CHAPTER 1
INTRODUCTION

Since the introduction of concealable body armor in 1973 (NIJ guide 100-01), at least 2500 lives have been saved (p. 12). Although body armor may offer adequate ballistic protection, it does not sufficiently meet other needs of the officers. Many officers fail to wear their vests because they are uncomfortable (Olsen, 1981; Watkins, 1995; Rutherford-Black & Khan, 1995).

The improvement of men’s ballistic vests is especially important, since the number of male law enforcement officers exceeded 700,000 in the year 2000, according to a study by the Bureau of Justice (August 2002, p. 8). That study also found that over 80% of sworn personnel were men. Consequently, the majority of officers on the streets in need of protection are male. Of the seven different protection levels available, the ballistic protection level most commonly chosen by law enforcement officers for the vests is Level II. This research will examine comfort related to Level II ballistic vests worn by male law enforcement officers, including such aspects as fit, mobility, and thermal acceptability.

Olsen (1981) and Rutherford-Black et al. (1995) have identified comfort as a need of officers not being met. The comfort of officers wearing ballistic vests has both physical and psychological dimensions. Physical comfort is affected by mobility (Huck, Maganga, & Kim, 1997). In addition, officers must feel safe and protected in vests, giving them psychological comfort.

Officers’ performance can be affected by their comfort level when wearing the vest (Watkins, 1995). Often, the thickness of ballistic materials used in the vest allows minimal heat dissipation (Watkins, 1995). Poor heat dissipation can cause thermal discomfort, hinder performance, and can be dangerous if heat illnesses develop.

Another factor in the comfort of bulletproof vests is fit. Fit is determined by the inter-relationships of the garment with measurements of the body and other garments worn. Good fit has been shown to be essential for the wearer's satisfaction with the garment (Ashdown & Delong, 1995). The poor fit of vests can make the wearer uncomfortable and hinder their movements (Watkins, 1995).

Watkins (1995) identifies mobility as a comfort need for those wearing ballistic vests. She identifies several factors in the ballistic vest design that affect mobility, including the weight and bulk of the fabric or other ballistics protection used. Hindrances on movement can be detrimental, even life threatening, to a law enforcement officer.

Purpose

A review of literature revealed the need to improve the comfort of traditional ballistic vests, including mobility, fit, and thermal assessment. The overall purpose of this study was to evaluate two types of bullet resistant vests for male police officers. The levels of satisfaction for each vest type were compared to help identify ways of improving ballistic vests. The two Level II vests were of similar design but the panels were of different fabrication: one was made of traditional ballistic fabric while the second was a prototype vest fabricated from an experimental ballistic fabric. Both vest types were the traditional ballistic vest design and used the same outer carrier. The research will follow DeJonge's Functional Design Process. Her process involves seven stages but this study will consider the first five. These stages are described as they relate to the research questions.

Research Questions

1. What are the daily activities of law enforcement officers while wearing Level II ballistic vests?

   As part of DeJonge's Functional Design Process, the problem structure is perceived through assessing critical factors (DeJonge, 1984). Activities performed while wearing ballistic vests will influence the design of the new prototype panels. A strong understanding of situations the vest is used for will help in the development of a task-specific prototype. Officers were interviewed to determine the types of activities they perform while wearing ballistic vests.

2. What effect did the new prototype fabric have on range-of-motion or movement of the officers?

   It is important that the prototype vest panels function properly during specific movements and activities the officers are required to make. For example, can the vest be worn while an officer sits in a car or runs after a suspect? A vest that hinders these types of movements would not meet the needs of officers. Officers wearing ballistic vests performed a movement analysis consisting of task-related movements and rated their level of satisfaction with each vest type.

3. What effect did the new prototype fabric have on a current Level II vest design?

   Current vest fabrics are not meeting comfort needs of law enforcement officers. An investigation of effects the prototype fabric has on the current vest design should be conducted to determine critical factors (DeJonge, 1984). This can include a wearer acceptability scale. It was expected that apparel needs of officers' would include comfort aspects. Additional criteria may be studied after specifications are organized into an interaction matrix.

Objectives

The researcher addressed this study's purpose through the application of the DeJonge Functional Design Process. Key objectives were to:

1. Ascertain specific daily tasks police officers perform when wearing Level II vests using input from officers and through researcher observation.
2. Identify specifications for prototype ballistic vest for police officers. Input came from a literature search, officer interviews, and an activity analysis.
3. Conduct a range of motion and movement analysis to measure the officers' performance objectively.
4. Conduct a wearer acceptability scale to identify the officers' needs. It was anticipated that comfort aspects (i.e. fit, mobility, thermal acceptability) and psychological aspects would be key components in the subjective evaluation.

5. Evaluate the prototype ballistic panels based on key criteria derived from the design specifications and the interactive matrix.

Hypotheses

The following hypotheses were examined during this study:

H_1: There is a significant difference with the prototype vest performing more positively than the traditional vest in vest function when officers perform task-related movements.

H_2: There is a significant difference in the level of fit satisfaction for the wearer with the prototype vest having more negative satisfaction ratings than the traditional vest.

H_3: A significant difference in comfort of the vests will occur with the prototype vest performing more positively than the traditional vest.

H_4: Overall satisfaction levels related to vest performance and comfort will show a significant difference with the prototype vest having ratings that are more positive when officers compare the traditional and the prototype vests.

Rationale for the Study

The literature review revealed a growing need for law enforcement officers to wear ballistics protection. Between 1991 and 2000, 644 law enforcement officers were killed (Federal Bureau of Investigation, 2001, p. 13). Firearms caused the majority of these deaths. Despite the need for officers to wear ballistic protection, many officers choose not to wear ballistic vests because current ballistic vest designs can be uncomfortable for the officers and hinder their movement (Olson, 1981; Watkins, 1995). The intent of this study was to use key criteria to assess the traditional Level II ballistic vest, and compare and contrast it to a Level II prototype vest with ballistic inserts of different fabrication. Further clarification was gained about the needs of law enforcement officers and the performance of the prototype fabric. The results of this study are useful for law enforcement officers, law enforcement agencies, and the military.

Limitations

The following limitations were placed on this study:

1. There were a limited number of participants in this study. Hence, only limited generalizations can be made beyond the selected population as defined by the sample.
2. The study was limited to the acquired and developed ballistic vest size and style.
3. A non-random selection of male subjects was used for this study.

Assumptions

The researcher made the following assumptions:

1. By using the American Society for Testing and Materials (ASTM) test, F1154-99, the researcher was able to effectively measure the range of motion officers use while performing daily tasks.
2. Officers were able to perform the movements required for the movement analysis.
3. Officers were able to understand any questions the researcher asked during the interview.
4. Officers were able to express their needs and responded conscientiously.

Definition of Terms

Armor carrier: "A component of the armor sample or armor panel whose primary purpose is to retain the ballistic panel and provide a means of supporting and securing the armor garment to the user. These carriers are not generally ballistic resistant." (NIJ standard 0101.04, 2000, p. 3)

Armor panel: "The portion of an armor sample that generally consists of an external carrier and its internal ballistic protective component(s)." (NIJ standard 0101.04, 2000, p. 3)

Comfort: "a mental state of ease or well-being, a state of balance or equilibrium that exists between a person and his or her environment." (Maher & Sontag, 1986, p. 2)

Fit: "the relationship of the garment to the body." (Watkins, 1995, p. 264)

Functional design process: "The nature of design and the thought processes and methods designers use to develop effective design solutions." (Watkins, 1995, p. 334) Stages of the design process are "request made, design situation explored, problem structure perceived, specifications described, design criteria established, prototype developed, design evaluation." (DeJonge, 1984, p. viii)

Design prototype: "is cut and sewn from the first pattern to evaluate the styling and fit." (Glock & Kunz, 2000, p. 168)

Insert: "a removable or nonremovable unit of ballistic material which can be part of either the armor or ballistic panel, which is utilized to enhance the ballistic performance of an armor in a specific area." (NIJ standard 0101.04, 2000, p. 5)

Mobility: "the ease with which an articulation, or a series of articulations, is allowed to move before being restricted by the surrounding structures." (Kreighbaum & Barthels, 1985, p. 644)

Movement analysis: "collects data by notating or recording body movement so that movement data from many participants can be compared and a complete cycle of movements can be charted." (Watkins, 1995, p. 226)

Officer safety: "the measures taken at the strategic, tactical, and operational levels to minimize the risk of harm from violence to officers." (Baskind, 1999, p.14)

Objective range of motion: "quantifies movement capability by measuring change in joint angles or reach distances with respect to some pre-determined reference position. Such measurements typically utilize goniometers or some other physical measurement device to quantify changes in body postures as subjects perform a carefully defined set of simple movements." (Adams & Keyserling, 1996, p. 312)

Perception of fit: "A constant stimulus difference test, or difference from control test…The test consists of the presentation of a series of samples to a panel of experts. Each sample of the series is presented along with a control sample. The panel member rates the difference of the sample from the control. The control is presented as a test sample at random intervals to test whether the participant will judge 'no difference' when the control is compared with itself." (Ashdown & DeLong, 1995, p. 49)

Range of motion: “the total amount of angular displacement through which two adjacent segments may move.” (Kreighbaum & Barthels, 1985, p. 645)

Strike face: “the surface of an armor sample or panel, designated by the manufacturer, as the surface that should face the incoming ballistic threat.” (NIJ standard 0101.04, 2000, p. 7)

Subjective range of motion: “relies on wearer perceptions, wherein wearers are asked to rate or otherwise indicate their feelings about the test garment after performing a battery of pre-defined movements. An alternate approach is to have subjects perform simulated tasks and then ask for feedback regarding the garment’s effect on mobility.” (Adams & Keyserling, 1996, p. 312)

Type II ballistic vest (9mm; 357 Magnum): “This armor protects against 9mm Full Metal Jacketed Round Nose (FMJ RN) bullets, with nominal masses of 8.0 g (124 gr) impacting at a minimum velocity of 358m/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 0101.04, 2000, p. 2)

Wear face: “the surface of an armor sample or panel, designated by the manufacturer, as the surface that should be worn against the body.” (NIJ standard 0101.04, 2000, p. 7)

CHAPTER 2
REVIEW OF LITERATURE

An examination of functional design, including DeJonge's Functional Design Process and clothing research related to comfort, including fit and mobility, a description of body armor and its uses, specifically Level II ballistic vests, and the problems related to body armor are included in this review of literature.

Functional Design

Designing clothing for a specific function requires more than just creativity. A designer should also seek out, absorb, and apply information regarding the wearer's needs and expectations. A systematic approach is often used in functional clothing research to help designers incorporate all aspects of design.

DeJonge's Functional Design Process

Watkins (1995) has suggested, "a designer must be familiar with both content and process" (p. 335). DeJonge's (1984) functional design process defines a systematic approach from the initial idea through the final design evaluation. A description of each step in the DeJonge process follows.

The first step of the DeJonge (1984) design process is the *general request*, a broad problem statement of the clothing need. The request can be a formal expression of need from the wearer or just a general statement of the objective made by the designer. This step can incorporate brainstorming with other designers, observations of garments and the wearer, and user interviews (Bergen, Capjack, McConnan, & Richards, 1996; DeJonge, 1984).

Exploration of the design situation follows, consisting of a statement of objectives, literature search, and further definition of the problem. Further observations or market analysis could also be part of this step (Bergen, Capjack, McConnan, & Richards, 1996; DeJonge, 1984; Huck & Kim, 1997; Lawson & Lorentzen, 1990).

The *problem structure* is *perceived* through an assessment of critical factors. A designer may find needs assessment, movement analysis, thermal assessment, impact testing, and social-psychological assessment helpful (Ashdown & DeLong, 1995; Black, 1988; Huck, Maganga, Kim, 1997; Bergen, Capjack, McConnan, Richards, 1996; DeJonge, 1984; Huck & Kim, 1997; Lawson & Lorentzen, 1990; Rutherford-Black & Khan, 1995; Yoo, 1996).

Next, the *design specifications and criteria are established*, including functional and psychological requirements. It may be necessary to prioritize the criteria. When the *prototype is developed*, it should be evaluated against the design specifications and tested for performance (Bergen, Capjack, McConnan, & Richards, 1996; DeJonge, 1984; Huck, Maganga, & Kim, 1997; Huck & Kim, 1997; Lawson & Lorentzen, 1990).

After the prototype is evaluated, the final *design development* occurs. There should be an objective analysis of the final design, which may include a range of motion analysis, video analysis, comfort testing, or movement analysis (Bergen, Capjack, McConnan, & Richards, 1996; DeJonge, 1984; Huck & Kim, 1997). There may also be a subjective analysis of the design (DeJonge, 1984; Huck & Kim, 1997).

Functional Clothing Research

Clothing should meet the needs and requirements of the wearer. For example, these needs can be fit, comfort, mobility, general acceptability, and protection (Crockford, 1977; Watkins, 1995). Functional design allows for task-related movement and can accommodate special needs of the wearer.

Task-related needs apply when the wearer expects the garment to function specifically for one task or objective, such as protective clothing for occupational or athletic purposes (e.g. chemical protective suits, football pads). When not performing that task, the wearer does not require this specification in other garments. Various studies show the inadequacies of clothing for tasks such as women's golf (Wheat & Dickson, 1999), ice hockey (Watkins, 1977), police bicycling (Rutherford-Black & Khan, 1995), grass fire fighting (Huck, Maganga, & Kim, 1997), and flight (Tan, Crown, & Capjack, 1998). The inadequacies range from poor fit and sizing problems (Tan, Crown, & Capjack, 1998; Wheat & Dickson, 1999; Yoo, 1996) to inappropriate design features (Huck, Maganga, & Kim, 1997; Rutherford-Black & Khan, 1995; Watkins, 1977; Yoo, 1996).

Wheat and Dickson (1999) examined golf team uniforms for female golfers and found a correlation between well-fitting, aesthetically attractive uniforms and uniform satisfaction. Fit was a source of dissatisfaction for 66% of female golfers when asked about their current uniforms (p. 7). In addition, 21% of players' reported aspects of comfort when describing their uniform satisfaction (p. 7). Another evaluation of uniforms examined ice hockey uniforms and found impact protection and mobility to be important factors when developing new ice hockey uniforms (Watkins, 1977).

A study of police bicycling uniforms investigated officers' satisfaction levels with their uniforms (Rutherford-Black & Khan, 1995). Findings suggested that the fabric and design of police bicycling uniforms be reevaluated with emphasis placed on fit, snagging, and wrinkle recovery. Officers also complained about their ballistic vests not being long enough or riding up when on their bicycles, leaving their lower backs unprotected (Black, personal communication, 2002).

In other studies, evaluations of protective overalls indicated that proper ease amounts could maximize wearer mobility (Huck, Maganga, & Kim, 1997). These studies identified safety, comfort, wearer acceptance, and production as design specifications (Huck & Kim, 1997; Huck, Maganga, & Kim, 1997; Rucker, Anderson, & Kangas, 2000). A 3.8% to 28.7% increase in range of motion while wearing protective overalls was associated with design features that allowed for more mobility, such as stretch panels and appropriate ease (Huck & Kim, 1997, p. 354). The study also attributes the increased range of movement to good fit for pertinent measurements like torso length (p. 355).

In a 1998 study of flightsuit design, interviews of pilots revealed that fit, comfort, and safety were the most critical criteria for flightsuits (Tan et al., 1998). A follow-up evaluation of flightsuits found differences in protection levels based on the style, fit, closure system, and seam type (Crown, Ackerman, Dale, & Tan, 1998). Significantly fewer burn injuries were observed in two-piece flightsuits than one-piece flightsuits (p.

82). In addition, higher protection levels were observed when garments had closer-fitting design details (p. 82). The findings of previous studies regarding task-related needs can be applied to future studies.

Designing for individuals with special needs is a branch of functional design focusing on individuals' needs rather than the task-related needs. Designing for special needs can have many requirements, including the comfort, mobility, accessibility, and ways of normalizing the wearer's appearance. For example, garment size, style selection, and comfort are listed among the most frequently reported problems of tall and petite consumers that have special needs (Yoo, Khan, & Rutherford-Black, 1999). When asked to evaluate clothing attributes by the degree of importance, both petite and tall-sized consumers rated fit as the most important factor (p. 227). Petite women rated comfort as the second most important attribute, while tall-sized women indicated comfort as the fourth most important attribute (p. 227).

A study of clothing for the neonate (Bergen, Capjack, McConnan, & Richards, 1996) identified clothing needs to be comfort, safety, adjustability, accessibility, aesthetics, and production. The same study also found thermal regulation, mobility, and pacification of the wearer to be important. The majority of neonatal caregivers who participated in the study preferred the prototype garments with design features for comfort, including seam allowances in the outside of the garment, different fabric, and fold-over closures on the sleeves and bottom (p. 230).

Comfort

Clothing provides comfort to the wearer, both physically and psychologically. Comfort is defined as "a value state that exists between the individual and the environment" (Maher & Sontag, 1986, p. 3). Branson and Sweeney (1991) propose that person attributes, clothing attributes, and environment attributes influence comfort.

Research indicates that clothing that is not comfortable will not be worn (Shanley, Slaten, & Shanley, 1993). Physical comfort is impacted by mobility, among other things. Mobility can be affected by ease and the dynamic aspects of fit, defined as "how manipulation of ease in one area of the garment may affect the fit of other areas of the garment" (Huck & Kim, 1997, p. 43).

The wearer's perception of fit is one aspect that influences their psychological comfort level. The surrounding culture and societal issues as well as visual and tactile information affect the perception of fit. In addition, perception of fit is affected by the wearer's past experiences with clothing, fit preferences, desire for comfort, and feelings about their body (Ashdown, 2001). When the wearer perceives a garment to fit well, they are more likely to feel psychologically comfortable.

Fit

The body/garment interface, or fit, is defined by Ashdown as the "perceived relationship between body surface and the garment" (DeLong, Ashdown, Butterfield, & Turnbladh, 1993, p.2). Fit is determined by the interaction of the garment with body measurements, which must be accurate and precise. The clothing size and design features also affect fit.

Good fit is essential for the wearer's comfort and satisfaction with the garment. LaBat and DeLong (1990) wrote, "Because the consumer determines on an individual basis what comprises good fit, an understanding of fit satisfaction from the consumer's perspective is an important and complex issue" (p. 47). An evaluation of fit of chemical protective gloves found that sizing and design criteria affect a wearer's fit satisfaction (Tremblay-Lutter, Crown, & Rigakis, 1996). The study found that as the final fit rating increased for a glove, the decrements in performance on dexterity tests decreased (p. 222).

The fit of a garment is affected by ease. Ease is the additional fabric needed to cover the body at certain locations and directly influences mobility and comfort through fit ease and style ease (DeLong et al., 1993). Fit ease allows for body movement and prevents the garment from binding. Style ease is "the amount of fullness added to create visual effect" (1993, p. 2).

DeLong et al. (1993) identified four factors that affect the amount of ease needed: Garment fashion, fabric type, body movement, and wearer's level of activity. Ashdown and DeLong's ease study (1995) found that ease preferences vary at different points on the body and that there is variation from one individual to the next. In addition, a better fitting garment requires less ease to accommodate mobility (DeLong et al., 1993).

Mobility

Mobility is required when performing any work that is not a purely cognitive task (Adams, Slocum, & Keyserling, 1994). There are different aspects of mobility, described as speed, direction, force, accuracy, and magnitude (Adams et al., 1994; Watkins, 1995). Adams et al. (1994) developed a framework for understanding the effects of personal protective clothing on worker performance. The model identifies four causal factors that may reduce productivity, increase physiological strain, and reduce comfort. The four causal factors are garment properties, task requirements, worker characteristics, and environmental conditions. The wearer's work requirements and activities will determine the movements and characteristics of those movements that should be studied (Adams et al, 1994; Watkins, 1995).

Movement studies are used to determine whether clothing (DeJonge, 1984) inhibits the subject's performance. A movement study "collects data by notating or recording body movement so that movement data from many participants can be compared and a complete cycle of movements can be charted" (Watkins, 1995, p. 226). Several steps are important when conducting a movement analysis: identify movement aspects critical to a person's activities, determine optimal movement patterns, gather data on garment strain, measure the range of motion for each movement, and analyze the data (Watkins, 1995, p. 225-226).

A number of research studies have employed methods to analyze mobility in various ways, such as exercise protocols (Huck, Maganga, & Kim, 1997; Ruckman, Murray, & Choi, 1999), range of motion measurements (Huck & Kim, 1997; Huck, Maganga, & Kim, 1997; Watkins, 1977), wearer acceptability questionnaires (Huck & Kim, 1997), dexterity tests (Tremblay-Lutter, Crown, & Rigakis, 1996), displacement tests (Lawson & Lorentzen, 1990) studying wearer's movements on film (Lawson & Lorentzen, 1990; Watkins, 1977), and observing garment strain in photographs (Ashdown, 1989; Watkins, 1977).

Range of motion measurements can be used to examine whether a garment inhibits the wearer's movement, and can also be used to compare the wearer's range of motion when wearing different garment treatments. When evaluating a prototype coverall design, range of motion measurements showed that design features in the prototype (i.e. stretch panels, appropriate ease) allowed for greater freedom of movement than the current coverall design, ranging from +3.8% to +28.7% (Huck & Kim, 1997; Huck, Maganga, & Kim, 1997).

Wearer acceptability questionnaires can be used to subjectively measure the wearer's experience with a garment. Huck, Maganga, and Kim (1997) asked subjects to perform an exercise protocol wearing three coverall designs. The subjects then completed a wearer acceptability questionnaire for each design. The results showed that subjects preferred the two prototype designs to the traditional design for most adjective sets.

The Need for Protection

During the 1960s and 1970s, there was a dramatic rise in law enforcement officer fatalities (Edwards, 1995; NIJ guide 100-01). The number of officers killed by firearms jumped dramatically from 55 in 1966 to 127 in 1975 (Edwards, 1995, p. 17). The country is still seeing a high number of officer fatalities. Between 1991 and 2000, 644 law enforcement officers were killed (Federal Bureau of Investigation, 2001, p. 13). Only 293 of these officers were wearing body armor (p. 13). Of those wearing body armor, 163 died of gunshot wounds to the head, 109 in the upper torso, and 16 below the waist (p. 13). These deaths suggest there is opportunity for improvement in body armor.

Body Armor

Body armor should be comfortable to allow for officer productivity and mobility. In order to provide adequate protection, it should fit well and be properly sized. It also must provide impact protection for the officers (Watkins, 1995). In an effort to understand body armor design and function, an examination of the history and the styles available proved necessary. A study of construction methods, materials used, and a description of the levels of protection are also included.

History of Body Armor

Early forms of weapons protection included brine-soaked leather, the metal breastplates of Roman soldiers, full suits of armor and chain mail in the Middle Ages, and military flak jackets during World War II (NIJ guide 110-01). Until an increase in officer fatalities occurred in the 1960s, body armor use for law enforcement had been largely ignored (Edwards, 1995). At that time, the National Law Enforcement and Criminal Justice (NILECJ), now the National Institute of Justice (NIJ), began a research program with the purpose of developing lightweight body armor for police officers (Edwards, 1995).

By the 1970s, DuPont had developed a fabric with bullet resistant properties, and the NILECJ began testing the fabric for use in body armor (NIJ guide 00-01). A 1975 field test involving 15 urban police departments found the developed ballistic vests to be a successful method of protection (NIJ guide 100-01). Law enforcement officers in the United States quickly adopted the vests for use. In 2000, the body armor industry comprised over 80 manufacturers, who together conducted $200 million in business per year (NIJ guide 100-01).

Styles of Body Armor

Body armor is designed to be concealable, semi-rigid, or rigid. When choosing between these styles, the wearer considers the end use and the comfort levels of the armor. Police, government officials, and military personnel all use body armor, but the style worn varies from group to group.

Concealable body armor (CBA) is a protective garment designed to be worn under the uniform shirt. Level II ballistic vests are included in this category. CBA is intended to be comfortable, lightweight, and unrestrictive. Concealable body armor usually provides full front, side and rear protection of the upper torso (NIJ guide 100-01; NLECTC 2002). Law enforcement officers use concealable body armor for protection from handguns or long rifles.

Body armor designed for higher threat levels is usually semi-rigid, consisting of a less flexible material with impregnated ballistic fabrics. Other semi-rigid armor uses small plates of ballistic material (steel, ceramic, or plastic) reinforced with a woven ballistic material. Semi-rigid body armor is more difficult to conceal and limits the wearer's movement (NIJ guide 100-01; Watkins, 1995).

Rigid body armor is the most restrictive and most difficult to conceal. It consists of ballistic material that is molded to cover a specific portion of the body (NIJ guide 100-01). This is used in situations with high threat levels requiring the most protection available, such as the military in intensive combat situations (Watkins, 1995).

Body Armor Construction

Concealable body armor consists of protective panels inserted into a carrier. The protective panels are constructed of multiple layers of ballistic-resistant materials and are inserted into the carrier, an outer garment made of typical garment fabrics like nylon or cotton. The protective panels may or may not be removable (NIJ guide 100-01).

The protective panels can be assembled numerous ways. Some manufacturers bias stitch around the edges of the panel; others tack the layers together in several places. The panel may be sewn with rows of vertical or horizontal stitching or quilted entirely (NIJ guide 100-01). The protective panels are made of materials designed for ballistic properties.

Materials Used

There are three major types of polymer fibers used in body armor: Aramid, high performance polyethylene (HPPE), and polyphehylenebenzobisoxazole (PBO). Each of these fiber types are used in constructing ballistic materials. The most commonly used materials according to the National Institute of Justice (NIJ guide 100-01) are marketed under the names Kevlar®, Spectra®, Dyneema®, and Zylon®. DuPont's Kevlar® fiber was the first material used in modern concealable body armor. Kevlar® is an organic manmade aramid fiber that is flame resistant, does not melt, and has high strength combined with low weight. It also has high chemical resistance and cut resistance (DuPont, 2001).

Kevlar 29 was developed by DuPont in the early 1970s and made flexible body armor possible for the first time. In 1988, DuPont introduced Kevlar 129, offering increased ballistic protection against high-energy rounds such as the 9mm. DuPont's Kevlar Protera, made available in 1996, allowed lighter weight, greater flexibility, and higher levels of protection due to improved tensile strength and energy-absorbing capabilities (Lesce, 1998; NIJ guide 100-01).

Honeywell manufactures Spectra® fiber, an ultra-high-strength polyethylene (HPPE) fiber with very high chemical and cut resistance. Two layers of Spectra® fibers, crossing at 0 and 90 degree angles, are fixed in place by a flexible resin and then sealed between two thin layers of polyethelene film. This nonwoven fabric is Honeywell's Spectra Shield, an extremely strong, flexible, and protective composite. Honeywell also uses this process with aramid fibers to produce another shield composite called GoldFlex (NIJ guide 100-01; NLECTC 2002).

Dyneema® (HPPE) and Zylon® (PBO) are both promising new fibers for body armor protective panels, featuring improvements in strength-to-weight ratios (Chocron-Benloulo, Rodriguez, & Sanchez-Galvez, 1997; NIJ guide 100-01).

Levels of Protection

Officer safety has been defined as "the measures taken at the strategic, tactical, and operational levels to minimize the risk of harm from violence to officers" (Baskind, 1999, p. 14). Body armor is designed for multiple threat levels that should be considered when an officer selects their armor (Olsen, 1981). There are seven levels of ballistic-resistant armor. The NIJ Standard-0101.04 (p. 2-3) outlines armor classification types as described in Table 1.

Police officers generally wear ballistic vests with a level II protection level. This level protects against the majority of handguns while still allowing the officers adequate levels of comfort and mobility.

Functional Design of Body Armor

To approach the functional design of body armor systematically, previous functional design studies can be used as a model, giving the researcher a framework (Watkins, 1995). Ballistic vest wearers have task-related needs that should be considered, as well as physical and psychological needs, such as comfort, fit, mobility, and protection. The literature revealed that wear studies, in such forms as a movement analysis or range of motion test, can be performed to determine the best way to meet the wearer's needs. In addition, literature shows historic and current styles of body armor, construction methods, and materials used which can aid the researcher in further understanding of the design problem.

Table 1

Ballistic-Resistant Armor Threat Levels

THREAT LEVEL	CALIBER	PROJECTILE DESCRIPTION	MASS (Gm)	VELOCITY (m/sec)	JOULES
I	.22 Long rifle	Lead ball	2.6	320	133
	.38 Special		10.2	259	
IIA	9 mm	FMJ	8.0	332	903
	.357 Magnum	Jacket soft point	10.2	381	
II	9 mm	FMJ	8.0	358	903
	.357 Magnum	Jacket soft point	10.2	425	
IIIA	9 mm	FMJ	8.0	426	1416
	.44 Magnum	Semi-wadcut	15.55	426	
III	7.62x39 mm	FMJ	9.7	838	3406
	.308 Winchester				
IV	.30-06	Armor piercing	10.8	868	4068

CHAPTER 3

METHODOLOGY

This chapter will outline the Functional Design Process as it was applied for this study, as well as the ASTM test method F1154-99, sample selection, construction of the prototype vest panels, instrument development and administration, data collection procedure, and the treatment of the data.

Functional Design Process

DeJonge (1984) proposed designers use a structured method to design functional clothing. In the Functional Design Process, DeJonge identifies seven stages a designer can use to devise a design solution. An illustration of the Functional Design Process as it was applied in this study is shown in Figure 1.

The *general objective* of this study was to evaluate the comfort of ballistic vests. To obtain this goal, the designer first *explored the design situation* through a review of literature. The problem was defined further through input from officers, expert opinions, and researcher observations. The researcher then *perceived the problem structure* through a literature search, user input, materials analysis, and market analysis. *Design specifications* (i.e. safety and comfort) were identified. After specifications were identified, the *interaction of design criteria was established* and the *prototype* was *developed* and evaluated to help the designer complete the *design development.*

Design Specifications and Interaction Matrix

After conducting a literature review (Tan, Crown, & Capjack, 1998; Huck & Kim, 1997; Bergen, Capjack, McConnan, & Richards, 1996; DeJonge, 1984) and interviewing police officers from the Tallahassee Police Department (Appendix C), the researcher and a colleague collaborated to identify design specifications. The specifications were

GENERAL REQUEST
More comfortable ballistic vest

EXPLORATION OF THE DESIGN SITUATION		
General Objective	Review of Literature	Problem Definition
• Develop and evaluate ballistic vests for law enforcement officers	• Functional Design Process • Law enforcement task requirements • Officer safety and comfort • Functional clothing	• Input from officers • Expert opinions • Researcher observations

PROBLEM STRUCTURE PERCEIVED			
Literature Search	User Input	Materials Analysis	Market Analysis
• Thermal regulation • Ballistic protection levels • Ballistic fabrics • Sizing and fit of protective clothing	• Interviews with officers	• Compliance with NIJ standards	• Analysis of similar garments on the market

DESIGN SPECIFICATIONS		
Safety	Comfort	Psychological
• Sizing/fit • Mobility • Protection levels	• Fit • Mobility • Thermal acceptability	• Acceptance

INTERACTION OF DESIGN CRITERIA ESTABLISHED	
Objective Analysis	Subjective Analysis
• Range of motion measurement • Movement analysis	• Wearer acceptability scale

Figure 1. *Functional Design Process for Ballistic Vests*

grouped into four categories: safety, wearer acceptance, mobility, and production. An interaction matrix was established (Figure 2). The interaction matrix was used to identify design specifications that either conflicted with each other, required accommodation to allow another specification to be met, or had no conflict with other specifications.

While many of the specifications would require accommodation for other specifications to be met, four pairs of specifications were identified as being in direct conflict with each other. All three specifications for safety ("fabric and notions", "body coverage", "protection level") were determined to be in direct conflict with specification #5, "thermal comfort". The lack of breathability, absorbency, and weight of the ballistic fabrics used in vests negatively affect the wearer's thermal comfort level. The amount of body coverage of the vest also conflicts with the wearer's thermal comfort. In addition, the protection level of the vest determines which fabrics are used and how many layers of fabric are needed in order to stop the ballistic threat.

It was also determined that specification #2, "body coverage", was in direct conflict with specification #9, "range of motion". As more of the torso area is covered, the wearer experiences more limited range of motion. For instance, as the front of the vest is lengthened, the wearer's spinal flexion range of motion decreases.

Instrument Development

A range of motion test was performed to assess any restriction in mobility caused by the vests. The test consisted of selected motions that could be affected by wearing a vest, such as shoulder flexion and hyperextension, shoulder abduction and adduction, and trunk flexion and hyperextension (Luttgens, Deutsch, & Hamilton, 1992).

A movement analysis was conducted using the procedure outlined in ASTM F1154-99 to measure the officers' functional range of motion. This test was designed for evaluating the comfort, fit, and function of chemical protective suits. The movement protocol was adapted from the ASTM test to include a series of movements that represent movements law enforcement officers are required to make while wearing ballistic vests. Movements added to the instrument included task-related movements identified in user interviews (Appendix C), such as head rotation, stair climbing, and sitting in a chair.

Garment Specifications	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Safety													
1. Fabric and notions		**2**	**1**	**1**	**0**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
2. Body coverage			**2**	**1**	**0**	**1**	**1**	**1**	**1**	**0**	**1**	**2**	**2**
3. Protection level				**2**	**0**	**2**	**1**	**2**	**2**	**1**	**1**	**2**	**1**
Wearer Acceptance													
4. Design features					**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
5. Thermal comfort						**2**	**2**	**1**	**1**	**2**	**2**	**2**	**2**
6. Fit of garment							**1**	**1**	**1**	**1**	**1**	**2**	**2**
7. Style of garment								**1**	**1**	**1**	**1**	**1**	**2**
8. Concealable									**1**	**2**	**2**	**2**	**2**
9. Interaction with uniform										**1**	**1**	**2**	**2**
Mobility													
10. Range of motion											**1**	**2**	**2**
11. Ease of movement												**2**	**2**
Production													
12. Ease of production													**2**
13. Complies with NIJ standards													

Note: 0 = Conflict; 1 = Accommodation; 2 = No conflict

Figure 2. *Interaction Matrix of Garment Specifications for Ballistic Vests*

Movements removed from the instrument were movements specific to chemical workers such as drum moving, hose coiling/uncoiling, valve manipulation, wrench manipulation, and screwdriver use. Officers were asked to rate their ability to perform each movement using a 5-point Likert-type scale. Open-ended questions were added asking the subjects to discuss the comfort, thermal acceptability, and general acceptability of their vest.

Subjects were also asked to rate the fit of their vest at specific locations as well as the general wearer acceptability. The 5-point Likert-type wearer acceptability scale was devised from Huck's (1997) wearer acceptability scale. Additional fit and comfort descriptors were added to the scale to aid the researcher in identifying the comfort levels and acceptability of the vests (Appendix B).

Construction of Prototype Vests

The two prototype Level II vest panels were constructed of four layers of a prototype fabric, ArmorFelt, three layers of Kevlar, and ten layers of Goldflex. The prototype vest panels were produced using ballistic vest manufacturing techniques to maintain consistent construction quality between vests. This also helped to control extraneous variables and increased the validity of the study.

The prototype fabric, ArmorFelt, is constructed differently than other ballistic fabrics. Traditional ballistic fabrics are woven, usually consisting of synthetic fibers such as aramid or high performance polyethylene (HPPE) (Thomas, 1998). These woven fabrics are layered to obtain the ballistic resistance level required for a vest. ArmorFelt is a needlepunched nonwoven composed of both aramid and HPPE fibers (Thomas, 1998). Blending fiber types allows increased energy absorption to be combined with lower fabric weight (Thomas, 1998).

On March 21, 2003, the prototype vest and traditional vest were tested using standard testing methods for ballistic vests. According to the NIJ Standard-0101.04 (p. 2-3), level II body armor should stop a 9 mm full metal jacket projectile at 1240 ± 10 feet per second with a maximum backface deformation of 44 mm (see Table 1, p. 24). The traditional vest weighed 11.82 oz/ft^2 (3606.89 g/m^2) and stopped the bullet with 42 mm of backface deformation, passing the NIJ requirements. The prototype vest weighed

11.60 oz/ft^2 (3539.76 g/m^2) and passed the testing with 35 mm of backface deformation, exhibiting higher protection at a lower weight than the traditional vest.

Testing Procedures

The protocol for the range of motion and movement analysis was as follows. Male subjects wore a Level II ballistic vest of traditional fabrication while performing the movements outlined in ASTM F1154-99 Standard Practices for Qualitatively Evaluating the Comfort, Fit, Function, and Integrity of Chemical-Protective Suit Ensembles. The test was adapted for use with ballistic vests by including tasks associated with law enforcement officers' duties. A detailed description of the movement procedures is listed in Tables 2 and 3 (Modified ASTM F1154-99).

The male subjects then performed these same movements while wearing a Level II ballistic vest of prototype fabrication. The same subjects also performed the movements without any vest to establish baseline measurements. A non-random order was used for the vest treatments due to time constraints for the officers, who were participating in the study while on duty.

After the subjects completed the range of motion and movement analysis, they completed a wearer acceptability questionnaire evaluating the ballistic vest on comfort and function (Appendix B). Their responses were used to compare and contrast the two vest treatments. The subjects were also videotaped and photographed with their permission in order to assist in further design development.

Pilot Test

Prior to the pilot test, human subject approval was obtained on March 6, 2003. A pilot test consisting of the adapted movement protocol and questionnaire was conducted using four male officers from the Florida State University police force. After the movement protocol and questionnaire responses were evaluated, modifications were made to the testing procedure, including adding open-ended questions asking officers to identify the activities they do most often, as well as open-ended questions regarding whether they could perceive a difference in their comfort levels when wearing a

Table 2

Movement Protocol for Procedure A

Movement order	Procedure
1	Kneel on left knee, kneel on both knees, kneel on right knee, stand. Repeat movement four times.
2	Duck squat, pivot right, pivot left, stand. Repeat movement four times.
3	Stand erect. With arms at sides, bend body to left and return, bend body forward and return, bend body to right and return. Repeat movement four times.
4	Stand erect. Extend arms overhead, then bend elbows. Repeat movement four times.
5	Stand erect. Extend arms perpendicular to the sides of torso. Twist torso left and return, twist torso right and return. Repeat movement four times.
6	Stand erect. Reach arms across chest completely to opposite sides. Repeat movement four times.
7	Walk a distance of 100 yards.
8	Crawl on hands and knees a distance of 20 feet.
9	Stand erect. Turn head to the left and return. Turn head to the right and return. Repeat movement four times.

Table 3

Movement Protocol for Procedure B

Movement order	Procedure
1	Individually lift four boxes from the floor and place on a table. Return each box to the floor.
2	Step up five stairs.
3	Stand erect beside a chair. Sit in chair. Return to standing position beside chair. Repeat four times.
4	Climb up to fifth rung of ladder.

traditional vest, prototype vest, or no vest. In addition, assessing the officers' gun movement was removed as permission to unholster their guns could not be obtained.

Subjects

Officers were selected from the Tallahassee Police Department for this study. A group of ten male subjects, each of consistent body size, was chosen to wear Level II ballistic vests for the range of motion, movement analysis, and wearer acceptability questionnaires. Only male subjects were used because the preliminary literature review revealed that there are significantly more male law enforcement officers than female officers. The size range of ballistic vests obtained for the study limited the body size of the subjects to the sizes 38 and 40.

Data Analysis

Four scales comprised the testing instrument which measured each vest function as it related to movement, fit, physical comfort, and performance. Movement was assessed using the protocol developed as suggested in ASTM F1154-99. This protocol included kneeling, duck squats, body bends, overhead arm extensions, torso twists, cross body arm reaches, walking, crawling, and head rotation, which are all basic body movements (Items 7 – 15, Appendix B). Additional ASTM task-related movements were also used, including box lifting, stair climbing, sitting in a chair, and ladder climbing (Items 17 – 20, Appendix B). The fit of the vests was measured through items 33 – 48 (Appendix B), which included questions regarding vest fit when officers were standing and sitting.

The scales for physical comfort and physical attributes of vest performance used adjective sets from the wearer acceptability scale (Huck et al., 1997). Physical comfort was assessed with the following bipolar adjective sets: "comfortable/uncomfortable", "flexible/rigid", "soft to the skin/harsh to the skin", "feels soft/feels stiff", "non-irritating/irritating", "loose/tight", "cold/hot", "breathable/does not breathe". The physical attributes of vest performance included "safe/unsafe", "acceptable/unacceptable", "lightweight/heavyweight", "sturdy/not sturdy", "high quality/low quality", "functional/nonfunctional", "provides protection/lack of protection", and "like/dislike".

The data was analyzed using the Statistical Package for the Social Sciences (SPSS) software. Subjects rated the vests on 5-point scales, and the means and frequencies of their responses were analyzed. Descriptive statistics including frequencies, percentages, means, and standard deviations were used to report the participants' characteristics as well as their responses to the vest treatments. The hypotheses were tested using inferential statistics, specifically general linear models for repeated measures.

CHAPTER 4
FINDINGS AND DISCUSSION

The overall purpose of this study was to evaluate two types of bullet resistant vests for male police officers. This study compares the levels of satisfaction for each vest type to help identify ways of improving ballistic vests. The two Level II vest types were of similar design but of different fabrication: one type made of traditional ballistic fabric and the second, a vest fabricated of a prototype fabric. Both vest types were the traditional ballistic vest design.

This chapter will outline the findings of the study and use the findings to answer the purpose and objectives of the study. Included is a discussion of the reliability of measures used, a description of the final sample, and the results of the range of motion test, movement analysis, and wearer acceptability questionnaire, including: the physical comfort levels of the subjects in each vest, the physical attributes of vest performance, and reported fitting problems. An interpretation of the data as it relates to the testing of the hypotheses will follow, as well as a comparison of this study's findings to prior research discussed in the literature review.

Reliability of Measures

The testing instrument was evaluated during a pilot study conducted in spring 2003. Four officers from the Florida State University Campus Police performed the range of motion test, movement analysis, and wearer acceptability questionnaire. The testing instrument was divided into separate scales for movement, fit, physical comfort, and physical attributes of vest performance. After the pilot test was conducted, a factor analysis was performed, and the reliability was evaluated for these specific measures in the testing protocol. Peterson (1994) defines reliability as "the degree to which measures are free from error and therefore yield consistent results." Peterson's research also shows that the most widely used reliability measure is Cronbach's coefficient alpha. Hence, this research relied on coefficient alphas to measure the reliability of each scale used. The coefficient alphas were as follows: movement = 0.80; fit = 0.70; physical comfort = 0.77; and physical attributes of vest performance = 0.67.

Peterson (1994) suggests that the alpha coefficients be at least 0.70 for preliminary research and recommends they be 0.80 or higher for basic research. The alpha coefficients for the movement, fit, and physical comfort scales in the pilot study all met the levels suggested by Peterson. The coefficient for physical attributes of vest performance was slightly below Peterson's suggested level. This may be due to the small number of subjects tested or their inability to measure certain variables. For example, when one of the items, "quality", was removed from the scale, the reliability for the scale increased to 0.81. The officers may have felt they could not accurately measure the quality of vests. Despite the lower alpha coefficient when quality was included in the scale, it was not deemed low enough to remove the variable from the scale. However, the decision was made to eliminate the "absorbency" variable from the scale for physical attributes of vest performance because there was concern that the officers would not be able to perceive the absorbency of the prototype vest during the short testing time. The testing conditions and small number of movements did not allow the officers to perspire and therefore did not allow opportunity for the officers to judge absorbency of the vests.

After the final study was conducted, the reliability of each scale was retested. The coefficient alphas were as follows: movement = 0.89; fit = 0.89; physical comfort = 0.69; and physical attributes of vest performance = 0.75. The alpha coefficients for movement and fit scales increased, and were found to be above Peterson's suggested level of 0.80 (1994). The scale for physical attributes of vest performance also showed an increase in reliability, and although the score is lower than recommended, the alpha coefficient level is still within the acceptable range Peterson suggests (at least 0.70).

Despite increases in reliability for the other scales, the physical comfort scale decreased slightly in reliability. The alpha coefficient of 0.69 is lower than desirable, but may have been caused by the officers' inability to perceive whether the vest was "cold" or "hot" during the short testing time and in the controlled testing environment. The officers also had variations in their desire for the vest to be flexible or stiff. Some perceived a more flexible vest to be a positive characteristic, while others felt a stiffer vest was more desirable.

Description of the Final Subjects

In May 2003, ten male law enforcement officers from the Tallahassee Police Department were selected to participate in the final study. The officers were chosen purposely from a pool of officers who fit one of the prototype vest panel sizes (sizes 38 and 40).

The ten officers ranged in age from 31 to 42 years, with a mean age of 36.9 years. Their heights ranged from 65 inches (5'5") to 72 inches (6'0"), with a mean height of 69.5 inches (5'9.5"). The officers' mean weight was 180 pounds, with a minimum measured weight of 155 pounds and maximum measured weight of 209 pounds. The officers' average time of law enforcement experience was 11.9 years, with a minimum service time of 3 years, and a maximum service time of 16 years. Each of the subjects' age, height, weight, and law enforcement experience are reported in Table 4. The average measurements of the officers were as follows: chest = 42.4 inches, waist = 36.3 inches, and trunk length = 70.3 inches (Table 5). Although the average chest measurement is larger than the two vest sizes of 38 and 40, the officers were measured by a SafariLand company representative and found to be within the acceptable size range for the vests, which have adjustable elastic straps at the sides.

The officers all wore their departmentally issued duty uniform, which consists of a short-sleeved button-down uniform shirt with collar, flat-front pants, black boots, leather belt, and gun belt. The gun belt held all of their gear, including their gun, a Sig Sauer P229 0.40 caliber semi-automatic pistol, gun holster, ammo pouch, baton ring and baton, flashlight ring or holder and flashlight, latex glove pouch, radio holder and radio. They all wore 2 to 5 belt keepers, which are thin strips of leather that secure the gun belt to the pants belt, helping to stabilize the gun belt. Underneath their uniform shirt, they wore their traditional ballistic vest (SafariLand Zero-G) over a plain T-shirt. On their

Table 4

Officers' physical characteristics and law enforcement experience.

Subject	Age (years)	Height (inches)	Weight (pounds)	Law enforcement experience (years)
1	32	71.5	209	4.0
2	36	70.0	165	15.0
3	41	68.0	180	12.0
4	31	65.0	155	3.0
5	35	69.0	190	12.0
6	35	69.0	180	12.5
7	39	72.0	185	15.0
8	38	71.0	176	14.0
9	42	69.0	178	16.0
10	40	70.0	182	15.5

Table 5

Mean body measurements of subjects.

Measurement	Mean (inches)	SD (inches)	Minimum (inches)	Maximum (inches)
Chest	42.4	0.67	42.0	44.0
Waist	36.3	1.71	34.0	40.0
Trunk length	70.4	1.54	68.0	73.0

uniform shirt, they wore their police badge, name badge, and any medal pins they may have received.

Range of Motion

Basic range of motion measurements (ROM) were taken for each subject in the three different treatments: (1) the traditional vest, (2) the prototype vest, and (3) no vest. A goniometer was used to measure the subjects' shoulder abduction, shoulder adduction, shoulder hyperextension, shoulder flexion, trunk hyperextension, and trunk flexion. Table 6 shows the mean range of motion (in degrees) for the six movements. The difference in range of motion of the two vest fabrications over the control, no vest, is included in the table to further illustrate any difference in wearer movement.

The prototype vest showed a greater range of movement for shoulder abduction, shoulder adduction, and trunk flexion than the traditional vest. This may have been caused by the use of more pliable fabrics for the prototype. However, freedom of movement decreased slightly for shoulder hyperextension and shoulder flexion, which is attributable to the increased thickness of the prototype fabrication. There was no significant difference ($p = 0.5663$) in freedom of movement for trunk hyperextension between the traditional vest panels and prototype vest panels.

In all, the range of motion measurements showed great variation between subjects as well as vest treatments. The minimum and maximum for each movement is reported in Table 7. An expanded sample size may be needed to draw any implications for range of motion.

Movement Analysis

The subjects performed a movement analysis wearing the traditional vest panels, the prototype vest panels, and no vest. The movement protocol included basic movements as well as task related movements, including kneeling, duck squats, body bends, arm extensions, torso twists, arm reaches, walking, crawling, head rotation, box lifting, stair climbing, sitting, and ladder climbing. The subjects rated each movement using a 5-point Likert-type scale with descriptors "easy to do" and "hard to do". Tables 8

Table 6

Officers' range of motion (ROM) for selected movements.

	Control (No Vest)	Vest Treatment 1 (Traditional)		Vest Treatment 2 (Prototype)	
Movement	ROM (*M*)	ROM (M)	Difference	ROM (*M*)	Difference
Shoulder Abduction	56.7º	57.8º	+1.1º	55.7º	-0.5º
Shoulder Adduction	81.3º	78.3º	-3.0º	74.8º	-6.5º
Shoulder Hyperextension	59.5º	59.4º	-0.1º	58.5º	-1.0º
Shoulder Flexion	147.4º	142.6º	-4.8º	140.6º	-6.8º
Trunk Hyperextension	150.9º	150.4º	-0.5º	150.5º	-0.4º
Trunk Flexion	99.0º	98.2º	-0.8º	92.4º	-6.6º

Note: Shown in degrees.

Table 7

Minimum and maximum reported range of motion movements.

Range of motion measurement	Control (No Vest)	Vest Treatment 1 (Traditional)	Vest Treatment 2 (Prototype)
Shoulder abduction			
Mean	56.7	57.8	55.7
Standard deviation	14.4	14.1	8.8
Minimum	37.0	33.0	43.0
Maximum	80.0	80.0	70.0
Shoulder adduction			
Mean	81.3	78.3	74.8
Standard deviation	12.4	19.1	14.4
Minimum	63.0	48.0	45.0
Maximum	105.0	120.0	93.0
Shoulder hyperextension			
Mean	59.5	59.4	58.5
Standard deviation	10.7	8.7	6.9
Minimum	120.0	42.0	50.0
Maximum	165.0	70.0	71.0
Shoulder flexion			
Mean	147.4	142.6	140.6
Standard deviation	13.6	11.4	16.6
Minimum	120.0	127.0	110.0
Maximum	165.0	163.0	164.0
Trunk hyperextension			
Mean	150.9	150.4	150.5
Standard deviation	8.2	7.0	7.2
Minimum	140.0	140.0	135.0
Maximum	171.0	162.0	156.0
Trunk flexion			
Mean	99.0	98.2	92.4
Standard deviation	21.9	19.9	17.3
Minimum	76.0	60.0	60.0
Maximum	156.0	130.0	120.0

and 9 show the frequencies and percentages for movement protocols A and B and each vest treatment. The mean of the subjects' responses for each movement and vest treatment are summarized in Table 10.

As was expected, there was significant difference [F (1,9) = 9.72, p = 0.022] (see Table 11) between the control group (no vest treatment) and both of the vest treatments (traditional and prototype panels). There was no significant difference [F (1,9) = 0.104, p = 0.754] (see Table 12) between the traditional vest panels and prototype vest panels when subjects performed the movement protocol. As Table 10 shows, the mean values of the two vest treatments are almost identical. All of the mean scores fall within the "easy to do" side of the scale. The officers were either positive or neutral when performing the movements with either vest treatment, illustrating that the vests did not impede their movements. The prototype vest panels were viewed as positively as the traditional vest panels.

When comparing the mean scores of the traditional vest to the mean scores of the prototype vest, 5 of the 13 scores were identical. On average, subjects found no difference in their ability to perform certain movements when wearing the traditional vest panels or prototype vest panels. These movements were kneeling, duck squats, walking, head rotation, and stair climbing. The prototype panels received more positive ratings for the following movements: overhead arm extensions, crawling, and sitting. Although the traditional vest panels received better ratings for the remaining five movements (body bends, torso twists, cross body arm reaches, box lifting, and ladder climbing), three of these movements received mean scores only 0.1 higher than the prototype vest, and two of the movements were rated an average of 0.2 higher.

Officers found certain movements harder to do than others when wearing either of the vests, including kneeling, duck squats, body bends, crawling, box lifting, and sitting. The majority of the subjects (N = 6) found it harder to perform the cross body arm reaches when wearing either the traditional or prototype vest. In addition, many of the officers commented that the movements were not hindered only by their vests, but by the vest's interaction with their gun belt, particularly when bending at the waist. When

Table 8

Subjects' responses for movement protocol A.

	Traditional vest ($N = 10$)		Prototype vest ($N = 10$)		No vest ($N = 10$)	
Movement	*f*	*P*	*f*	*P*	*f*	*P*
Kneeling						
1	2	20	2	20	6	60
2	6	60	7	70	3	30
3	2	20	0	0	0	0
4	0	0	1	10	1	10
5	0	0	0	0	0	0
Duck squats						
1	2	20	1	10	6	60
2	6	60	8	80	3	30
3	2	20	1	10	1	10
4	0	0	0	0	0	0
5	0	0	0	0	0	0
Body bends						
1	4	40	3	30	7	70
2	3	30	3	30	3	30
3	3	30	4	40	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
Overhead arm extensions						
1	8	80	8	80	9	90
2	1	10	2	20	1	10
3	1	10	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
Torso twists						
1	7	70	6	60	9	90
2	3	30	3	30	1	10
3	0	0	1	10	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
Cross body arm reaches						
1	4	40	4	40	10	100
2	5	50	4	40	0	0
3	1	10	2	20	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0

Table 8 - continued

	Traditional vest (*N* = 10)		Prototype vest (*N* = 10)		No vest (*N* = 10)	
Movement	*f*	*P*	*f*	*P*	*f*	*P*
Walking						
1	8	80	8	80	10	100
2	2	20	2	20	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
Crawling						
1	3	30	3	30	6	60
2	2	20	4	40	2	20
3	4	40	1	10	1	10
4	1	10	2	20	1	10
5	0	0	0	0	0	0
Head rotation						
1	9	90	9	90	10	100
2	1	10	1	10	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0

Note: Movements were rated on a 5-point Likert-type scale where “1” = Easy to do, and “5” = Hard to do.

Protocol A refers to basic body movements derived from ASTM F1154-99 (see page 26).

Table 9

Subjects' responses for movement protocol B.

	Traditional vest (N = 10)		Prototype vest (N = 10)		No vest (N = 10)	
Movement	*f*	*P*	*f*	*P*	*f*	*P*
Box lifting						
1	3	30	2	20	7	70
2	4	40	6	60	2	20
3	3	30	1	10	1	10
4	0	0	1	10	0	0
5	0	0	0	0	0	0
Stair climbing						
1	7	70	8	80	9	90
2	3	30	1	10	1	10
3	0	0	1	10	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
Sitting						
1	4	40	4	40	7	70
2	3	30	4	40	3	30
3	3	30	2	20	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
Ladder climbing						
1	5	50	5	50	8	80
2	5	50	4	40	1	10
3	0	0	1	10	1	10
4	0	0	0	0	0	0
5	0	0	0	0	0	0

Note: Movements were rated on a 5-point Likert-type scale where "1" = Easy to do, and "5" = Hard to do.

Protocol B refers to task-related movements derived from ASTM F1154-99 (see page 27).

Table 10

Subjects' ratings for movement analysis.

Movement	Traditional vest *(M)*	Prototype vest *(M)*	No vest *(M)*
Kneeling	2.0	2.0	1.6
Duck squats	2.0	2.0	1.5
Body bends	1.9	2.1	1.3
Overhead arm extensions	1.3	1.2	1.1
Torso twists	1.3	1.5	1.1
Cross body arm reaches	1.7	1.8	1.0
Walking	1.2	1.2	1.0
Crawling	2.3	2.2	1.7
Head rotation	1.1	1.1	1.0
Box lifting	2.0	2.1	1.4
Stair climbing	1.3	1.3	1.1
Sitting	1.9	1.8	1.3
Ladder climbing	1.5	1.6	1.3

Note: Movements were rated on a 5-point Likert-type scale where "1" = Easy to do, and "5" = Hard to do.

Table 11

General linear model on Movement between three vest treatments.

Source	*SS*	*df*	*MS*	*F*	*P*
Group	130.05	1	130.05	9.72	0.022
Error	120.45	9	13.38		
Total	250.40	10			

Table 12

General linear model on Movement between traditional and prototype vest treatments.

Source	*SS*	*df*	*MS*	*F*	*P*
Group	0.80	1	0.80	0.104	0.754
Error	69.20	9	7.69		
Total	70.00	10			

bending at the waist, the gun belt does not move, and often pushes the front of the vest up into the base of the neck. All of the previously mentioned movements required the subject to bend at the waist, which may have caused the mean scores to be higher than the mean scores of non-bending movements.

The subjects also had trouble with the vest panels bunching up when bending at the waist. They commented that their traditional vest panels bunched up ($N = 6$) and did not regain the original form ($N = 4$). The body bend movement was the movement that elicited the most comments related to this. One subject responded that when he bent to the left or right, his traditional vest panels hit the gear on his gun belt and created a lip. There were fewer comments about the prototype vest panels bunching up; however, the scores do not reflect this difference.

In addition to rating the movements, the subjects also rated their general mobility while wearing the two vests on a 5-point Likert-type scale, with end descriptors of 1 = "easy to move" and 5 = "hard to move". For the traditional vest, 30% ($N = 3$) of subjects rated their mobility as "1", 60% ($N = 6$) rated their mobility as "2", and 10% ($N = 1$) rated their mobility as "3". For the prototype vest, 30% rated their mobility as "1" and 70% ($N = 7$) rated their mobility as "2". There was a slight increase in the officers' mobility ratings for the prototype vest over the traditional vest. One subject commented that he felt the prototype vest moved with him better than the traditional vest, which may account for the increased mobility score. The general linear model for repeated measures was used to test for significant differences in the scores for general mobility, but they were not found to be significantly different ($p = 0.591$).

Subjects listed numerous movements or activities hindered by their traditional vest (Appendix C), including sitting ($N = 5$), shooting a shotgun ($N = 2$), crossing their arms ($N = 4$), running ($N = 3$), and body bends ($N = 4$). Subjects listed fewer movements that were hindered by the prototype vest: sitting ($N = 4$), crossing their arms ($N = 2$), and body bends ($N = 1$). This may be attributed to the vest carrier design, which may explain similarities between the activities hindered by the traditional and prototype vest. Further research is needed to identify the cause of these problems.

Wearer Acceptability of Vests

After completing the movement protocol in both the traditional and prototype vest, the subjects completed a wearer acceptability scale consisting of 24 adjective sets. The mean value of each adjective set was calculated, and the results are presented in Table 13. The prototype vest panels were preferred for the majority of the adjective sets. The prototype vest was rated as positive for 19 of 24 adjective sets, while the remaining 5 sets were rated as neutral. The traditional vest was rated positively for 21 of 24 adjective sets. It was rated neutral for 2 adjective sets and negatively for 1 set.

General linear models were run for each adjective set to determine if there was any significant difference between the two vest treatments. The ratings for the adjective set "cold/hot" were significantly positive for the prototype vest panels ($p = 0.029$). No other adjective sets were significantly different between the two vest treatments.

The prototype vest was reported as cooler to wear, more comfortable, easier to move in, and more flexible. The officers also indicated the prototype vest was more acceptable to wear than the traditional vest. Multiple subjects commented that they felt the prototype vest was more flexible than the traditional vest, which is reflected in the higher ratings for "easy to move in/hard to move in" and "flexible/rigid". These factors appear to be significant regardless of garment type (Huck, Maganga, & Kim, 1997).

The prototype panels were not rated as positively as the traditional vest panels for the following: provides less protection, lower quality, less absorbent, and more bulky. Although the subjects were briefed at the beginning of the study concerning the prototype vest's protection level of Level II and construction using typical ballistic vest manufacturing techniques, the subjects still rated the prototype vest panels lower for protection and quality. This may be attributed to the officers' perception that the researcher does not share the same level of expertise as those who purchase the vests for the police department. In addition, it was previously noted that the officers may not have been able to adequately determine the absorbency levels of the prototype vest during the testing procedure, which may account for the prototype vest's lower rating for absorbency. The prototype vest was thicker than the traditional vest, and the subjects'

Table 13

Subjects' ratings for wearer acceptability scale.

Item	Traditional vest (*M*)	Prototype vest (*M*)	Change prototype vest from traditional vest (percent)
Physical Comfort of Vest			
Comfortable/uncomfortable	2.4	2.1	+6
Flexible/rigid	2.6	2.1	+10
Soft to the skin/harsh to the skin	2.5	2.6	-2
Feels soft/feels stiff	2.5	2.1	+8
Non-irritating/irritating	2.9	2.5	+8
Loose/tight	3.3	3.3	0
Cold/hot	4.5	3.6	+18
Breathable/does not breathe	3.2	3.0	+4
Physical Attributes of Vest			
Acceptable/unacceptable	2.4	1.9	+10
Safe/unsafe	1.8	1.9	-2
Lightweight/heavyweight	2.5	2.5	0
Sturdy/not sturdy	2.3	2.2	+2
High quality/low quality	1.9	2.2	-6
Functional/nonfunctional	1.9	2.1	-4
Provides protection/lack of protection	1.7	2.5	-16
Like/dislike	2.2	1.9	+6
Fits well/does not fit well	2.2	2.1	+2
Not bulky/bulky	2.8	3.1	-6
Absorbent/nonabsorbent	2.8	3.1	-6
Easy to move in/hard to move in	2.5	1.9	+12
Ease of movement/confining	2.5	2.2	+6
Freedom of movement of arms/restricted movement of arms	1.9	1.9	0
Freedom of movement of torso/restricted movement of torso	2.7	2.8	-2
Overall satisfied/overall dissatisfied	2.0	1.9	+2

Note: Movements were rated on a 5-point semantic differential scale where "1" was positive and "5" was negative.

negative ratings for "not bulky/bulky" were expected. However, the ratings were not significantly lower than the traditional vest's ratings for this adjective set.

The adjective sets were grouped into two different scales for physical comfort and physical attributes of vest performance. The subjects' ratings for each of these adjective sets will be discussed in relation to each vest treatment.

Physical Comfort of Vests

The physical comfort scale included the following adjective sets: "comfortable/uncomfortable", "flexible/rigid", "soft to the skin/harsh to the skin", "feels soft/feels stiff", "non-irritating/irritating", "loose/tight", "cold/hot", "breathable/does not breathe". The officers rated the adjective sets on a 5-point semantic differential scale from positive ("1") to negative ("5").

When rating the traditional vest panels using the 8 adjective sets, subjects rated the panels most negatively for "cold/hot" ($M = 4.5$, $SD = 0.71$). The prototype vest panels were also rated most negatively for "cold/hot" ($M = 3.6$, $SD = 0.70$). The traditional vest panels were rated the most positively for the adjective set "comfortable/uncomfortable" ($M = 2.4$, $SD = 0.97$). The most positive rating for the prototype vest was a mean score of 2.1, which applied to three different adjective sets: "comfortable/uncomfortable" ($SD = 0.32$), "flexible/not flexible" ($SD = 1.37$), "soft to the skin/harsh to the skin" ($SD = 0.74$).

A general linear model was run for repeated measures to test the results for the physical comfort scale. There was no significant difference [$F(1,9) = 2.00$, $p = 0.191$] (see Table 14) found between the traditional vest panels and the prototype vest panels. The prototype vest, however, received more positive ratings for all adjective sets on the scale, with the exception of "soft to the skin/harsh to the skin". For this adjective set, the traditional vest received a mean score of 2.5, and the prototype vest received a mean score of 2.6. This represents a negative 2% change from the traditional to the prototype vest.

The subjects also rated each of the vest panels for general comfort on a 5-point Likert-type scale from a positive "1" to a negative "5". The responses for the traditional

Table 14

General linear model on Physical Comfort between traditional and prototype vests.

Source	*SS*	*df*	*MS*	*F*	*P*
Group	33.80	1	33.80	2.00	0.191
Error	152.20	9	16.91		
Total	185.00	10			

vest were as follows: 10% of participants rated the vest comfort as “1”, 60% rated the vest comfort as “2”, and 30% rated the vest as “3”. Ninety percent of the participants rated the prototype vest comfort as “2”, while 10% rated their comfort experience as “3”. The mean score for the traditional vest’s general comfort was 2.2 ($SD = 0.63$). The mean score of general comfort for the prototype vest was slightly lower at 2.1 ($SD = 0.32$). Although the mean scores for the two vest treatments were similar, the ratings for the prototype vest panels were more consistent between test subjects than the ratings for the traditional vest panels.

Although the subjects rated the physical comfort of the vests, there is concern that they were unable to perceive their actual physical comfort. For example, the subjects were asked to rate the vest panels as “cold” or “hot”. Participants may have felt hot while wearing the vests, but without ergonomic metric data such as body core temperature, heart rate, and breathing rate, their experience can only be judged on their psychological perceptions and not the actual physical experience while wearing the vest treatments. Branson and Sweeney (1991) note this discrepancy in their clothing comfort model. An expanded study may be necessary to accurately determine the wearer’s physical comfort.

Physical Attributes of Vest Performance

The scale for physical attributes of vest performance included “acceptable/unacceptable”, “safe/unsafe”, “lightweight/heavyweight”, “sturdy/not sturdy”, “high quality/low quality”, “functional/nonfunctional”, “provides protection/lack of protection”, and “like/dislike”. The subjects’ ratings for each of these adjective sets will be discussed in relation to each vest treatment.

A general linear model for repeated measures was run to test the results for the physical attributes of vest performance scale. There was no significant difference [$F(1,9) = 0.129$, $p = 0.728$] (see Table 15) found between the traditional vest and the prototype vest. The prototype vest received more positive ratings for “acceptable/unacceptable”, “sturdy/not sturdy”, and “like/dislike”. Both vest treatments received the same mean rating for the adjectives “lightweight/heavyweight” ($M = 2.5$).

Table 15

General linear model on Physical Attributes of Vest Performance between traditional and prototype vests.

Source	*SS*	*df*	*MS*	*F*	*P*
Group	1.25	1	1.25	0.129	0.728
Error	87.25	9	9.69		
Total	88.50	10			

The traditional vest received more positive ratings for the following adjective sets: "safe/unsafe", "high quality/low quality", "functional/nonfunctional", and "provides protection/lack of protection". All of these adjective sets are related to the vest's main function as a protective garment. Officers may not feel that the prototype vest had undergone enough testing to provide the same quality and protection as their traditional vest.

Although the adjective set, "absorbent/nonabsorbent", was removed from this scale, the scores are still important to consider. The prototype vest panels received more negative scores for the absorbency adjective ($M = 3.1$, $SD = 0.57$) than the traditional vest panels ($M = 2.8$, $SD = 1.03$). However, due to the limited test protocol, implications cannot be made from these results without further testing.

Fitting Problems

As part of the wearer acceptability scale, subjects completed a 5-point Likert-type scale regarding the fit of their vests from a positive "excellent fit" (1) to a negative "does not fit" (5). Eight of the questions related to the fit of vests when officers were standing, while another eight questions addressed the fit of vests when officer were sitting. Table 16 shows the mean values for these questions as they relate to each vest treatment.

Although the design of the traditional vest and prototype vest were identical, the subjects rated the fit of the prototype vest more positively than the fit of the traditional vest in all areas when sitting. A general linear model for repeated measures was run to test the results for the fit scale. Results were approaching significance. Despite more positive scores for the prototype vest panels for all items except "fit of chest area when standing", there was no significant difference [$F\,(1,9) = 5.122$, $p = 0.050$] (see Table 17) found between the traditional and prototype vest panels.

The fit of the prototype vest was rated more positively when standing except for the armhole pinching, which received the same score ($M = 1.3$) as the traditional vest. In addition, the traditional vest received more positive scores ($M = 1.5$) than the prototype vest ($M = 1.8$) for the fit of the chest area when standing. Either of these differences in scores may be attributed to the increased thickness of the prototype panels. For example,

Table 16

Subjects' ratings for fit.

Fit area	Standing: Traditional vest (*M*)	Standing: Prototype vest (*M*)	Sitting: Traditional vest (*M*)	Sitting: Prototype vest (*M*)
Tightness of neckline	1.6	1.3	1.9	1.5
Armhole pinching	1.3	1.3	1.9	1.7
Fit of shoulder area	1.6	1.5	1.8	1.6
Fit of chest area	1.5	1.8	1.9	1.8
Fit of waist area	2.0	1.6	2.5	1.9
Overall length	1.9	1.6	2.0	1.6

Note: Fit descriptors were rated on a 5-point Likert-type scale where "1" = Excellent fit, and "5" = Does not fit.

Table 17

General linear model on Fit between traditional and prototype vests.

Source	*SS*	*df*	*MS*	*F*	*P*
Group	36.45	1	36.45	5.122	0.050
Error	64.05	9	7.12		
Total	100.50	10			

subjects may have perceived the prototype to be tighter in the chest because the additional thickness of the prototype panels may have filled out the carrier, causing the vest to fit more closely to the body.

When standing and sitting, officers indicated some similar areas lacking comfort in both vests, such as the waist ($N = 9$) and chest ($N = 6$). The fit issues for the traditional vest were more varied than the fit issues of the prototype, which were limited to the waist and chest. Areas of issue for the traditional vest not reported for the prototype vest included the neck ($N = 3$), underarms ($N = 2$), and shoulders ($N = 1$).

Subjects' comments included the following: "The prototype vest fits better around my middle"; "It's tight at the lower waist, but more comfortable than the other [traditional] vest"; "I would like the Zero-G carrier to be tighter around the waist". The perceived difference in the waist fit may be caused by the additional thickness of the prototype vest panels. Further testing is needed to improve the fit of the ballistic vest design.

Testing of Hypotheses

Hypotheses were tested using statistical analysis, including general linear models for repeated measures to determine any significant differences between the two vest treatments. Means, frequencies, and percentages were calculated for all of the independent and dependent variables. Hypothesis 1 was tested using general linear models to determine if there was any significant difference in the subjects' ability to perform task-related movements when wearing the different treatments. General linear models were used to test hypothesis 2 to determine if there was significance in the level of fit satisfaction for the subjects between different vest treatments. Hypothesis 3 was tested using general linear models to determine if there was any significant difference in comfort between the two vest panels. Hypothesis 4 was also tested using general linear models to compare the overall satisfaction levels of officers' when wearing the two vest treatments.

Hypothesis 1: There is a significant difference with the prototype vest performing more positively in vest function when officers perform task-related movements.

Subjects completed a series of task-related movements wearing the traditional vest panels, prototype vest panels, and no vest. The following movements were included: kneeling, duck squats, body bends, overhead arm extensions, torso twists, cross body arm extensions, walking, crawling, and head rotation. The officers were also asked to perform box lifting, stair climbing, sitting, and ladder climbing. After performing each movement, the officers were asked to rate the movement on a 5-point Likert-type scale (easy to do = 1, hard to do = 5). The scores for each movement were totaled to provide the movement score for each vest panel treatment, and the general linear model was run to test for significant differences between the vest panels. There was no significant difference [F (1,9) = 0.104, p = 0.754] (refer to Table 12) between the traditional vest panels and the prototype vest panels. Since no significant difference was determined between the two vest treatments, hypothesis 1 was rejected.

Hypothesis 2: There is a significant difference in the level of fit satisfaction for the wearer with the prototype vest having more negative satisfaction ratings than the traditional vest.

Participants were asked to complete a wearer acceptability questionnaire for the traditional vest panels and the prototype vest panels. This included questions regarding the fit of the vest while standing and sitting. They rated the vest fit on a 5-point Likert-type scale from “excellent fit” (1) to “does not fit” (5). The scores for each vest panel were summed to create a total fit score. A general linear model was run to test for significance, but there was no significant difference [F (1,9) = 5.122, p = 0.050] (refer to Table 17) between the two vest treatments, therefore hypothesis 2 was rejected.

Hypothesis 3: A significant difference in comfort of the vests will occur with the prototype vest performing more positively than the traditional vest.

The physical comfort of the vests was measured using adjective sets from the semantic differential wearer acceptability scale, such as “cold/hot”. Subjects completed the wearer acceptability scale while wearing the traditional vest and the prototype vest. They rated the adjective sets from 1 to 5. The scores were summed and general linear models were run to test for significant differences between the two vest panels. There was no significant difference [F (1,9) = 2.00, p = 0.191] (refer to Table 14) between the physical comfort of the two vest panels. Hypothesis 3 was rejected.

Hypothesis 4: Overall satisfaction levels related to vest performance and comfort will show a significant difference with the prototype vest having ratings that are more positive when officers compare the traditional and the prototype vests.

Officers rated the traditional vest and prototype vest for overall satisfaction on a 5-point scale. The scores were totaled for each, and a general linear model was run to analyze the differences between the two vest panels. Although the scores varied, there was no significant difference between the traditional and prototype vest panels [F (1,9) = 0.153, p = 0.678]. Therefore, hypothesis 4 was rejected. Further testing is needed to determine if the slight differences in scores have any significance.

Although there were no significant differences between the two vest treatments, the prototype vest panels rated very favorably when compared to the traditional vest panels. Overall, 5 officers preferred the prototype vest panels, indicating that it was lighter (N = 4), more flexible (N = 4), and had more give under the armholes (N = 1). One officer preferred the rigidity of the prototype panels. Four officers preferred the traditional vest panel, stating that it was softer (N = 1), more breathable (N = 1), and more pliable (N = 2). One officer liked both ballistic panel treatments.

The rejection of the hypotheses shows that there was no significant difference in mobility, fit, comfort, or satisfaction the officers' experienced when wearing the prototype vest treatment and the traditional vest treatment. These findings suggest the prototype vest panels provide the same general comfort as the traditional vest panels, while allowing higher ballistics protection at a lower weight.

CHAPTER 5
SUMMARY AND RECOMMENDATIONS

The overall purpose of this study was to compare and contrast the comfort levels of two Level II ballistic vests. The vests were of different fabrications: one vest made of traditional ballistic fabrics, and another vest made of a prototype fabric, ArmorFelt. ArmorFelt is a needlepunched nonwoven composed of both aramid and HPPE fibers (Thomas, 1998). Blending fiber types allows increased energy absorption to be combined with lower fabric weight (Thomas, 1998). Comfort aspects such as fit, mobility, and thermal acceptability were examined for each vest.

This chapter will summarize the findings related to the studies' objectives and outline the results for each hypothesis that was tested. Suggestions for ballistic vests manufacturers will follow, as well as suggestions for future research.

Summary of the Study

A research instrument was adapted to address the purpose and the objectives of the study. Ten male law enforcement officers from the Tallahassee Police Department participated in a range of motion test, movement analysis, and then completed a wearer acceptability scale to evaluate the differences between a traditional vest fabrication and a prototype vest fabrication.

The resulting data was analyzed using frequency distributions to show the subject's demographics descriptively. The aspects of comfort, including aspects such as fit and mobility, and the physical attributes of the vest, were analyzed using frequencies, means, and percentages. General linear models were run to test significant differences between the three treatments, in order to address the objectives of the study and test the hypotheses.

Summary of the Findings

The researcher addressed this study's purpose through the application of the DeJonge Functional Design Process. The findings of the study were used to address key objectives and hypotheses as outlined below.

Objective 1: To ascertain specific daily tasks police officers perform when wearing Level II vests using input from officers and through researcher observation; Officers identified their daily tasks through preliminary interviews to be sitting in cars or at desks, squatting, drawing their gun, and walking/running. These tasks were broken down into basic body movements or task-related movements and then included in the movement analysis, such as kneeling, duck squats, torso twists, cross body arm reaches, and sitting.

Objective 2: To identify specifications for a prototype ballistic vest for police officers; Input came from a literature search, officer interviews, and an activity analysis. Specifications for the prototype vest were developed to be similar to the traditional vest currently in use by the Tallahassee Police Department (page 28). The SafariLand Zero-G vest they were using was designed for Level II protection. This determined that the prototype vest must also be for Level II protection.

The design of the Zero-G carrier was analyzed, and prototype ballistic panels were created to fit inside. These panels were the identical design as the Zero-G panels, but consisted of different fabrication: 3 layers of Kevlar, 10 layers of Goldflex, and 4 layers of ArmorFelt. The unique fabrication of the prototype allowed for the same protection level to be achieved, while allowing for lighter weight in the panels.

Objective 3: To conduct a range of motion and movement analysis to measure the officers' performance objectively; Once the prototype vest was constructed and human subjects approval was obtained, ten officers from the Tallahassee Police Department participated in a range of motion test and movement analysis wearing their traditional vest, the prototype vest, and no vest. The results rejected Hypothesis 1. There was no significant difference between the prototype and traditional vest function when officers perform task-related movements. However, there was a positive significant difference (*p*

= 0.022) in officers' ease of movement when wearing no vest compared to wearing either of the vest treatments.

Objective 4: Conduct a wearer acceptability scale to identify the officers' needs. It was anticipated that comfort aspects (i.e. fit, mobility, thermal acceptability) and psychological aspects would be key components in the subjective evaluation; The wearer acceptability scale was a semantic differential scale, which included 24 adjective sets. The results were analyzed and used to answer Hypotheses 2, 3, and 4.

Testing of Hypothesis 2 determined there was no significant difference in the level of fit satisfaction for the wearer between the prototype vest and traditional vest. There were tendencies for officers to prefer the fit of the prototype vest to the traditional, despite the identical designs. This may be attributed to the different fabrication used for the prototype. Officers may have perceived the vest to fit better due to the fabrication. For instance, officers preferred the prototype vest fit when sitting to the traditional vest fit when sitting. Participants' comments about the prototype vest panels not bunching up as much as the traditional vest panels when they sat down may have been an important factor when they perceived fit. Further study is needed in the fit of ballistic vests.

Hypothesis 3 was rejected. There was no significant difference in comfort of the vests when the traditional and the prototype vests are compared. Although the vests differed in fabrication, the comfort of the vests was not perceived to be very different. The officers' perceptions of the vests may have been limited by the testing, which required only a few movements to be performed in each vest. The testing was also done under favorable environmental conditions, which may not have allowed the officers to perceive any discomfort. Follow-up testing may be necessary in hotter temperatures or over a longer testing time to properly determine any difference in comfort levels.

Hypothesis 4 was also rejected. Overall satisfaction levels related to vest performance and comfort did not show a positive significant difference when officers compared the traditional and the prototype vests. As previously mentioned, the testing protocol and environment may have limited the officers' ability to perceive any difference between the two vests. It is recommended that further testing be done to evaluate this.

Objective 5: Evaluate the prototype based on key criteria derived from the design specifications and the interactive matrix. Design specifications were identified and grouped into four categories: safety, wearer acceptance, mobility, and production. An interaction matrix was established to identify design specifications that either conflicted with each other, required accommodation to allow another specification to be met, or had no conflict with other specifications. The prototype vest panels met the specifications for safety, wearer acceptance, mobility, and production.

The prototype fabric showed positive results when tested for ballistic vests. The prototype vest weighed 11.60 oz/ft^2 (3539.76 g/m^2), which was less than the traditional vest weight of 11.82 oz/ft^2 (3606.89 g/m^2), and exhibited higher ballistics protection (35 mm of backface deformation) than the traditional vest (42 mm of backface deformation). All four of the hypotheses were rejected, showing officers' did not experience any significant difference in mobility, fit, comfort, or satisfaction when wearing the prototype vest treatment as compared to the traditional vest treatment. These findings suggest the prototype panels provide the same general comfort as the traditional vest panels, while allowing higher ballistics protection at a lower weight.

The officers' did experience problems with the comfort of the prototype vest which may be attributed to the thickness of the fabric. It may be necessary to reduce the number of layers of ArmorFelt used in the vest panels or reduce the fabric thickness. The development of the prototype fabric continues to determine ways of reducing the thickness of the prototype vest panels without compromising the ballistics protection.

Design specifications identified through the literature review were examined after completion of the study to reevaluate the interaction of the specifications in the matrix (p. 28). It was determined that the conflicts and accommodations previously identified through the literature review and user interviews were the same as the officers identified in the study. For example, officers indicated that "body coverage" conflicted with "thermal comfort". The higher body coverage the vest provided, the more discomfort officers experienced related to the thermal properties of the vest. Specifications identified in the literature review still needing improvement are: body coverage, design features, and fabric and notions.

Suggestions for Ballistic Vest Manufacturers

Many of the subjects expressed their discontent with the breatheability and absorbency of the vests ($N = 7$). Both breatheability and absorbency qualities of ballistic vests are related to the fabrics used for both the vest carrier and ballistic panels. Using a more absorbent carrier fabric may reduce the officers' thermal discomfort. However, this was not examined in this study, as the same carrier was used for both the traditional and ballistic vest panels.

In addition, subjects expressed discontent with the flexibility of the fabric used in both the traditional and prototype vest panels. It was reported that when the ballistic panels bunched up, officers had more difficulty moving. Further testing of the comfort of ballistic fabrics is recommended.

The design of the traditional ballistic vest also proved troublesome to subjects. The panels were too long, and often caused problems when the subject tried to sit or bend at the waist, shortening their body length. The vest also cut across the area of the shoulder where officers need to rest their shoulder weapons. Although the results identified issues with the traditional vest design, this study did not evaluate the design of the vest because both the traditional and prototype vests were the same design. Further examination of the design of ballistics vests is needed to properly address these problems.

Recommendations for Further Research

Based upon the findings of this study, it is recommended that future research may be conducted to:

1. Study a wider range of law enforcement officers with different characteristics, such as a broader range of vest sizes, body types, ages, work experience, and rank. This could be done using more of the Tallahassee Police Department, or it could be expanded further to include a number of police departments that use the SafariLand Zero-G vest.
2. Compare a larger number of traditional Level II ballistic vests to the prototype vest. An expanded study may prove different findings due to increased comparisons.

3. Examine and compare different protection levels of ballistic vests with other ballistic protection levels constructed of the prototype fabric. The additional bulk of the fabric may be more noticeable to the officers when the numbers of layers is increased for higher protection levels.
4. Examine Level II ballistic vests for women. The study of women's ballistic vest would introduce other factors specific to women in areas such as fit, which may or may not change the results of the study.
5. Analyze the traditional vest design. Some concerns expressed by participants related to the design of the vest, which this study did not address. These concerns bring to light the need for further research in this area.
6. Analyze the fit of ballistic vests. Issues related to the fit of the traditional vest included the vest straps not providing the adjustability intended, the neck riding up, the chest bunching up, and the tightness of the waist. Further examination is needed to identify ways of improving vest fit for increased comfort and performance.
7. Study the individual comfort factors of ballistic vests, i.e. breathability and absorbency. It is recommended that varied environmental conditions be used to further examine the vests' thermal acceptability.
8. Examine ballistic vests related to other applications, such as the military. There may be additional issues with the ballistic vests depending on the application.
9. Investigate other design features, fabrications, and styles for the vest carrier. Some of the issues identified by this study may be caused or influenced by the vest carrier, not the vest panels.
10. Analyze the interaction of the ballistic vest with other uniform parts. Officers reported having problems with the vest related to their shirt, gun belt, and gear. The comfort level of officers may be increased by eliminating some of these negative experiences.