 16 to 21 in section III are a series of questions about the movement that the female soldiers might perform when wearing the vest. This section helped the researcher to analyze the relationship between the movements and vest.

Question 16: When wearing the vest (without plates), how important is it to be able to do the following movements: 1) Walking, 2) Running, 3) Jumping, 4) Kneeling, 5) Sitting, 6) Standing, 7) Squatting, 8) Lifting, 9) Crawling, 10) Shouldering, 11) Shooting, 12) Head rotation, 13) Torso twist, 14) Bending at waist, 15) Cross arms, & 16) Take on & off?

Question 17: Are there any other movements that you think are important to be able to do when wearing the vest but not on the list above?

Question 18: If you answered "Yes" in Question 17, what are the movements?

Question 16 to 18 helped the researcher analyzed the importance of the movements when wearing the vest. Table 12 shows that option “5”, very important, generally has highest percentage in each movement importance ranking. In other words, the results show that respondents thought every movement was important to be able to perform. There is one respondent also mentioned that climbing is another important movements but not in the list; also, one of the respondents thought getting in and out of vehicles is another important movement to be able to perform.

Table 12. *Movements and Activity Importance*

	Not Important				Very Important
	1	2	3	4	5
1) Walking	9%	0%	9 %	9%	**73%**
2) Running	18%	0%	0%	18%	**64%**
3) Jumping	9%	9%	0%	9%	**73%**
4) Kneeling	9%	9%	0%	9%	**73%**
5) Sitting	9%	18%	0%	9%	**64%**
6) Standing	9%	0%	18%	9%	**64%**
7) Squatting	9%	0%	9%	18%	**64%**
8) Lifting	9%	9%	0%	18%	**64%**
9) Crawling	9%	9%	9%	9%	**64%**
10) Shouldering	9%	18%	0%	9%	**64%**
11) Shooting	9%	0%	0%	9%	**82%**
12) Head rotation	9%	0%	0%	9%	**82%**
13) Torso twist	9%	18%	0%	9%	**64%**
14) Bending at waist	9%	9%	0%	0%	**82%**
15) Cross arms	9%	9%	9%	27%	**46%**
16) Take on & off	9%	9%	0%	18%	**64%**

Question 19: When wearing the vest (<u>with plates</u>), how easy is it to perform the following movements: 1) Walking, 2) Running, 3) Jumping, 4) Kneeling, 5) Sitting, 6) Standing, 7) Squatting, 8) Lifting, 9) Crawling, 10) Shouldering, 11) Shooting, 12) Head rotation, 13) Torso twist, 14) Bending at waist, 15) Cross arms, & 16) Take on & off?

Question 20: Are there any other movements that are not easy to perform when wearing the vest (<u>with plates</u>) and not on the list above?

Question 21: If you answered "Yes" in Question 20 what are the movements?

After understanding the relationship between the movements and the vest, the researcher developed questions 19 to 21 in order to discover how easy it is to perform those movements when wearing the vest with the plates which added almost an additional 10 pounds. Table 13 shows the statistics: 64% of the respondents thought when wearing the vest with plates it was hard to perform squatting and crawling; 55% to 56% of the respondents thought jumping and shouldering were hard to perform.

Section IV conducted the questions that helped the researcher to analyze the design elements needed for the vest. There are two questions were included in this section: question 22 and question 23.

Table 13. *The Performance Difficulty of the Movements*

	N/A	Easy		Hard
	0	1	2	3
1) Walking	27%	27%	**46%**	0%
2) Running	27%	0%	27%	**46%**
3) Jumping	27%	0%	18%	**55%**
4) Kneeling	27%	9%	18%	**46%**
5) Sitting	27%	**46%**	0%	27%
6) Standing	27%	37%	27%	9%
7) Squatting	27%	0%	9%	**64%**
8) Lifting	27%	0%	36.5%	36.5%
9) Crawling	27%	0%	9%	**64%**
10) Shouldering	27%	0%	18%	**56%**
11) Shooting	27%	9%	18%	**46%**
12) Head rotation	27%	18%	27.5%	27.5%
13) Torso twist	27%	0%	**55%**	18%
14) Bending at waist	27%	19%	18%	**46%**
15) Cross arms	27%	0%	27%	**46%**
16) Take on & off	27%	27%	37%	9%

Question 22: Do you think it is important to have these following features on the vest? Please indicate the importance of the following vest design features: 1) Fit for Female Body, 2) Lighter Vest Weight, 3) Arm Mobility, 4) Torso Mobility, 5) Flexibility, 6) Quick take on & off, 7) Color, 8) Outer Pocket, 9) Inner Pocket, 10) Side Plates, 11) Soft Outer Fabric, 12) Breathable Outer Fabric, 13) Have Short Sleeves, 14) Have Long Sleeves, 15) Removable Front & Back Plates, 16) Lighter Plate Weight, 17) Compatible with LBV?

Question 23: According to Question 22, are there any other features that are not on the list above but are important/useful to have on a vest?

Table 14 shows that 91% of the respondents thought it was very important for the vest to fit for female body, give good arm ability, and be compatible with load bearing vest (LBV). 82% of the respondents thought it was very important to take on and off quickly and have lighter plate weight. 73% of the respondents thought it was very important to have good torso mobility and removable front and back plate. Other design elements that respondents also thought they were important and are lighter vest weight (55%), flexibility (64%), outer pockets (55%), side plates (55%), and short sleeves (56%). The only feature that most of the respondents thought it was not important at all is color (56%).

Table 14. *The Evaluation of Importance of Design Elements*

	Not Important				Very Important
	1	2	3	4	5
1) Fit for Female Body	0 %	0 %	9 %	0 %	**91%**
2) Lighter Vest Weight	9 %	0 %	18 %	18 %	**55 %**
3) Arm Mobility	0 %	0 %	0 %	9 %	**91 %**
4) Torso Mobility	0 %	0 %	9 %	18 %	**73 %**
5) Flexibility	0 %	0 %	9 %	27 %	**64 %**
6) Quick take on & off	0 %	9 %	9 %	0 %	**82 %**
7) Color	**56 %**	9 %	0 %	0 %	36 %
8) Outer Pocket	18 %	9 %	9 %	9 %	**55 %**
9) Inner Pocket	36 %	9 %	9 %	0 %	46 %
10) Side Plates	0 %	0 %	9 %	36 %	**55%**
11) Soft Outer Fabric	46 %	9 %	18 %	9 %	18 %
12) Breathable Outer Fabric	0 %	0 %	18 %	36 %	46 %
13) Have Short Sleeves	33 %	0 %	11 %	0 %	**56 %**
14) Have Long Sleeves	45 %	0 %	22 %	0 %	33 %
15) Removable Front & Back Plates	18 %	0 %	9 %	0 %	**73 %**
16) Lighter Plate Weight	9 %	0 %	0 %	9 %	**82 %**
17) Compatible with LBV	0 %	0 %	0 %	9 %	**91 %**

Questionnaire results discussion

The researcher analyzed the questionnaire data quantitatively and qualitatively. By doing these the researcher was able to conduct the deeper analyses and also provide more precise viewpoints on the relationship between the vest and wearer. These results made a great contribution on the new vest development. The result discussions are presented in the following paragraphs.

The vest manufacturer provided various standard sizes from size extra small (XS), small (S), medium (M), large (L), to extra large (XL). According to the results, the vest size range was from size XS to L. Table 15 shows the respondent body feature and the vest size they owned. Among these data, respondent 1, 3, and 9 (RN1, RN3, and RN9) showed some interesting factors. First, RN1 has a size medium vest. RN3 has bigger bust and waist than RN1, but RN3 has a size S vest. Second, RN 1 and 9 have the same bust size and similar waist size, but RN9 has an XS vest. These factors show that the vest assignment had defects in the military. If a soldier is assigned an overall too small vest, the vest might become too tight to breathe. If the vest is too big, the extra vest area might disturb her shooting. Female soldiers who didn’t acquire “right” vests are in a more dangerous condition. In the new vest design sizing information is provided and marked on the label to help people to determine what size of the vest is the “right” one for them.

Table 15. *The Vest Size and Wearer Body Measurements*

RN	Vest Size	Height (feet, inch)	Waist (inch)	Bust Size (inch + cup size)	Diff. B-W (inch)
1	M	5, 6	26	36B	10
2	(missing)	5, 4	28	32B	4
3	S	5, 5	30	36C	6
4	M	5, 2	29	34B to C	5
5	L	5, 7	38	38D	0
6	M	5, 10	34	36C	2
7	M	5, 7	32	34D	2
8	M	5, 5	28	36A	8
9	XS	5, 9	27	36B	9
10	M	5, 4	36	38D	2
11	M	5, 6	28	34A	6
Average		5, 6	30.5		

Note: RN = respondent identification number. Diff B-W is the circumference difference between bust and waist (bust – waist).

Fit Assessment. In the fit assessment results, overall, the degree of fit decreased when adding plates into the vest, especially in the chest area. The particular vest was built according to dimensions of the male body. It is common to find a chest fit problem when putting a male garment on a female. After inserting front and back plates, the ease of the vest declined. Many responses from the questionnaire indicated that the chest area is too tight to breathe. In addition, respondents also mentioned that the vest shape is not for their bodies. One of the respondents also mentioned that the neckline is "… a little snug until it gets worn…."

Generally speaking, a man's body is straighter than a woman's; in other words, a woman's body is curvier than a man's. For instance, RN1 had a 26-inch-waist but a 36-inch-bust circumference. The circumference difference is up to ten inches (See Table 16). Although the vest did provide a side adjustment system to allow wearers to adjust the vest waist fit, the system didn't give a total ten inches adjustment.

The other area that the data showed irregular is armhole. Data show that respondents had inconsistent and polar reaction about armholes. This also reflected in the open-ended responses. Some people thought the armhole is too big and rub their underarms, but some thought it is too small and pinches their arm pits. The size of an armhole varies between different people because of their body sizes or muscle development.

One of the respondents mentioned the neckline is too snug. Snug usually refer to fit well. However, when the wear is too aware of the snugness of the neckline, on a certain level it is not comfortable anymore.

To solve fit problems, the designers can change the materials or designs of the product. The ballistic materials have to be able to achieve certain requirements related to

the protection issue. Besides, there are no much options for the researcher to evaluate and change materials. Thus, the solution here focuses on changing the design so that it would not only conform to female body but also give efficient adjustment to wearers.

Mobility Assessment. In the questionnaire the researcher specially interested in how the plate weight changed people's mobility. The result showed that the respondents anticipated the vest could be worn all the time in the battle and allow them to perform every possible movement. However, in the real situation due to the weight of the plates some movements became difficult to perform when wearing the vest with plates. 82% of the respondents replied that it was important to have lighter weight plates (See Table 14). Moreover, movement importance evaluation showed that 82% of the residents thought shooting and head rotation were important movements to be able to perform. The importance of arm mobility had reflected from the result because shooting performance was directly related to arm mobility. Some responses indicated the arm area of the vest didn't give appropriate fit to wearers. Thus, improving the arm mobility became crucial in the future design.

Design Element Assessment. The design elements section gave the researcher significant design ideas that came from the wearers. What kinds of components are important reflected on the statistic results. Table 14 showed among the 17 elements the most significant design elements are "Fit for female body," "Arm mobility," and "Compatible with LBV." Inspecting the current design, the resaercher had found many defects that were likely to cause hazard to wearers. The defects were mainly related to fit. We had talked about the fit problems earlier in this chapter. Therefore, the researcher analyzed the possible improvements and modifications of these three design elements, which the wearers indicated they were important: fit female body, arm mobility,

compatible with LBV. Later on, the researcher evaluated the compatibility between each possible idea and developed a set of design criteria. The compatibility would be shown in the design criteria matrix in the “working problem identification” step.

Market Research

As presented in the chapter II, Review of Literature, the researcher performed general market research on the female body armor. In the step, the researcher focused on analyzing the particular model, *Interceptor*™, because this is the only model used in the military. The *Interceptor*™ is made to meet the standard of type IV body armor because of the hazard situation in the battle. The measurement locations of the *Interceptor*™ are presented in Figure 8 and Figure 9 the specification information is collected in Table 16. It is a size medium vest. Based on the label inside, a size medium vest fit the chest circumference from 37 to 41 inch. The protect panel, the Kevlar layers, was laminated together, and the thickness is one quarter of an inch. The front and back plates have no differences. They looked exactly the same in terms of shapes and curves. A size medium plate weights five pounds.

Working Problem Identification

After a series of research and analysis, the researcher found three main areas of the vest that had shown problems that needed to be solved were: 1) neck, 2) chest, and 3) armhole. The problems were identified as the vest shape doesn’t fit female body, especially around neck, chest, and armhole areas. The design criteria were built based on the problems and the wearer needs: fit for female, arm mobility, and compatible with LBV.

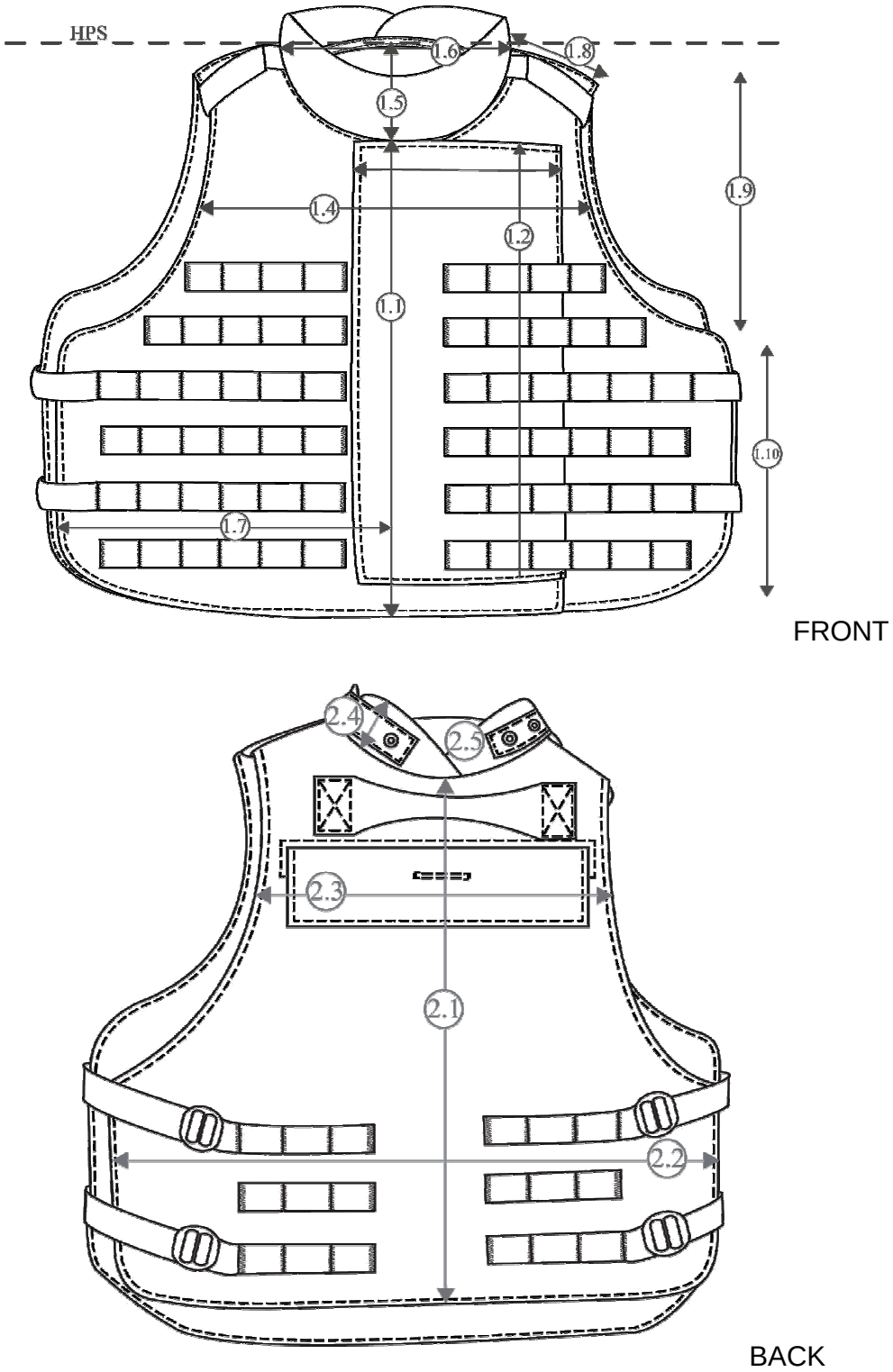


Figure 8. The Measurement Locations of the *Interceptor*™ Vest

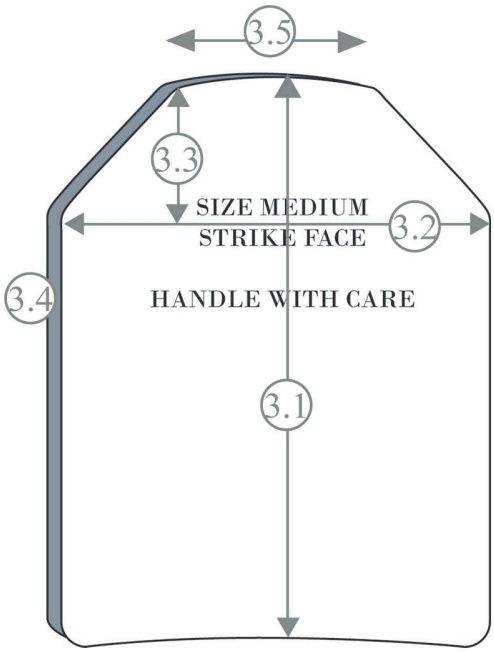


Figure 9. The Measurement Locations of Ballistic Plate for the Interceptor™

Table 16. *Specification of the the Interceptor™*

Locations	Measurements	Location Description
1.1	17	CF (Center Front)
1.2	15 1/2	Length of the front opening cover
1.3	7	Width of the front opening cover
1.4	13	Armhole to armhole, 2 1/2 inch down from front neckline
1.5	4 1/2	Neck drop (From HPS line to the front neckline)
1.6	8	Neck width
1.7	11	CF to side seam
1.8	3 1/2	Shoulder length
1.9	10	Armhole length
1.10	9	Side seam length
2.1	18	CB (Center Back)
2.2	22 1/2	Side seam to side seam (Back)
2.3	13 1/2	Armhole to armhole, 4 1/2 inch down from back neckline
2.4	2 1/2	The height of the collar
2.5	1/2	The overlap of two separate collars
3.1	12	Length of the plate
3.2	9 1/2	Width of the plate bottom
3.3	3 1/2	Length of the plate top
3.4	3/4	Thickness of the plate
3.5	5 1/4	Width of the plate top

Note: Unit = inch.

Stage Two: Creative Exploration

At this stage, design brainstorming, design refinement, prototype development and evaluation were conducted. All the data and information obtained from the first stage, problem identification and research, were imported into the exploration stage and considered as a creation guide.

Design Brainstorming

The design criteria determined from the former stage helped the researcher conduct the creative exploration of the vest. The design brainstorming focused on the previously developed criteria and created many design possibilities. For the purpose of the present project, need assessment was the best starting point for brainstorming. In this research, those elements that over 50% of the respondents thought important were evaluated for their compatibility. In general, it is common to find the constructional or logic conflicts among the design elements. Table 17 helped the researcher inspect the relationships and implement possibilities among each design element. In the interaction matrix, “2” meant there was no conflict between these two elements; “1” meant they were accommodative; “0” meant they conflicted with each other. As the matrix showed, most of the design elements proposed were not in conflict with each other. The only pair that conflicts with each other is “arm mobility” and “short sleeve.” The reason is that arm mobility will reach the maximum with no sleeves.

Since most of the design elements were compatible, we needed to consider their workability. In Table 18 the researcher picked out the highest ranked features, fit for female body, arm mobility, and compatible with LBV, and created some preliminary

design ideas depending on these three features. Again, the matrix told us whether the idea was workable or compatible to each other. After the brainstorming, the researcher started to refine the ideas and develop the new vest design.

Table 17. *Interaction Matrix of Design Elements for the Vest*

	1	2	3	4	5	6	7	8	9	10	11	12
1 Fit for Female Body		2	2	2	2	2	2	2	2	2	2	2
2 Lighter Vest Weight			2	2	2	2	2	2	2	2	2	2
3 Arm Mobility				2	2	2	2	2	0	2	2	2
4 Torso Mobility					2	2	2	1	2	2	2	2
5 Flexibility						2	2	2	2	2	2	2
6 Quick take on & off							2	2	2	2	2	2
7 Outer Pocket								2	2	2	2	1
8 Side Plates									2	2	2	1
9 Short Sleeves										2	2	2
10 Removable F/B Plates											2	1
11 Lighter Pate weight												2
12 Compatible w/ LBV												

Note: 0 = Conflict; 1 = accommodation; 2 = No Conflict

Design Refinement

After identifying the important features, fit for female body, arm mobility, and compatible with LBV, we developed several ideas in order to achieve the features. However, not every idea was suitable for the design/product. Table 18 showed many

possibilities for the three key features. Design refinement allowed the researcher to pick out the adequate and workable ideas and develop the most suitable design.

Table 18. *Interaction Matrix of Design Implementation Possibilities for the Vest*

	1	2	3	4	5	6	7	8	9	10	11	12	13
Fit for Female Body (neck/chest/armhole)													
1 use stretch fabric		2	0	2	2	2	2	2	2	2	2	2	2
2 change patterns			2	2	2	2	2	2	2	2	2	2	2
3 build darts				2	2	2	2	2	1	0	2	2	2
4 adjustable neckline					2	2	2	2	2	2	1	1	2
5 adjustable armholes						2	2	2	2	0	0	2	2
6 change neckline shape							2	2	2	2	2	2	2
7 change armhole shape								2	2	2	2	2	2
Arm Mobility													
8 no sleeves									2	2	2	2	2
9 no bulky fabric around armholes										2	2	2	2
10 use stretch fabric around armholes											2	2	2
Compatible With LBV													
11 smooth outer surface of vest												0	2
12 attached clips or snaps on the vest													1
13 new LBV													

Note: 0 = Conflict; 1 = accommodation; 2 = No Conflict

Prototype Development

Based on the information obtained before, a new design that meets user needs and other requirements was developed. In this step I will discuss the vest in two parts. One will be the specifications and design of the vest itself, the outer carrier. Second I will discuss how the plate might be changed to better fit the female body.

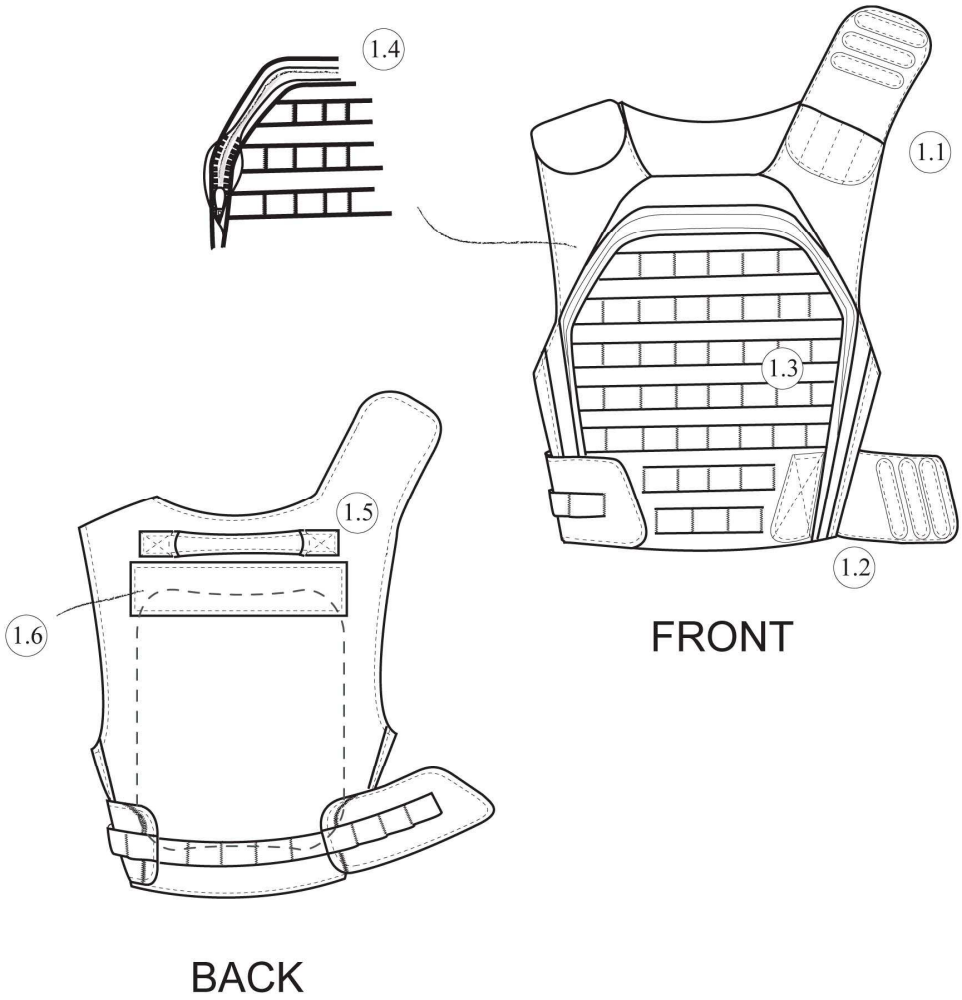
Outer Carrier

Figure 10 shows the front and back views of the new design and its features. The 4” adjustable armhole design (1.1) allows wearers adjust the armhole size as their preference. The 10” side fastening system (1.2) gives wearers extra security at the waist area and also helps fasten down the front plate pocket. The load-bearing system (1.3) is a modular belt that was permanently constructed into the vest and divided into several 1” by 1 1/4” loops. This system allows wearers attach much equipment at one time. The concealable front plate pocket (1.4) was built on the outside of the vest. To allow the plate to fit various bust sizes, and will be discussed in the next section related to the plates. The pocket will be pushed forward while inserting the plate instead inward. This feature helps decrease the pressure that comes from the plates. The pocket also can be zipped up to reduce the volume while the plate is taken out. In the battle when the soldier is down, the rescuer strap (1.5) provides the fast-rescue mechanism that accelerates the rescue movement. The back pocket cover (1.6) provides a full coverage for the back pocket. Velcro closure is used.

Figure 11 shows the open view of the vest. The quick take on and off mechanism is achieved by using the 1 1/2”wide Velcro closure (2.1). To enhance the closure, a couple of snaps with a 5/8” diameter are added on the front Velcro opening to increase the

function. The plate-inserting opening (2.2) also uses Velcro to close up. The length of the plate-inserting opening is 8 1/2”. The 12” long plate fastening elastic strap (2.3) helps secure the plate at the right location and makes sure the plate leans toward.

Figure 12 shows the side view of the vest. The knit side panel (3.1) provides more comfort and fit to wearers. The mesh-like pocket is a multi-function design that can be used as a regular loading pocket or protective side-plate pocket to enhance the protection.



1.1. Adjustable Armhole

1.2. Side Security & Fastening

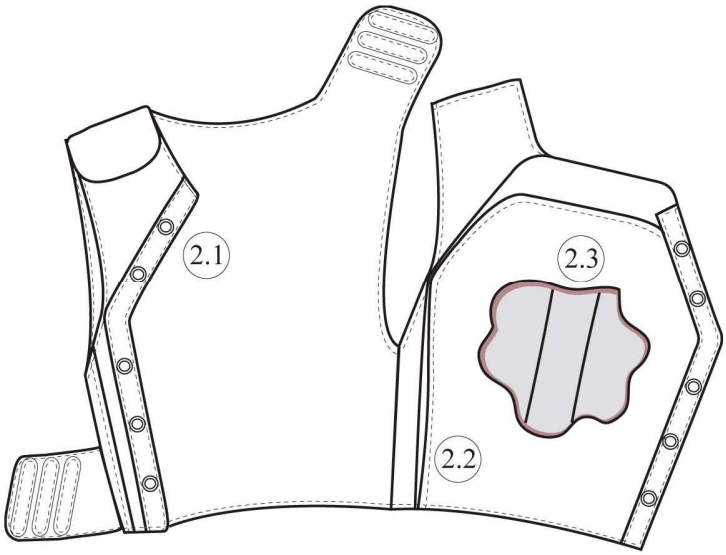
1.3. Loading-Carrying Attachment System

1.4. Concealable Front Plate Pocket

1.5. Rescuer Strap

1.6. Back Plate Pocket Cover

Figure 10. Front and Back Views of the New Design and Its Features

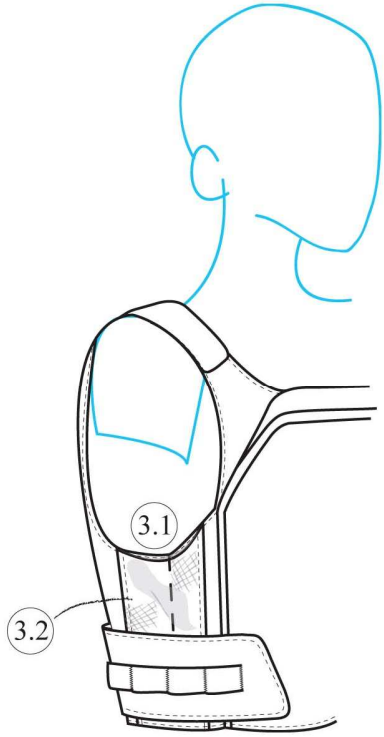


2.1. Double-Secured Front Closure

2.2. Plate-Inserting Opening

2.3. Plate Fastening Elastic Strap

Figure 11. Open View of the New Design and Its Features



3.1. Knit Side Panel

3.2. Mesh-Like Side Pocket

Figure 12. Side View of the New Design and Its Features

Plates

The plates inserted into the vest include one front and one back plate. The front and back of human body are naturally different in shapes, and especially for women there is a big distinction. The coverage for front and back should be different. Moreover, men's torso length is longer then women's. When women were using the plates the plate projected into their chin. Therefore, according to these factors, the researcher provided some modifications to the vest to fit female body.

The biggest problem for the front plate is the length of the plate and its flat shape. From the questionnaire we found the average height of the participants is five feet and six inches, which is a standard height of women. The average bust size for the women in our study had a Bust of 36C. The C cup size can be estimated to project forward approximately 3 inches. Using these body measurements and a calculated bust level of 8 inches it was determined that a plate needs to project out at the top approximately 3 to 4 inches (See Figure 13).

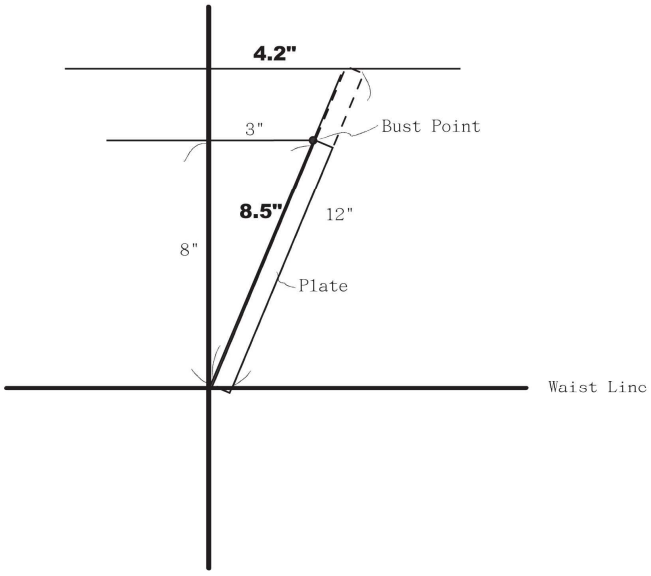


Figure 13. The Dimensional Relationship of the Front Plate & Body

The back could have more coverage. The original back plate shape (See Chapter 2 & 3) was the same as the front one. This is not necessary and actually reduces the amount of back area that the plate can cover. Therefore, the back plate was changed to a near rectangle shape (See Figure 14) to provide more effective protection.

Figure 14. The Back Plate of the New Design

Prototype Evaluation

Design. According to LaBat & Sokolowski's design process (1999), the prototype will not only be made but also evaluated its practicability. In this study, due to the technical reasons the prototype was presented in the specification fashion. Instead of

doing the actual wearing assessment, the feature comparison and evaluation between the *Interceptor*™ and the new design was conducted. The three criteria that obtained from the survey were focused: fit for female body, arm mobility, and compatible with LBV. The features of the *Interceptor*™ and the new design were categorized and then evaluated. Table 19 shows the evaluation results.

Table 19. *The Feature Comparison between the Interceptor™ and New Design*

Features	***Interceptor*™**	**New Design**
Fit for Female Body		
Neck	• Doesn't fit body feature. Poke user's neck in certain postures. • More coverage.	• Lower neckline to avoid the vest poke user's neck. • Less coverage
Chest	• Press user's chest.	• Concealable front plate pocket: leans the plate forward and release the pressure from the plate. • Front pocket projection angle is un-adjustable.
Armhole	• Too big or small.	• Fit better because of the Adjustable Shoulder Straps.
Waist	• Adjustable waist: provides size ease.	• Fit better because of the Side Security & Fastening system. • Knit side panels may

		bring bulky fabric when adjusting the fit.
Arm Mobility	• Low: because of the armhole size and vest.	• High: because of the adjustable shoulder strap and ergonomic armhole shape.
Compatible With LBV	• Compatible.	• Compatible.
Others		
Quick Take on & off	• Front Velcro & snaps opening: gives quick and secure closure mechanism.	• Front Velcro & snaps opening: gives quick and secure closure mechanism.
Neck Protection	• Removable back split collar: provides neck protection. • Uncomfortable (it increases neck area temperature and reduce neck mobility).	• Lower neck protection.

Note: Underlined statements are the defects that were found after the assessment.

The advantages and disadvantages of the *Interceptor*™ and new design were compared in Table 19. Due to the evaluation, some defects of the new design were found. Three flaws were underlined in Table 19: less coverage at neck area, front pocket projection angle is not adjustable, lower neck protection, and side knit panel may bring bulky fabric when adjusting the fit. The neck problem can be solved by developing a neck

protection. Referring to the front pocket projection angle, an adjustable strap can be added on the surface of the front pocket so that wearers can change the projection angle according to their bust size. Knit side panels were built to provide flexible fit. If the waist difference between the wear and the vest is up to 4 inches, the researcher will recommend the wearer change the vest size. So far, in this study the vest size hasn't been discussed, and this could be a topic of future study. Regardless of size, the waist fit can be research a better manner if changing the side panels to unconnected pieces with full side overlap coverage. The solution may provide larger range of adjustment, but it forms a thicker side panel. The researcher believed that there is more than one way to solve each problem. Due to the study schedule, the researcher was not able to implement the suggestions mentioned here, but solutions here could be used for future studies.

Materials. A tactical armor (Type IV) consists of the outer carrier, protection panels, and ballistic plates. The protection panel and ballistic plate have to meet the NIJ standard that had been present in Chapter II. The selection of the outer carrier fabric has more flexibility because it doesn't necessarily contain ballistic materials. In other words, every fabrics meets the specification could be used for the outer carrier. However, in order to ensure the product workability and quality, the researcher provided the material specification that addressed the requirements for the material performances, like abrasion resistance and seam strength. The specification, the minimum requirement, and test method for each characteristic were presented in Table 20.

Table 20. *The Outer Carrier Material Spec.*

Characteristic (Test Type)	Requirement	Test Method
Dimensional Stability/Shrinkage:		
Dimensional change after 5 launderings	3% MAX.	AATCC 135 (Fabric)
Garment Performance:		
Tensile Strength	40 LB	ASTM D5034
Elmendorf Tear	4.0 LB	ASTM D1424
Seam Strength	40 LB	ASTM D1683
Lightfastness	20 HR – Class 4	AATCC 16E

Stage Three: Implementation

The implementation stage is beyond the scope of this study. This stage is very important for companies during the product development process. The exact cost and time to produce as well as the method of production needs to be analyzed in order to mass manufacture the product. The market and sales potentials also need to be taken into consideration. Later, the information becomes knowledge to improve future products. However, in this research, the implementation consists of to many factors that can not be achieved by the researcher.

CHAPTER V

SUMMARY AND RECOMMONDATIONS

This study followed LaBat and Sokolowski's three stage design process through the second stage. The literatures regarding the design process and currently available body armors were presented in the chapter two; the research method and design process were presented in the chapter three and four respectively. User needs were evaluated and taken into consideration during the design development. In this chapter, the study's procedure and findings were summarized. Recommendations for use and for future research were presented.

Summary

The current body armor, the *Interceptor*™, used by the military does not provide enough fit for women. Female soldiers are ordered to wear the body armor that was not built to conform to their bodies. The inadequate body armor could bring more threats than safety to the wearers. Complaints from a female soldier and a comic strip (Figure 1) that talked about the failures of the Interceptor attracted the researcher's attention.

Because women in the military are required to wear the same type IV vest as men, and women do not have the same shape or size as men, the purpose of this study is to develop a type IV body armor which will conform to the female anatomy but also provide more comfort, fit, and mobility to females. Women's body shape demands different shaping of the materials to contour to the body. Under this concept, research focused on identifying female soldiers needs that are not met by the *Interceptor*™ and developing a

new design for women.

There were four objectives the researcher wanted to achieve in this study: 1) To determine the comfort needs of the female wearers for the level IV body armor, 2)to comprehend the current Interceptor level IV vest, including materials, style, and design, 3) To identify the design criteria of the level IV body armor for women based on Objective 1 and Objective 2, 4) To design type IV body armor for women based on the design criteria established in Objective 3.

According to the differences in the protection level of the vests, the body armors are categorized into seven types: type I, type IIA, type II, type IIIA, type III, type IV, and special type (customized specification). Each level has its own specification. The Interceptor belongs to type IV. It is composed of the woven ballistic fabrics and a rigid plate of ballistic material, such as steel, ceramic, or plastic, which meets the ballistic resistant performance requirements of the National Institute of Justice standard-0101.04 (NIJ Standard-0101.40).

LaBat and Sokolowski's three stage design process (1999) was applied in this research. The three stages are 1) problem definition and research, 2) creative exploration, and 3) implementation. In the first stage, problem definition and research, the researcher identified the initial problems, did the research on user needs and market, and determined the working problems. A questionnaire was used to collect information and opinions in this study. There were 11 female soldiers from Oregon National Guard who participated in this study. Questions pertained to the user's personal information, general information between them and the vest, movements and activities, experience of wearing the *Interceptor*™ body armor, and their perceptions about the vest design were asked. Quantitative and qualitative methods were used to analyze the data. Based on the results

chest, neckline, and armhole areas were determine as the areas that need to be modified. Generally, the respondents indicated that the chest area is too tight; the neckline edge sometimes pokes the wearers' throat; the armhole is too big or small. In the users' opinions, it is important for the vest to fit female's body, give good arm mobility, and compatible with LBV. The researcher also did some market research on interceptor and other women's body armor. The information helped the researcher analysis the advantages and disadvantages of the interceptor and existing vests as well as get some design ideas for the new design.

In the second stage, creative exploration, the new vest design was based on the user needs. The design criteria obtained from the research stage also helped the researcher to analyze and develop the new design. The design specification was accomplished. In the third stage, implementation, because it consists of many factors that are not able to achieve only through the researcher, this stage is beyond the study.

Limitations of the Study

Some limitations occurred during conducting the study. The study would own a different or better value if the limitations could be eliminated. The limitations of the study are:

1. **The number of the research participants is limited.**

Only 11 female soldiers participated in this study. To a quantitative study, 11 participants is a very small population. If the population could increase to at least 30, the

statistic results would be more meaningful. The focus group is not general. This study focused on a certain cohort, female soldiers, thus the researcher encountered the difficulty of finding participants.

Although the researcher provided a web survey and paper survey for potential participants, the response was out of the researcher's expectation. The web survey obtained zero response. The researcher thinks that potential participants were not willing to spend 10 minutes answering the web survey because there was no incentive provided for participating/answering the questionnaire. Therefore, for the future studies it would be a good idea to provide a little incentive to attract participants.

2. The participating group is not a random sample according to the limitation 1.

As the researcher presented for the first limitation, the participating group focused on only female soldiers in Oregon National Guard. It had been hard to find participants, thus it was not appropriate to use random sample. However, if in the future the participant resource could be extent, in order to generalize and to provide a more powerful study results it would be helpful to use random sample.

3. Due to the complexity of manufacturing a prototype, design specifications will be used to describe the new design.

Type IV body armor consists of ballistic materials that are too rigid to sew or produce: Kevlar for protection panels and boron carbide ceramic for plates. Without the special construction machine, the outer carrier (the soft armor) with protection panel (Kevlar) is hard to make. The plates also need a certain technique and facility to produce. Therefore, the study is not able to construction a prototype and a wear test.

Recommendation for Use of the Study

The design criteria proposed in this study could be beneficial to the scholars and manufacturers who are interested in developing body armor, especially for women. The new design provides a future perspective of the vest. Female soldiers would benefit greatly from its implementation.

Recommendation for Further Research

Based on the results of this study, further research could be conducted in the following areas:

1. A larger sample size could be used for the questionnaire data collection.
2. The resources of participants could be sought from more military departments or divisions, such as marine crop or more National Guard divisions.
3. The prototype of the design could be made and evaluated.
4. The study could be continued through the last stage, implementation, of LaBat and Sokolowski's three stage design process.

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APPENDICES

APPENDIX A

HUMAN SUBJECT APPROVAL LETTER

TO: Kathy Mullet
Design and Human Environment

IRB #: 3880 – Design Criteria of Type IV Body Armor for Women (Student Researcher: Tsun-Yin Tung)

Level of Review: Expedited

Expiration Date: 2-27-09

Approved Number of Participants: 150

The referenced project was reviewed under the guidelines of Oregon State University's Institutional Review Board (IRB). The IRB has **approved** the:

( ) Initial Application ( ) Continuing Review (X) Project Revision dated 4-10-08

with a (if applicable): ( ) Waiver of documentation of Informed Consent ( ) Waiver of Consent

A copy of this information will be provided to the full IRB committee.

- **CONSENT FORM:** All participants must receive the IRB-stamped informed consent document. If the consent is in a format that could not have stamp placement (i.e. web site language, email language, etc), then the language must be **exactly** as the IRB approved it.
- **PROJECT REVISION REQUEST:** Any changes to the approved protocol (e.g. protocol, informed consent form(s), testing instrument(s), research staff, recruitment material, or increase in the number of participants) must be submitted for approval before implementation.
- **ADVERSE EVENTS:** Must be reported within three days of occurrence. This includes any outcome that is not expected, routine and that result in bodily injury and/or psychological, emotional, or physical harm or stress.

- **CONTINUING REVIEW:** A courtesy notice will be sent to remind researchers to complete the continuing review form to renew this project, however – it is the researcher's responsibility to ensure that continuing review occurs prior to the expiration date. Material must be submitted with adequate time for the office to process paperwork. If there is a lapse in approval, suspension of all activity including data analysis, will occur.
- **DEVIATION/EXCEPTIONS:** Any departure from the approved protocol must be reported within 10 business days of occurrence or when discovered.

Forms are available at: http://oregonstate.edu/research/osprc/rc/humansubjects.htm.

If you have any questions, please contact the IRB Human Protections Administrator at IRB@oregonstate.edu or by phone at (541) 737-8008.

Elisa Espinoza Fallows

Date: 4-23-08

Elisa Espinoza Fallows
IRB Human Protections Administrator

APPENDIX B

QUESTIONNAIRE

Informed Consent Document

Project Title: **Design Criteria of Type IV Body Armor for Women**
Principal Investigator: **Dr. Kathy Mullet, Design and Human Environment**
Co-Investigator(s): **Tsun-Yin Tung, Master student, Design and Human Environment**

- **WHAT IS THE PURPOSE OF THIS STUDY?**

You are being invited to take part in a research study designed to develop a type IV body armor which will conformed to the female anatomy but also provides more comfort, fit, and mobility to females. The body armor using in the military, called *Interceptor*™, is only made for men's bodies. Women's body shape demands different shaping of the materials to contour to the body. The questionnaire is designed to collect female soldiers' opinions which can help the researcher develop new women body armor. The results from the questionnaire will be used in the scholarly journals and researcher's thesis. We are studying this because it is important to raise female solders' safety level in the battle.

- **WHAT IS THE PURPOSE OF THIS FORM?**

This consent form gives you the information you will need to help you decide whether to be in the study or not. Please read the form carefully. You may ask any questions about the research, the possible risks and benefits, your rights as a volunteer, and anything else that is not clear. When all of your questions have been answered, you can decide if you want to be in this study or not.

- **WHY AM I BEING INVITED TO TAKE PART IN THIS STUDY?**

If you are a female soldier who has the experience of wearing the *Interceptor*™ body armor, acquired from the government, you are being invited to take part in this study. However, if you are under 18 years old, we ask for a waiver of parental permission as well as consent from you.

- **WHAT WILL HAPPEN DURING THIS STUDY AND HOW LONG WILL IT TAKE?**

If you agree to take part in this study, your involvement will last for 5~10 minutes during which you would complete the questionnaire. You will be asked questions pertaining to your personal information, general information between you and the vest, and experience of wearing the *Interceptor*™ body armor.

- **WHAT ARE THE RISKS OF THIS STUDY?**

There are no foreseeable risks to participating in this study.

- **WHAT ARE THE BENEFITS OF THIS STUDY?**

You will not benefit from being in this study. However, we hope that, in the future, other people might benefit from this study because this study will help raise the safety of female soldiers in the battle.

- **WILL I BE PAID FOR PARTICIPATING?**

You will not be paid for being in this research study.

- **WHO WILL SEE THE INFORMATION I GIVE?**

The information you provide during this research study will be kept confidential to the extent permitted by law. To help protect your confidentiality, any identifying information will be removed when transcribing questionnaire data. Your name will not be associated with your response. If the results of this project are published your identity will not be made public.

- **DO I HAVE A CHOICE TO BE IN THE STUDY?**

If you decide to take part in the study, it should be because you really want to volunteer. You will not lose any benefits or rights you would normally have if you choose not to volunteer. You can stop at any time during the study and still keep the benefits and rights you had before volunteering.

You will not be treated differently if you decide to stop taking part in the study. You are free to skip any question(s) that you would prefer not to answer in the questionnaire. If you choose to withdraw from this project before it ends, the researchers may keep information collected about you and this information may be included in study reports.

- **WHAT IF I HAVE QUESTIONS?**

If you have any questions about this research project, please contact: Dr. Kathy Mullet, at 541-737-3818, or by email at: Kathy.Mullet@oregonstate.edu or Tsun-Yin Tung (Tracie), at 541-908-0305, or by email at: tungt@onid.orst.edu

If you have questions about your rights as a participant, please contact the Oregon State University Institutional Review Board (IRB) Human Protections Administrator, at (541) 737-4933 or by email at IRB@oregonstate.edu.

If you would like to participate in this research, please turn the page over and answer the following questions.

BODY ARMOR QUESTIONNAIRE

I am a graduate student at Oregon State University, majoring in Apparel Design. For my thesis I am interested in the *fit* and *use* of the Interceptor™ body armor by female soldiers.
The Interceptor™ vest is the body armor which the US government provides to combat soldiers.
This questionnaire is for female soldiers who have worn the Interceptor™ body armor.
Your contribution will help the researcher develop a better vest and improve female soldier's safety in battle. Please answer the following questions based on your experiences.

Section I: General Information

Please answer the following questions to help the researcher understand the relationship between you and the vest you own. If you have owned more than one InterceptorTM vest, please choose the one you acquired most recently as the answering reference.

Please **Circle** the Answer.

e.g.

* Do you have the experience of wearing the Interceptor™ vest?

1) No
2) Yes

1. What size is your most recently acquired vest?

1) XS (Extra Small)
2) S (Small)
3) M (Medium)
4) L (Large)
5) XL (Extra Large)

2. How long have you been serving in the military?

1) Less than 1 year
2) 1~5 years
3) 6~10 years
4) 11~15 years
5) 16~20 years
6) More than 20 years

3. How long have you owned the vest?

1) Less than 1 year
2) 1~3 years
3) 4~6 years
4) More than 6 years
5) Never owned one

4. How many times have you worn the vest with the plates inserted?

1) Less than 5 times
2) 5~10 times
3) More than 10 times
4) Never

5. On occasions when you wear the plates, what is the average length of time that you wear the plates?

1) Less than 1 hour
2) 1~6 hours
3) 7~12 hours
4) More than 12 hours

Section II: Fit Assessment

Please answer the following questions to help the researcher to evaluate the fit of the current vest. For this research fit is defined as how well a garment conforms to the female body shape. The following questions relate to the vest fit **without** and **with** plates.

6. **Evaluate the fit of each area when wearing the vest without plates.**

	Does not fit.				Fit is good.
1) Neckline (without plates)	1	2	3	4	5
2) Chest (without plates)	1	2	3	4	5
3) Waist (without plates)	1	2	3	4	5
4) Bottom edge of the vest-"Hem" (without plates)	1	2	3	4	5
5) Armholes (without plates)	1	2	3	4	5
6) Vest length (without plates)	1	2	3	4	5

7. **If you've answered "1" (Does Not Fit) in the previous question, use the space below to write down the specific area/areas and elaborate on why each area does not fit.**

_____

_____

_____

8. **Are there any other areas that do not fit and are not on the list above?**
   1) No
   2) Yes

9. **If you answered "Yes" in Question 8, use the space below to write down the specific area/areas and elaborate on why each area does not fit.**

_____

_____

_____

10. **Based on your responses to Question 6 & Question 9, indicate which one specific area of the vest (without plates inserted) has the poorest fit.**

_____

11. **Evaluate the fit of each area when wearing the vest with plates.**

	Does not fit.				Fit is good.
1) Neckline (with plates)	1	2	3	4	5
2) Chest (with plates)	1	2	3	4	5
3) Waist (with plates)	1	2	3	4	5
4) Bottom edge of the vest-"Hem" (with plates)	1	2	3	4	5

5) Armholes (with plates)	1	2	3	4	5
6) Vest length (with plates)	1	2	3	4	5

12. If you've answered "1" (Does Not Fit) in the previous question, use the space below to write down the specific area/areas and elaborate on why each area does not fit.

_____

_____

_____

13. Are there any other areas that do not fit and are not on the list above?

1) No
2) Yes

14. If you answered "Yes" in Question 13, use the space below to write down the specific area/areas and elaborate on why each area does not fit.

_____

_____

_____

15. Based on your responses to Question 11 & Question 14, indicate which one specific area of the vest (without plates inserted) has the poorest fit.

_____

Section III: Movement Analysis

Please answer the following questions to help the researcher understand what activities/movements are important for you to perform when wearing a vest.

16. When wearing the vest (<u>without plates</u>), how important is it to be able to do the following movements?

	Not Important				Very Important
1) Walking	1	2	3	4	5
2) Running	1	2	3	4	5
3) Jumping	1	2	3	4	5
4) Kneeling	1	2	3	4	5
5) Sitting	1	2	3	4	5
6) Standing	1	2	3	4	5
7) Squatting	1	2	3	4	5
8) Lifting	1	2	3	4	5
9) Crawling	1	2	3	4	5
10) Shouldering	1	2	3	4	5
11) Shooting	1	2	3	4	5
12) Head rotation	1	2	3	4	5
13) Torso twist	1	2	3	4	5
14) Bending at waist	1	2	3	4	5
15) Cross arms	1	2	3	4	5
16) Take on & off	1	2	3	4	5

17. Are there any other movements that you think are important to be able to do when wearing the vest but not on the list above?

1) No
2) Yes

18. If you answered "Yes" in Question 17, what are the movements?

_____

19. When wearing the vest (with plates), how easy is it to perform the following movements?

	Easy		Hard	N/A
1) Walking	1	2	3	4
2) Running	1	2	3	4
3) Jumping	1	2	3	4
4) Kneeling	1	2	3	4
5) Sitting	1	2	3	4
6) Standing	1	2	3	4
7) Squatting	1	2	3	4
8) Lifting	1	2	3	4
9) Crawling	1	2	3	4
10) Shouldering	1	2	3	4
11) Shooting	1	2	3	4
12) Head rotation	1	2	3	4
13) Torso twist	1	2	3	4
14) Bending at waist	1	2	3	4
15) Cross arms	1	2	3	4
16) Take on & off	1	2	3	4

20. Are there any other movements that not easy to perform when wearing the vest (with plates) and not on the list above?

1) No
2) Yes

21. If you answered "Yes" in Question 20 what are the movements?

_____

Section IV: Design Elements Analysis

Please answer the following questions to help the researcher determine the design elements needed for the vest.

22. Do you think it is important to have these following features on the vest? Please indicate the importance of the following vest design features:

	Not Important				Very Important
1) Fit for Female Body	1	2	3	4	5
2) Lighter Vest Weight	1	2	3	4	5
3) Arm Mobility	1	2	3	4	5
4) Torso Mobility	1	2	3	4	5
5) Flexibility	1	2	3	4	5
6) Quick take on & off	1	2	3	4	5
7) Color	1	2	3	4	5
8) Outer Pocket	1	2	3	4	5
9) Inner Pocket	1	2	3	4	5
10) Side Plates	1	2	3	4	5
11) Soft Outer Fabric	1	2	3	4	5
12) Breathable Outer Fabric	1	2	3	4	5
13) Have Short Sleeves	1	2	3	4	5
14) Have Long Sleeves	1	2	3	4	5
15) Removable Front & Back Plates	1	2	3	4	5

16) Lighter Plate Weight	1	2	3	4	5
17) Compatible with LBV	1	2	3	4	5

23. According to Question 22, are there any other features that are not on the list above but are important/useful to have on a vest? Like:

_____

_____

_____

Section V: Personal information

The following questions are related to your personal information. However, **they are very significant and critical to this research.** Please answer following questions to help the researcher analysis the questionnaire. This is an anonymous survey, so people will not be able to identify you by looking at your answers.

24. How tall are you (feet and inches)?

_____

25. What is your waist size (inch)?

_____

26. What is your bust size? In the space below, write down your chest circumference & cup size (for example, if you wear a size 36 C bra, write down "36 C" to the space below).

_____

Thank you very much for your contribution!

We appreciate your time and sharing!

If you have any questions about this research project/survey or you want to provide some information, please contact:

- Dr. Kathy Mullet, at 541-737-3818, or by email at: Kathy.Mullet@oregonstate.edu or
- Tsun-Yin Tung (Tracie), at 541-908-0305, or by email at: tungt@onid.orst.edu