NC STATE UNIVERSITY
COLLEGE OF Textiles NC STATE UNIVERSITY
JTATM
Journal of Textile and Apparel, Technology and Management

Volume 6, Issue 3, Spring2010

Comfort Comparison of Ballistic Vest Panels for Police Officers

Jessica Barker, Assistant Professor
Apparel, Educational Studies and Hospitality Management
Iowa State University

Catherine Black, Associate Professor
Textiles and Consumer Sciences
Florida State University

Rinn Cloud, Professor
Textiles and Consumer Sciences
Florida State University

ABSTRACT

This study examined the comparative comfort performance of an experimental ballistic panel and a standard-issue ballistic panel for use in a Level II ballistic vest. Experimental panels were constructed using an innovative fabric that had not previously been incorporated into the layers of ballistic vest panels. The experimental fabric weighs less but is thicker than the corresponding fabric layers used in a standard-issue ballistic vest panel. Vest panels incorporating the experimental fabric performed at higher ballistic protection than standard-issue panels in previous research (Thomas, 2003), but wearability of the panels has not been established. Ballistic vest panels were inserted into a vest carrier and evaluated for wearability using controlled wear testing in a repeated measures design. Ten police officers rated the experimental ballistic panels equivalent to the standard-issue ballistic panels for their influence on range of motion and ease of movement. A no-vest condition was used as a baseline measure for mobility testing. Officers also rated the experimental ballistic panels equivalent to the standard-issue ballistic panels for perceived vest fit and comfort. Participants reported the experimental vest panels were cooler to wear, offered greater mobility, were more flexible and were more acceptable to wear. The study demonstrated that the innovative fabric could be used in ballistic vest panels to decrease the weight of ballistic vests and potentially reduce the physiological impact of ballistic vests on the wearer.

Keywords: Ballistic fabrics, comfort, fit, functional design, mobility, protective clothing

Introduction

Since the introduction of concealable body armor in 1973, over 3000 lives have been saved (National Institute of Justice, 2006, p. 2). However, between 1996 and 2005, 332 officers died while wearing body armor, and 105 (31%) of these deaths were attributed to gunshot wounds in the upper torso (Federal Bureau of Investigation, 2006, Table 36). While the exact reasons for these deaths are not all known, these deaths do suggest there is need for improvement in body armor, particularly ballistic vests that are used to protect the upper torso. Additionally, research indicates that ballistic vests can be uncomfortable and hinder movement resulting in officers opting not to wear their vests (Shanley, Slaten, & Shanley, 1993; Thomas, 2008). Therefore, it is critical to understand how ballistic vests impact officer comfort and movement to maximize the number of officers willing to wear ballistic vests.

There are seven protection levels of ballistic vests identified by the National Institute of Justice (2001); each is designed to protect from successively higher ballistic threats. The ballistic protection level most commonly worn by law enforcement officers is Level II. Level II ballistic vests are designed to be worn under the uniform shirt and consist of a vest carrier made of fabrics such as nylon or cotton with pockets to insert protective ballistic panels in both the front and back. These panels are constructed of multiple layers of ballistic-resistant fabrics, and are designed to wrap around the sides of the body for additional protection. Level II ballistic vests are intended to be comfortable, lightweight, and unrestrictive, while providing protection of the upper torso and essential body organs by means of the inserted panels.

The purpose of this study was to examine the comparative comfort performance of an experimental ballistic panel and a standard-issue ballistic panel for use in a Level II ballistic vest through a controlled wear study. A no-vest condition was included as a baseline measure for mobility testing. Specific objectives were to: (1) evaluate the range of motion and ease of movement allowed by each type of ballistic panel; (2) assess the fit perceptions of officers while wearing each type of ballistic panel; and (3) determine officers' perception of comfort related to each type of ballistic vest panel.

Literature Review

Three primary types of polymer fibers are currently used in producing fabrics for use in ballistic panels: aramid, high performance polyethylene (HPPE), and polyphenylenebenzobisoxazole (PBO). These fibers are used either singly or in combination to create ballistic-resistant fabrics.

According to the National Institute of Justice (2001), two of the most commonly used ballistic fabrics are DuPont's Kevlar® and Honeywell's GoldFlex®. Kevlar®, the first material used in modern concealable body armor, is woven using aramid fibers that are flame resistant, do not melt, and provide high strength combined with low weight. Kevlar® fabrics also have high chemical and cut/tear resistance (DuPont, 2008). GoldFlex® is a high strength shield composite of aramid fibers; two layers of fibers, crossing at 0 and 90 degree angles, are held in place by a flexible resin and then sealed between thin layers of polyethylene film. This nonwoven fabric produces an extremely strong, flexible, and protective composite (National Institute of Justice, 2001).

ArmorFelt, an innovative ballistic fabric, is a blend of aramid and HPPE fibers needle punched into a nonwoven structure (Thomas, 2008). The blended fibers provide increased energy absorption as compared to a single fiber fabric and the needle-punched nonwoven structure results in greater thickness but lower fabric weight than woven structures (Thomas, 2008). Therefore, incorporating ArmorFelt into ballistic vests would decrease the weight of ballistic vests and potentially reduce the physiological impact of ballistic vests on the wearer.

To obtain the ballistic resistance level required for a body armor product, ballistic panels are constructed of multiple layers of one or more types of ballistic-resistant fabric. Ballistic panels are assembled numerous ways: manufacturers bias stitch around the panel edges, tack fabric layers together in several places, or sew panels together with rows of vertical and/or horizontal stitching (National Institute of Justice, 2001). Front and back panels are then inserted into a vest carrier, typically made using basic woven fabrics of nylon or cotton.

In this study, two commonly used ballistic fabrics, Kevlar® and GoldFlex®, were used in both standard-issue and experimental ballistic panels with the same nylon vest carrier. The experimental ballistic panels also utilized the innovative ArmorFelt fabric, which is thicker than other ballistic fabrics, in addition to and in place of one of the Kevlar® layers. Thus, the experimental ballistic panels were thicker than the standard-issue panels. The thicker, bulkier panels raised concerns that wearer mobility would be negatively impacted, which could affect officers' comfort and willingness to wear vests utilizing the experimental panels, as previously noted by Shanley et al. (1993) and Thomas (2008). Other research also documents the relationship of mobility affecting wearer comfort and willingness to wear garments. Adams and Keyserling (1996) found that wearer comfort was positively correlated with the mobility allowed by a garment. Likewise, Huck, Maganga, and Kim (1997) found that wearers preferred garments that allowed maximum range of motion for task-related movements over garments that restricted wearer mobility. The first objective of this study was to determine whether or not the additional thickness of the experimental ballistic panels with the ArmorFelt fabric had a negative impact on wearer mobility as compared to the mobility provided by the standard-issue vest panels. Therefore, the following hypothesis was tested:

Hypothesis 1: There will be a significant difference in (a) range of motion and (b) the perceived ease of performing task-related movements between the experimental ballistic panel and the standard-issue ballistic panel when used as inserts in the same vest carrier.

Good fit is also identified as critical for wearer comfort and satisfaction with garments (Ashdown & DeLong, 1995; Barker, 2002; Holme, 2006). Protective clothing that does not fit correctly can cause discomfort and may negatively impact protection (OSHA, 1992). A study of military clothing comfort (Schutz, Cardello, & Winterhalter, 2005) found that satisfactory fit of a garment was most important in achieving wearer comfort. In addition, an evaluation of protective gloves found that fabric thickness affected wearer fit satisfaction (Tremblay-Lutter, Crown, & Rigakis, 1996). Accordingly, it is important to assess wearer perception of the fit of ballistic vests to identify necessary comfort-related improvements. The standard-issue ballistic panels and experimental ballistic panels differed in thickness due to the use of ArmorFelt layers; therefore, the second objective of this study was to determine if the additional thickness of the experimental ballistic panels affected officers' perceptions of vest fit.

Hypothesis 2: There will be a significant difference in fit perceptions reported by officers when wearing the vest carrier with experimental ballistic panels as compared to wearing the vest carrier with the standard-issue ballistic panels.

While mobility and fit are two important factors for ballistic vest wearers, research also documents that overall comfort and satisfaction with clothing can be influenced by the fabrics used to construct clothing (Barker, 2002; Schutz et al., 2005). Barker's (2002) study found that fabric properties, such as moisture transport, were crucial to wearer comfort. Likewise, Schutz et al. (2005) reported fabric properties affected consumer ratings of discomfort and general satisfaction with garments. Thus, this study investigated effects of ballistic panel fabrication on wearer comfort through the following hypothesis.

Hypothesis 3: There will be a significant difference in the perceptions of comfort provided by the ballistic vest when using the experimental ballistic panel inserts as compared to using the standard-issue ballistic panel inserts.

Methods

This research was conducted as a controlled wear study to investigate the effect of ballistic vest panels on officer mobility, fit perception, and comfort. A repeated measures design was utilized; participants wore one ballistic vest carrier with standard-issue panels inserted and then with experimental panels inserted. The study was approved by the university's Institutional Review Board.

Subjects

A purposive sample of ten male law enforcement officers from a Southeastern city police department was employed for this study. Officers were chosen randomly from a pool of officers who fit either a size 38 or 40 ballistic vest. The mean age of the officers was 37 years. Participants ranged in height from 5'5" to 6'0" (*M* = 5'9.5"), and weighed from 155 lbs. to 209 lbs. (*M* = 180 lbs). Average length of law enforcement experience was 11.9 years.

Uniform and Standard-Issue Ballistic Vest

Officers arrived wearing their department-issued duty uniform consisting of a short-sleeved uniform shirt with collar, pants, boots, leather belt, and gun belt. The gun belt held their gear, comprising a pistol and holster, ammo pouch, baton, flashlight, handcuffs, and radio. Their duty uniform included a standard-issue ballistic vest worn beneath their uniform shirt and a plain T-shirt worn beneath the vest. The standard-issue ballistic vest comprised of a vest carrier made of a 100% nylon fabric and front and back ballistic panels, each consisting of 4 layers of Kevlar® and 12 layers of GoldFlex®. The vest carrier had one pocket for insertion of the front ballistic panel and one pocket for insertion of the back ballistic panel (Figure 1).

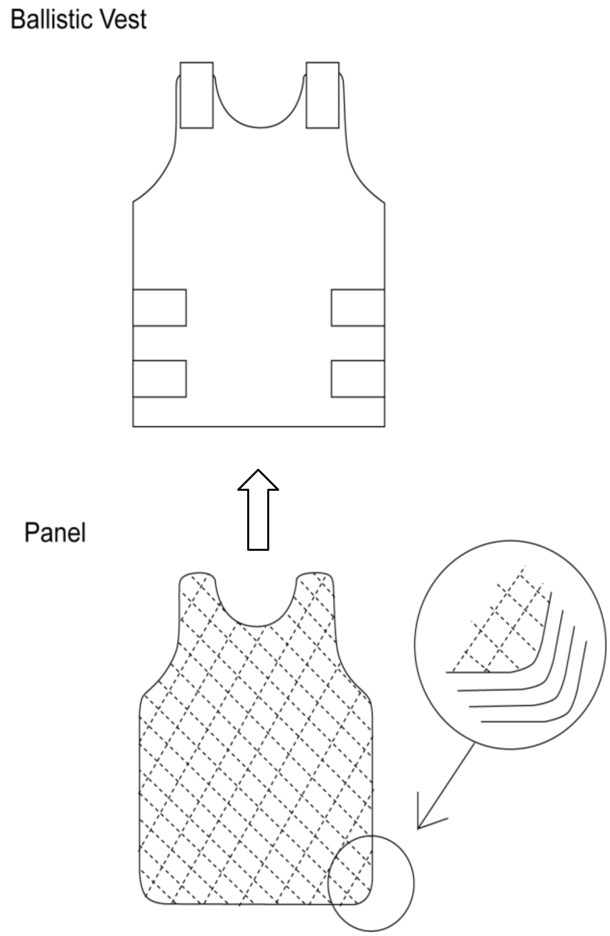

Figure 1. Ballistic Vest and Quilted Ballistic Panel.

Experimental Ballistic Panels

Experimental ballistic panels were constructed utilizing the innovative ArmorFelt fabric to evaluate if wearers could perceive differences in their mobility, fit, and comfort when wearing the thicker and lighter weight experimental vest panels as compared to the standard-issue vest panels. The experimental ballistic panels consisted of three layers of Kevlar®, ten layers of GoldFlex® and four layers of ArmorFelt (Figure 2).

Figure 2. Kevlar®, Goldflex®, and ArmorFelt Ballistic Fabrics.

In previous ballistic testing, the experimental ballistic panels exhibited higher protection at a lower weight than the standard-issue panels using close to the same number of fabric layers (Thomas, 2003). The number of fabric layers was varied slightly to achieve an optimal combination of fabric layers while still complying with ballistic protection standards set by the National Institute of Justice (2001). This same combination was used for the experimental vest panels in this study to maintain consistency with the vest panel structure used in ballistic testing (Thomas, 2003). Table 1 outlines the weight, fabric layers, and ballistic protection (as shown by backface deformation, a measurement of bullet penetration into the ballistic vest) for the standard-issue and experimental ballistic panels.

Table 1. Ballistic Vest Panel Weight, Fabric Layers, and Backface Deformation

Vest Panels	Projectile and Velocity Tested	Fabrics Used			Backface Deformation
		Kevlar® 840	GoldFlex®	ArmorFelt	
Standard-Issue ($11.82\ oz/ft^2$)	9 mm FMJ 115 gr; 1240±10	4	12	0	42 mm
Experimental ($11.62\ oz/ft^2$)	9 mm FMJ 115 gr; 1240±10	3	10	4	35 mm

Note: Backface deformation for Level II ballistic vest panels must not exceed 44mm (NIJ 2001).

The experimental ballistic panels were constructed using ballistic panel manufacturing techniques similar to those used to produce the standard-issue ballistic panels to maintain consistency in construction quality. Ballistic fabrics (Kevlar®, Goldflex®, and ArmorFelt; see Figure 2) were obtained in sheet form and cut to specification at a manufacturing site. Each panel was quilted in the same two inch diamond pattern as the standard-issue panels using Kevlar® thread. Front and back panels were constructed to fit into one of the two men's vest sizes most commonly worn by officers, 38 and 40. The two types of ballistic panels were then subjected to a battery of tests and observations which incorporated both objective and subjective measures to assess differences in range of motion, ease of movement, fit perceptions, and wearer comfort.

Testing Procedures

Testing took place in a controlled laboratory environment using two garment treatments, the vest with standard-issue ballistic panels and the vest with experimental ballistic panels, and a no-vest condition to establish baseline mobility measurements. The testing procedure comprised three phases. Officers completed the three testing phases while wearing their uniform and ballistic vest with standard-issue panels. The vest was worn over a T-shirt and under the short-sleeved uniform shirt. Each officer then removed the standard-issue panels and inserted the experimental ballistic panels into the vest carrier. The testing phases were repeated while officers wore their uniform and ballistic vest with the experimental ballistic panels. Officers then removed their ballistic vest and completed the movement testing (Phase I) while only wearing their uniform. Order of vest treatments could not be randomized due to the time required to don and doff the vests and uniforms. A description of the three testing phases is given in the following paragraphs.

Phase I: A range of motion test was performed to assess any restriction in mobility caused by the vest treatments. The test consisted of six selected motions researchers identified as critical movements during observations of officers' task-related movements: shoulder flexion[1] and hyperextension[2], shoulder abduction[3] and adduction[4], and trunk flexion[5] and hyperextension[6]. Measurements of range of motion were taken by the researcher using a goniometer to determine the amount of movement possible in a joint while wearing the different vest treatments. The range of motion measurements taken for each subject without vest served as the baseline measurements.

Ease of movement was assessed using a modified ASTM F1154-99 protocol (ASTM 1999). The protocol was expanded to include movements law enforcement officers are required to make while wearing ballistic vests. The final movement protocol included kneeling, duck squats, body bends, arm extensions, torso twists, arm reaches, walking, crawling, head rotation, box lifting, stair climbing, sitting, and ladder climbing. Officers were asked to rate their ability to perform each movement, from *easy to do* (1) to *hard to do* (5) using a 5-point Likert-type scale. Ease of movement scores taken for each subject without vest served as a control for comparison. Scores for the individual movements were tallied to create an overall ease of movement score for each vest treatment. Reliability for the movement scale was 0.89 as measured by Cronbach's alpha.

Phase II: Perceived fit of the vests was assessed through sixteen questions. The officers reported the fit for each vest treatment in different garment areas (neckline, armhole, shoulder, chest, waist, length) when standing and when sitting, using a 5-point Likert-type scale, from *excellent fit* (1) to *does not fit* (5). These scores were tallied to create general standing and sitting perceived fit scores, as well as an overall perceived fit score. Reliability for the perceived fit scale was 0.89.

Phase III: After the officers completed the movement and fit analysis, they completed a questionnaire while wearing vest treatments with the standard-issue panels and the experimental panels. The questionnaire measured vest panel comfort using 8 adjective sets on a 5-point semantic differential scale from *positive* (1) to *negative* (5) derived from Huck et al. (1997)

---

[1] Shoulder Flexion – A forward upward movement of the arm*
[2] Shoulder Hyperextension – A backward upward movement of the arm*
[3] Shoulder Abduction – A sideward upward movement of the arm*
[4] Shoulder Adduction – An upward movement of the arm across the body*
[5] Trunk Flexion – Bending forward at the waist to move the upper torso*
[6] Trunk Hyperextension – Bending backward at the waist to move the upper torso*

*Adapted from Luttgens, Deutsch & Hamilton, 1992.

and Rutherford-Black and Khan (1995). Comfort adjective sets included: comfortable/uncomfortable, flexible/rigid, non-irritating/irritating, loose/tight, cold/hot, breathable/does not breathe, like/dislike, and satisfied/dissatisfied. Reliability for the vest panel comfort scale was 0.72.

Findings and Discussion Range of Motion

Mean range of motion measurements for each vest treatment are shown in Table 2. Changes in range of motion were calculated by subtracting the baseline measurement (without vest) from the range of motion measurement taken when officers wore the standard-issue ballistic panels or the experimental ballistic panels. General linear model (GLM) repeated measures was used to compare changes in range of motion that occurred for the vest with the standard-issue ballistic panels and the vest with the experimental ballistic panels. We found no significant difference between the change in range of motion officers' experienced when wearing the two vest panel treatments for all measures: shoulder abduction [F (1,9) = 0.31, p = 0.59], shoulder adduction [F (1,9) = 0.42, p = 0.53], shoulder hyperextension [F (1,9) = 0.06, p = 0.82], shoulder flexion [F (1,9) = 0.18, p = 0.68], trunk hyperextension [F (1,9) = 0.02, p = 0.96], and trunk flexion [F (1,9) = 0.49, p = 0.50]. These results indicate that the thicker experimental ballistic panels allowed the same freedom of movement as the standard-issue panel.

Table 2. Officers' Range of Motion in Degrees for Selected Movements

	No Vest	Standard-Issue Panels		Experimental Panels	
Movement	*M*	*M*	Change	*M*	Change
Shoulder Abduction	56.7°	57.8°	+1.1°	55.7°	-0.5°
Shoulder Adduction	81.3°	78.3°	-3.0°	74.8°	-6.5°
Shoulder Hyperextension	59.5°	59.4°	-0.1°	58.5°	-1.0°
Shoulder Flexion	147.4°	142.6°	-4.8°	140.6°	-6.8°
Trunk Hyperextension	150.9°	150.4°	-0.5°	150.5°	-0.4°
Trunk Flexion	99.0°	98.2°	-0.8°	92.4°	-6.6°

Note: N = 10. p < .05.

The data were further evaluated using GLM repeated measures to determine if the differences between the range of motion participants experienced when wearing either the standard-issue or experimental ballistic vest panels was significantly different from the range of motion experienced without a ballistic vest. No significant differences were found between the range of motion when wearing the vest with standard-issue vest panels and when not wearing a ballistic vest (Table 3). Similarly, no significant differences were found between range of motion measures when wearing the vest with experimental vest panels and when not wearing a ballistic vest (Table 3). Thus, range of motion for officers in our study was not hindered by wearing a ballistic vest, regardless of which vest panel was used.

Table 3. Officer Range of Motion Wearing Vest Panel Treatments Compared to No Vest

	Standard-Issue Vest Panels		Experimental Vest Panels	
Movement	*F*(1,9)	*p*	*F* (1,9)	*p*
Shoulder Abduction	0.30	0.60	0.91	0.77
Shoulder Adduction	0.23	0.64	1.98	0.19
Shoulder Hyperextension	0.03	0.91	0.96	0.76
Shoulder Flexion	2.23	0.17	2.18	0.17
Trunk Hyperextension	0.09	0.93	0.51	0.49
Trunk Flexion	0.03	0.87	0.21	0.87

Note: $N = 10$. $p < .05$.

Ease of Movement

General linear model repeated measures was used to test for significant differences in the overall ease of movement scores. We found no significant difference [F (1, 9) = 0.10, p = 0.75] between the standard-issue panels and experimental panels for the ease of movement measure.

Officers were either positive or neutral when performing the movements with both types of ballistic panels (Table 4). The experimental ballistic panels were perceived as positively as the standard-issue ballistic panels for ease of movement, indicating that the experimental fabric has potential for use in ballistic vests.

Table 4. Officers' Mean Ratings for Ease of Movement

Movement	No Vest	Standard-Issue Panels	Experimental Panels
Kneeling	1.6	2.0	2.0
Duck Squats	1.5	2.0	2.0
Body Bends	1.3	1.9	2.1
Overhead Arm Extensions	1.1	1.3	1.2
Torso Twists	1.1	1.3	1.5
Cross Body Arm Reaches	1.0	1.7	1.8
Walking	1.0	1.2	1.2
Crawling	1.7	2.3	2.2
Head Rotation	1.0	1.1	1.1
Box Lifting	1.4	2.0	2.1
Stair Climbing	1.1	1.3	1.3
Sitting	1.3	1.9	1.8
Ladder Climbing	1.3	1.5	1.6

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

In addition to rating the movements, the subjects also rated their general mobility while wearing the standard-issue vest panels and the experimental vest panels on a 5-point Likert-type scale, from *easy to do* (1) to *hard to do* (5). GLM repeated measures was used to test for significant differences for the general mobility measure; the vest treatments were not found to be significantly different [F (1, 9) = 0.31, p = 0.59]. Since no significant differences were found between the standard-issue and experimental vest panels in either range of motion measures or ease of movement scores, hypothesis 1 was rejected. Overall, the vest treatment with experimental ballistic panels performed as well as the vest treatment with standard-issue panels in both range of motion and task-related movement testing.

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 panel treatment, illustrating that the vests did not impede their movements. Many of the officers (*N* = 7) commented that the movements were not hindered only by their vests, but by the vest interaction with their gun belt, particularly when bending at the waist. When 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. The subjects also had trouble with the vest panels bunching up when bending at the waist. They commented that their standard-issue vest panels bunched up (*N* = 6) and did not regain the original form (*N* = 4). One subject also commented that when he bent to the left or right, his standard-issue vest panels hit the gear on his gun belt and created a lip. These comments indicate a need for the ballistic vest panels to facilitate bending at the waist.

GLM repeated measures analysis of variance was also used to assess differences between the ease of movement ratings when officers wore no vest and when they wore the vest with either the standard-issue or experimental vest panels. We found significant differences between the standard-issue vest panel and no vest treatments [F (1,9) = 9.72, p = 0.01], as well as between the experimental vest panel and no vest treatments [F (1,9) = 13.86, p = 0.00] for ease of movement scores. This result indicates that although officers' actual range of motion was not affected by wearing ballistic vests (see Table 3), officers perceive that their movement decreases when wearing ballistic vests.

Perceived Vest Fit

Subjects rated the fit of the vest with the experimental ballistic panels more positively than the fit of the vest with the standard-issue ballistic panels in all areas when sitting (Table 5), and the experimental ballistic panels received more positive scores for all items except *fit of chest area when standing.* GLM repeated measures was used to test the results for the perceived fit scale. Results were approaching significance [F (1, 9) = 5.12, p = 0.051]; Hypothesis 2 was rejected since the difference in fit scores was not statistically significant.

The overall means for fit perceptions indicate that the vest treatments were perceived as having good fit in all areas. Subjects' comments, however, focused in on the waist area: "The experimental vest panels fit better around my middle"; "It's tight at the lower waist, but more comfortable than the other [standard-issue] vest panels"; "I would like the [standard-issue] vest to be tighter around the waist". The perceived difference in the waist fit may be caused by the additional thickness of the experimental vest panels. Participants (*N* = 5) also commented that the experimental ballistic panels did not bunch up as much as the standard-issue vest panels when they sat down. Both vests received the highest mean ratings for waist area fit when sitting. These findings support Ashdown and DeLong's (1995) study that also found satisfaction of fit varied at different body locations.

Table 5. Officers' Mean Ratings for Perceived Vest Fit

	Standing		Sitting	
Fit Area	Standard-Issue Panels	Experimental Panels	Standard-Issue Panels	Experimental Panels
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.

Wearer Comfort

During Phase III, wearers rated their comfort using 8 adjective sets, which were grouped into one scale to assess vest panel comfort. Table 6 lists the adjective sets and the mean scores for each vest treatment. Based on GLM repeated measures analysis of variance, there was no significant difference [F (1,9) = 1.63, p = 0.23] found between wearer comfort of the vest treatment with standard-issue vest panels and the vest treatment with experimental ballistic panels; hence, hypothesis 3 was also rejected. Multiple subjects (N = 3) commented that the experimental ballistic vest panels were more flexible than the standard-issue vest panels, which may have had an impact on the comfort ratings. Similarly, Huck et al. (1997) also found that flexibility and ease of movement were important qualities for grass fire fighter uniforms. Although there were no significant differences among the comfort ratings, 60% of officers indicated that they have to adjust their standard-issue vest regularly to improve their comfort and did not always wear the vest as it should be worn. These adjustments may put the officers at greater risk for injury.

Table 6. Mean Ratings for Wearer Comfort

Comfort of Vest Panels	Standard-Issue Panels (*M*)	Experimental Panels (*M*)
Comfortable/uncomfortable	2.4	2.1
Flexible/rigid	2.6	2.1
Non-irritating/irritating	2.9	2.5
Loose/tight	3.3	3.3
Cold/hot	4.5	3.6
Breathable/does not breathe	3.2	3.0
Like/dislike	2.2	1.9
Satisfied/dissatisfied	2.0	1.9

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

The experimental ballistic panels rated very favorably when compared to the standard-issue vest panels. Overall, 50% of officers preferred the experimental ballistic panels, indicating that they were lighter and more flexible. Forty percent of officers preferred the standard-issue vest panels, and 10% had no preference.

Summary and Suggestions for Future Research

The purpose of this study was to examine the comparative comfort performance of an experimental ballistic panel and a standard-issue ballistic panel for use in a Level II ballistic vest through a controlled wear study. ArmorFelt, an innovative ballistic fabric, was incorporated into the experimental ballistic panels to reduce the fabric weight and increase the ballistics protection; however, the fabric was thicker and bulkier, causing the experimental vest panels to be thicker than the standard-issue vest panels. Our study was designed to evaluate if officers could perceive these differences between the standard-issue and experimental vest panels. Specific aims of the study were to: (1) evaluate the range of motion and ease of movement allowed by each type of ballistic panel; (2) assess the fit perceptions of officers while wearing each type of ballistic panel; and (3) determine officers' comfort related to each type of ballistic vest panel.

Our findings indicate that the experimental ballistic panels could be used in ballistic vests to enhance protection without negatively affecting officer mobility, perceived vest fit, or comfort. No significant differences were found in range of motion, ease of movement, perceived fit, and wearer comfort when the standard-issue and experimental ballistic vest panels were compared. Some officers did experience problems with the fit of the experimental ballistic panels that may be attributed to the thickness of the fabric. It may be necessary to reduce either the fabric thickness or the number of layers of experimental fabric used in the vest panels.

Several officers commented on problems encountered with the length of the vest when performing certain movements. Additional studies are needed to evaluate the ballistic vest design to identify ways to reduce discomfort caused by sitting or bending at the waist. While reducing the length of the vest may make sitting and bending at the waist more comfortable, it would decrease the protective coverage of the vest. Therefore, it is necessary to identify a design solution that improves vest/panel flexibility while maintaining body coverage.

There was a marked difference between the actual range of motion officers experience and officers' perceived ease of movement when wearing ballistic vests compared to when not wearing ballistic vests. Officers' actual range of motion was not affected by wearing ballistic vests, but they perceived that their ease of movement decreased when wearing ballistic vests. Further, the majority of officers indicated that they regularly adjust the standard-issue ballistic vest in various ways to improve their wearing comfort. This suggests that officers might adjust vests to improve mobility and comfort, when in reality, no adjustment is necessary. Adjusting ballistic vests to enhance perceived mobility or comfort may place officers at risk unnecessarily. More research is needed to evaluate the kinds of ballistic vest adjustments officers make and whether these adjustments compromise their safety.

The experimental vest panels performed similarly to the standard-issue ballistic panels in range of motion, ease of movement, perceived fit, and wearer comfort. Although the two types of ballistic panels differed in number, type and thickness of fabric layers, the mobility, fit, and comfort provided by the panels was not significantly different. These findings indicate that the experimental ballistic panels could be utilized in ballistic vests to improve protection of the wearer beyond what is currently available on the market without sacrificing wearability. Positive reactions of the officers' to the experimental ballistic panels suggest continued study of the use of the experimental fabric in ballistic vest panels is important.

References

Adams, P. S. & Keyserling, W. M. (1996). Methods for assessing protective clothing effects on worker mobility. In J. S. Johnson & S.Z. Mansdorf (Eds.), *Performance of protective clothing: Fifth volume, ASTM STP 123* (pp. 311-326). Philadelphia, PA: American Society for Testing and Materials.

ASTM Committee F-23 on Protective Clothing. (1999). Standard practices for qualitatively evaluating the comfort, fit, function and integrity of chemical-protective suit ensembles (F1154-99).

Philadelphia, PA: American Society for Testing and Materials.

Ashdown, S. & DeLong, M. (1995). Perception testing of apparel ease variation. *Applied Ergonomics*, *26*, 47-54.

Barker, R. L. (2002). From fabric hand to thermal comfort: The evolving role of objective measurements in explaining human comfort response to textiles. *International Journal of Clothing Science and Technology*, *14*, 181-200.

DeJonge, J. O. (1984). Forward: The design process. In Watkins, S. M. *Clothing: The portable Environment* (pp. vii – xi). Ames, IA: Iowa State University Press.

DuPont. (2008). Kevlar®: Aramic fiber. Retrieved on August 21, 2009, from http://www2.dupont.com/Kevlar/en_US/assets/downloads/KEVLAR_Technical_Guide.pdf.

Federal Bureau of Investigation. (2006). *Law enforcement officers killed and assaulted, 2005.* Retrieved August 21, 2009, from http://www.fbi.gov/ucr/killed/2005/.

Holme, I. (July/August 2006). Understanding comfort issues in high-level protective apparel. Technical Textiles International, 15-20.

Huck, J. & Kim, Y. (1997). Coveralls for grass fire fighting. *International Journal of Clothing Science and Technology, 9,* 346-359.

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

Luttgens, K., Deutsch, H., & Hamilton, N. (1992). Anatomical and physiological fundamentals of human motion. In *Kinesiology: Scientific basis of human motion (8^{th} ed.)* (pp.3-290). Dubuque, IA: Brown and Benchmark.

National Institute of Justice. (November 2001). *Selection and application guide to personal body armor, NIJ guide 100-01*. Retrieved August 21, 2009, from http://www.justnet.org/Lists/JUSTNET%20Resources/Attachments/370/selectapp2001.pdf.

National Institute of Justice. (July 2006). Body armor safety initiative: To protect and serve…better. *NIJ Journal,* 2-6.

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

Schutz, H., Cardello, A., & Winterhalter, C. (2005). Perceptions of fiber and fabric uses and the factors contributing to military clothing comfort and satisfaction. *Textile Research Journal*, *75,* 223-232.

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

Thomas, G. A. (2003). [Results of United States Marine Corps Ballistic Armor Field Testing] Unpublished raw data, Auburn University, Alabama.

Thomas, G. A. (2008). Non-woven fabrics for military applications. In Wilusz, E. *Military Textiles* (pp. 44-47). Cambridge, England: Woodhead Publishing, Ltd.

Tremblay-Lutter, J., Crown, E., & Rigakis, K. (1996). Evaluation of functional fit of chemical protective gloves for agricultural workers. *Clothing and Textiles Research Journal*, *14*, 216-224.