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FIT ANALYSIS OF LIQUID COOLED VEST PROTOTYPES USING 3D BODY SCANNING TECHNOLOGY

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ABSTRACT

First responders are frequently exposed to hazardous materials and hostile environments that necessitate wearing specially devised personal protective equipment (PPE). Personal cooling garments play an important role in reducing thermal stress associated with wearing insulative and impermeable PPE. As conduction is the primary cooling mechanism for liquid cooled garments (LCGs), there is need for intimate contact between the skin and garment. The fit of two liquid cooled vests was compared and analyzed through use of a 3D body scanner. Visual images from thirteen volunteer subjects, primarily first responders and life safety specialists, were used to evaluate the fit of both cooling vest prototypes. Perceptual data from the subjects provided user feedback on the prototype vests. The results indicated that both prototypes received high scores in the expert fit ratings although prototype II received higher ratings in many body areas. Ratings from the subjects' perceived fit ballot also indicated that prototype II was rated higher although both vests received high marks.

Keywords: 3D body scanning, anthropometric data, cooling garment, LCGs, cooling vest, liquid cooled vest, fit analysis

Introduction

Cooling garments were introduced in the late 1950's to protect the wearer from hostile hot environments, primarily for military and space exploration purposes. Today, the use of cooling garments has broadened to various civilian applications.

This research was conducted as one component of a large three-year, academic/ industry collaborative research project to develop a personal cooling system for first responders wearing personal protective equipment (PPE) for level A and B protection. First responders are frequently exposed to hazardous materials and hostile environments including chemical and biological toxic materials necessitating personal protection with specially devised PPE. Due to the weight of auxiliary equipment such as the SCBA (Self-Contained Breathing Apparatus) respiratory system that is carried as well as to the impermeable and highly insulative characteristics of the PPE, the first responder's heat dissipative capacity is restricted which can cause an elevated core temperature working at even mild work rates and environmental temperatures.

Heat stress is potentially one of the critical causes of firefighters' fatal incidents. According to the Firefighter Fatality Retrospective Study by the U.S. Fire Administration (2000), overexertion/strain was identified as the cause of 46.4% of fatal firefighter injuries in 2000. This is consistent with the high incidence of deaths from heart attacks (44%) and accounts for nearly half of firefighter deaths. A personal cooling system can play an important role in decreasing a worker's heat stress by maintaining the wearer's body temperature at a safe level (Nunneley, 1970; Crockford & Lee, 1967; Duncan & Konz, 1975).

Several types of cooling garments are available in the marketplace including air cooled, solid coolant cooled and liquid cooled garments. All of these cooling garments have demonstrated considerable heat reduction capabilities. Liquid cooled garments (LCGs) show several advantages over other types of personal cooling garments including providing greater heat reduction as compared to air cooled personnel cooling systems (Nunneley, 1970). In addition, the liquid cooled garment has advantages in terms of desirable fit over the solid coolant cooled garment, since bulky solid coolant materials such as ice packs, gel packs and phase change materials can restrict the wearer's movement and impede garment fit through the torso area (Strydom, Mitchell, Rensburg, & Graan, 1973, 1974; Mucke, 1982).

Conduction, the primary cooling mechanism for LCGs, requires direct physical skin contact. Therefore, a well fitting garment that is in intimate contact with a greater amount of body surface area, provides more cooling than a garment covering less body surface area Maximizing skin contact for a three-dimensional human body with a tubed garment made from a two-dimensional pattern while minimizing restriction in movement and breathing is a challenge. Achieving a tight fit when mass-producing a garment in a given set of sizes to fit many individuals is a greater challenge. Most cooling vest users are typically limited to specific populations like astronauts and pilots with the potential for custom-made vests. However, as cooling vests are adopted for a wider range of industrial and military applications, mass production of the vests is needed to acquire market feasibility. To fit a range of individuals with variation in body measurements at different body sites, application of relevant anthropometric data and technology is needed.

Purpose

The purpose of this study was to compare the fit of two prototype LCGs vests using visual image data acquired using a 3D body scanner. As an earlier step to this research a vest size classification system was developed based on existing anthropometric military data. This sizing system was used to modify the fit of a LCG prototype vest and an alternative LCG prototype vest created to test different design features than the original prototype (Nam, 2004). This manuscript focuses on the subsequent fit evaluation analysis of the two vests.

Method and Procedure

Subjects

Thirteen volunteer first responders from local area fire departments and life safety departments between the ages of 20 and 50 with chest sizes 42 to 46.5 inches were recruited to participate in the study. Only eight subjects met the desired size criteria, three were smaller including one woman and two were larger. The eight subjects who satisfied the size requirement consisted of six first responders (one emergency management coordinator/ volunteer firefighter, two firefighters, one firefighter/ paramedic, two firefighters/ emergency medical technician) and two male undergraduate university students. The students were recruited to increase the number of subjects. The research purpose and nature of the experiment was explained to the subjects and they signed the informed consent form.

Independent Variables

Two independent variables, each with three levels, were manipulated in the 3 x 3 factorial design with repeated measures. The three garment treatments were minimally clothed (subjects wore shorts), prototype I and prototype II. Table 1 provides information on both prototypes. The three body positions, selected to be representative of body positions that first responders might assume when performing their work, were standing, bending and twisting.

Table 1. Design Features of Two Prototype Cooling Vests

	Prototype I	Prototype II
Garment Style	• Pullover style	• Center front zipper closure
Fabric	• 80% polyester 20% Lycra® knit fabric, 0.58 mm (0.023?) thickness (single layer)	• 80% polyester 20% Lycra® knit fabric,1.16 mm (0.046?) thickness (two layer bonded fabrication)
Tubing	• PVC (Poly Vinyl Chloride) with 3.96 mm (5/32?) outer diameter, 2.38 mm (3/32?) inner diameter, and 0.79 mm (1/32?) thick	• PVC (Poly Vinyl Chloride) with 3.96 mm (5/32?) outer diameter, 2.38 mm (3/32?) inner diameter, and 0.79 mm (1/32?) thick
Technique for incorporating tubing within the garment	• Tubing web inserted between outer and inner fabric layers and anchored at the shoulder and lower garment edge	• Tubing adhered between two layers of fabric using heat, pressure and a thermal adhesive
Design Features	• Fabric stretch property available for accommodating measurement range • Belt allowed waist adjustment • Lower side slit provided flexibility for larger individuals	• Limited stretch following bonding process to create composite • Velcro® shoulder for length adjustability • Side and back stretch panels for chest, waist and hip circumference flexibility
Adhesives	• Not used	• Heat Sealed Adhesive
Thread	• 50/50 polyester/ cotton thread	• 50/50 polyester/ cotton thread

Dependent Variables

To evaluate vest fit, body measurement data from the 3D scans, perceived fit evaluation data by the test subjects, and visual fit evaluation data as judged by an expert panel using the 3D visual scans were used. First, measurement data for five critical body sites for an existing army anthropometric database (Gordon et al.,1989) and the sample were compared to see whether the army database was an appropriate data source for the user group. Second, a perceived fit evaluation ballot consisting of ten items was used to acquire feedback from the subjects regarding wearing comfort. A 5-point response scale was used to answer the first nine items. Questions 1 to 4 requested information on wearing comfort, flexibility, tightness, and movement restriction. Questions 5 to 7 addressed donning and doffing and fit adjustment, question 8 focused on vest design and question 9 addressed overall garment design evaluation. An open-ended question on overall garment comfort was the tenth item. Third, the 3D body scan images were evaluated by a three person expert panel using a visual fit evaluation ballot developed for this project. The torso was segmented into 36 areas: neckline, shoulder, armscye, upper chest, chest, midriff, waist and lower torso areas in the front; neckline, armscye, shoulder blade, mid back, waist back and lower back torso in the back; and underarm, midriff, waist and lower torso areas for the side. Evaluations of both the right and left sides were completed since it seemed reasonable that bilateral differences could exist due to the three body poses. Each rater independently viewed 3D images of each subject for these evaluations. The rater could rotate each image to view interactively from all sides, and could zoom in to view details of the vests (see Figure 1). Arms and heads were removed from the scans so that all areas of the torso could be viewed clearly.

Figure 1: Screen capture images from the 3D scans showing the minimally clothed, Prototype I, and Prototype II scans of a participant in the twisting position.

Testing Protocol

Upon arrival at the Body Scanning Laboratory, each subject was given an introduction to the study objectives, protocol, instruments and informed consent form. After signing the consent form, each subject donned a pair of knit shorts over their ordinary underwear, entered the scanning chamber and assumed the anatomical standing position for the first scan. Eight cameras and four eye-safe lasers at the corners of the scanning chamber captured about 300,000 body data points for each scan within 12 seconds. In total, nine scans were taken of each subject following a predetermined experimental sequence of garment treatments (knit shorts only and two test garments) and position treatments (standing position and two working positions). To minimize presentation bias, the order of wearing prototypes I and II was alternated so that half of the subjects wore prototype I first and the other half wore prototype II first. Since maintaining a consistent position for each scan was a considerable challenge, foot positions were marked on the platform in the scanner and other positioning devices were used to establish hand positions. Subjects were asked to place their feet and hands on the pre-marked positions. The subjects were also asked to straighten their limbs as much as possible and to focus their eyes on a predetermined position and to maintain a consistent position.

After all body scans were completed, the researcher measured each subject's weight and height and recorded the data. Each subject filled out two perceived fit ballots, one for each prototype. Subjects were given $ 30 and a rotating movie file of one of their scans as compensation for their participation.

Results

<u>Body Measurement Data Analyses: Comparison of Anthropometric Data</u>
Hypothesis 1: *There will be no significant difference between the army personnel database measurements and the measurements of the sample in regard to: chest circumference, waist circumference, hip circumference, shoulder length and back waist length.*

Data from 117 subjects whose ages were between 31 and 48 from a 1988 military anthropometric database (Gordon et al.,1989) were used as an alternative for the user population. To determine if there was a significant difference between the two groups at any of the five body sites, an independent T-test was used, since the army personnel and the subject group were independent groups. Table 2 shows these results. Levene's Test for Equality of Variance showed more than .005 for each body measurement (chest circumference = 0.544, waist circumference = 0.145, hip (buttock) circumference = 0.425, waist back length= 0.540, shoulder length = 0.186), thus the army personnel group and the subject group were regarded as having equal variances in each of the five body measurements. T-test for equality of means showed that there were no significant differences between the five sets of measurements for the two groups. Thus, the army database was an adequate substitute for the first responder sample.

Table 2. T-test Results for Five Critical Body Sites between Army Personnel Group and Sample Group

		N	Min.	Max.	Mean	SD	t	P
Chest Circumferences	Army Database	117	1067	1174	1107.26	27.07	0.84	0.40
	Subject Group	8	1054	1140	1098.88	32.63		
Waist Circumferences	Army Database	117	865	1173	1000.96	56.27	0.62	0.54
	Subject Group	8	906	1060	987.96	69.53		
Hip (Buttock) circumferences	Army Database	117	969	1239	1064.42	41.83	1.07	0.29
	Subject Group	8	906	1096	1047.63	60.75		
Waist Back Length	Army Database	117	440	571	507.33	29.38	1.61	0.11
	Subject Group	8	454	518	490.25	24.04		
Shoulder Length	Army Database	117	114	183	151.62	12.79	0.45	0.65
	Subject Group	8	144	163	153.69	7.79		

Unit:mm

<u>Perceived Fit Evaluation Data Analyses</u>
Hypothesis 2: *There will be no significant difference in subjects' fit perceptions between prototype I and prototype II.*

The perceived fit responses to ten identified questions about each prototype were analyzed to compare the wearers' responses for each prototype. Paired sample T-tests, assuming equal variances, were used to determine if a significant difference in ratings between the two prototypes existed for each question. Significant differences were not found for any of the questions related to wearing comfort and adjustability as shown in Table 3. However, for questions 5 and 6 (donning and doffing) and question 9 (overall preference), significant differences were found with subjects rating prototype II higher than prototype I.

Table 3. T-test Results of Wearers' Perceived Fit and Comfort Ratings of the Prototype Vests

Question	Prototype	N	M[a]	SD	t	p
1. This garment is comfortable.	Prototype I (Pullover Style)	8	4.00	0.54	0.552	0.598
	Prototype II (Vest Style)	8	3.75	1.28		
2. This garment is flexible.	Prototype I (Pullover Style)	8	4.00	0.00	-0.357	0.732
	Prototype II (Vest Style)	8	4.13	0.99		
3. This garment is not too tight.	Prototype I (Pullover Style)	8	3.75	0.71	-1.528	0.170
	Prototype II (Vest Style)	8	4.00	0.76		
4. This garment doesn't restrict my movement.	Prototype I (Pullover Style)	8	3.88	0.64	0.000	1.000
	Prototype II (Vest Style)	8	3.88	0.99		
5. This garment is easy to put on.	Prototype I (Pullover Style)	7	2.57	0.79	-4.583	0.004**
	Prototype II (Vest Style)	7	4.57	0.53		
6. This garment is easy to take off.	Prototype I (Pullover Style)	8	2.63	0.92	-4.255	0.004**
	Prototype II (Vest Style)	8	4.50	0.54		
7. Adjusting the garment to fit me was easy.	Prototype I (Pullover Style)	8	3.63	0.52	-1.528	0.170
	Prototype II (Vest Style)	8	4.13	0.83		
8. I really like the design of this garment.	Prototype I (Pullover Style)	8	3.50	0.93	-0.683	0.516
	Prototype II (Vest Style)	8	3.75	0.71		
9. Overall, I really like the design of this vest.	Prototype I (Pullover Style)	8	2.62	0.92	-2.986	0.020*
	Prototype II (Vest Style)	8	4.00	0.76		

[a] On a 5-point response scale with 1= Strongly Disagree, 2 = Disagree, 3= Neutral, 4=Agree, 5= Strongly Agree.
*p = 0.05 **p = 0.01

Visual Fit Evaluation Data Analyses

Hypotheses 3-5: *There will be no significant difference in the expert panels' fit evaluations between prototype I and prototype II in the standing position, bending position and twisting position.*

A visual fit evaluation instrument was created by the researchers that segmented the torso into 36 areas, 16 front segments, 12 back segments and 8 side segments. Each panel member was asked to indicate the extent of their agreement/ disagreement with the goodness of fit for all 36 torso segments using a 5-point response scale with 5 representing "strongly agree" and 1 representing "strongly disagree" for each item. The three-person university expert panel, consisting of two design faculty members and one doctoral student, rated the fit of each subject for 36 body segments for both prototypes in the three positions. Thus, a total of 5,184 ratings (3 raters x 8 subjects x 36 segments x 2 prototypes x 3 body positions) were obtained.

T-test Results

T-tests were done to determine whether there were significant differences between the mean ratings for prototypes I and II for each segment in each position. The significant T-test results for the standing position are given in Table 4. In the standing position, significant differences were found for 20 of the 36 segments (56%) including the front shoulder, front upper chest, front midriff, front lower torso, side right waist, side lower torso, back neckline, back right armscye, back left shoulder blade, mid back and the back torso area. For 19 of the 20 segments, prototype II received significantly higher ratings than prototype I. Prototype I received a significantly higher rating in the right side waist area, probably due to the belt. Of the remaining 16 items that were not significantly different, two means were higher for prototype I, namely left and right waist back, probably due to the belt. Examination of the 72 means (36 for Prototype I and 36 for Prototype II) showed 40 (55.6%) areas were above 4.0 (41.9%), 30 were between 3.0 and 3.99, and only 2 (2.8%) were below 3.0. Thus in the standing position, the ratings for both prototypes were relatively high.

Table 4. Significant T-test Results for the Standing Position by the Expert Panel's Evaluation

Item	Prototype	N	M	SD	t	p
3. The vest fits well in the front right shoulder.	Prototype I	24	3.95	0.86	-2.84	0.009**
	Prototype II	24	4.33	0.87		
4. The vest fits well in the front left shoulder.	Prototype I	24	3.71	0.91	-3.69	0.001**
	Prototype II	24	4.29	0.81		
7. The vest fits well in the front right upper chest.	Prototype I	24	3.88	1.15	-2.88	0.008**
	Prototype II	24	4.33	0.81		
8. The vest fits well in the front left upper chest.	Prototype I	24	3.54	1.10	-4.63	0.000**
	Prototype II	24	4.30	0.95		
11. The vest fits well in the front right midriff.	Prototype I	24	3.96	1.00	-3.98	0.001**
	Prototype II	24	4.54	0.66		
12. The vest fits well in the front left midriff.	Prototype I	24	3.96	1.00	-3.98	0.001**
	Prototype II	24	4.54	0.66		
15. The vest fits well in the front right lower torso.	Prototype I	23	2.83	1.13	-6.26	0.000**
	Prototype II	23	3.79	0.98		
16. The vest fits well in the front left lower torso.	Prototype I	23	2.71	1.20	-6.40	0.000**
	Prototype II	23	3.79	0.98		
19. The vest fits well in the right side waist.	**Prototype I**	24	4.58	0.65	2.15	0.043*
	Prototype II	24	4.41	0.78		
20. The vest fits well in the right side lower torso.	Prototype I	24	3.54	1.10	-5.03	0.000**
	Prototype II	24	4.25	0.74		
24. The vest fits well in the left side lower torso.	Prototype I	24	3.42	1.02	-5.47	0.000**
	Prototype II	24	4.38	0.71		
25. The vest fits well in the left back neckline.	Prototype I	22	3.50	0.98	-5.00	0.000**
	Prototype II	22	4.33	1.05		
26. The vest fits well in the right back neckline.	Prototype I	24	3.50	0.98	-5.79	0.000**
	Prototype II	24	4.38	0.92		
27. The vest fits well in the left back armscye.	Prototype I	23	4.21	0.90	-2.58	0.017*
	Prototype II	23	4.57	0.66		
28. The vest fits well in the right back armscye.	Prototype I	24	4.12	0.90	-2.85	0.009**
	Prototype II	24	4.54	0.66		
29. The vest fits well in the left shoulder blade.	Prototype I	24	4.21	0.98	-2.84	0.009**
	Prototype II	24	4.58	0.58		
31. The vest fits well in the left mid back.	Prototype I	24	3.96	0.69	-3.11	0.005**
	Prototype II	24	4.42	0.58		
32. The vest fits well in the right mid back.	Prototype I	24	3.88	0.68	-2.94	0.007**
	Prototype II	24	4.38	0.65		
35. The vest fits well in the left lower back torso.	Prototype I	24	3.25	1.33	-2.56	0.017**
	Prototype II	24	3.58	1.18		

36. The vest fits well in the right lower back torso.	Prototype I	24	3.25	1.29	-2.33	0.029**
	Prototype II	24	3.58	1.21		

N=24 (3 raters x 8 subjects)
The prototype which acquired higher ratings is marked in bold type.
On a 5-point response scale with 1= Strongly Disagree, 2 = Disagree, 3= Neutral, 4=Agree, 5= Strongly Agree
*p = 0.05 **p = 0.01

In the bending position (Table 5), a significant difference was found for 19 of the 36 (53%) segments including the front neckline, front shoulder, front armscye, front waist, front lower torso, left side under arm, side midriff, side lower torso, mid back and back torso area. For 16 of the 19 segments, the three independent raters rated the fit of prototype II significantly better than prototype I. For 3 out of 19 segments (front right waist, front left waist, and left under arm), the raters rated the fit of prototype I significantly higher than prototype II, probably due to the belt. Examination of the 72 means (36 for Prototype Y and 36 for Prototype II) showed 43 or almost 60% above 4.0, 25 or 34.7% were between 3.0 and 3.99, and only 4 (5.6%) were between 3.0. Thus, in the bending position, the ratings for both prototypes were quite high.

Table 5. Significant T-test Results for the Bending Position by the Expert Panel's Evaluation

Question	Prototype	N	M	SD	t	p
1. The vest fits well in the front right neckline.	Prototype I	23	2.86	0.76	-3.166	0.004**
	Prototype II	23	3.39	0.72		
2. The vest fits well in the front left neckline.	Prototype I	23	2.74	0.92	-3.185	0.004**
	Prototype II	23	3.39	0.72		
3. The vest fits well in the front right shoulder.	Prototype I	24	3.63	1.10	-4.338	0.000**
	Prototype II	24	4.38	0.65		
4. The vest fits well in the front left shoulder.	Prototype I	24	3.54	1.06	-4.656	0.000**
	Prototype II	24	4.33	0.64		
5. The vest fits well in the front right armscye.	Prototype I	24	3.75	1.30	-3.037	0.006**
	Prototype II	24	4.23	1.18		
6. The vest fits well in the front left armsye.	Prototype I	24	3.79	1.25	-3.607	0.001**
	Prototype II	24	4.27	1.03		
13. The vest fits well in the front right waist.	**Prototype I**	24	4.67	0.48	2.541	0.018*
	Prototype II	24	4.21	0.93		
14. The vest fits well in the front left waist.	**Prototype I**	23	4.65	0.49	2.554	0.018*
	Prototype II	23	4.17	0.93		
15. The vest fits well in the front right lower torso.	Prototype I	23	2.91	0.49	-7.772	0.000**
	Prototype II	23	4.26	0.94		
16. The vest fits well in the front left lower torso.	Prototype I	23	2.87	1.00	-7.955	0.000**
	Prototype II	23	4.26	0.86		
18. The vest fits well in the right side midriff.	Prototype I	24	3.79	0.88	-4.303	0.000**
	Prototype II	24	4.50	0.59		
20. The vest fits well in the right side lower torso.	Prototype I	24	3.04	0.75	-10.343	0.000**
	Prototype II	24	4.67	0.48		
21. The vest fits well in the left side under arm.	**Prototype I**	24	4.00	1.35	2.882	0.008**
	Prototype II	24	3.54	1.31		
22. The vest fits well in the left side midriff.	Prototype I	24	3.71	1.20	-2.077	0.049*
	Prototype II	24	4.21	0.88		
24. The vest fits well in the left side lower torso.	Prototype I	24	3.17	0.82	-5.412	0.000**
	Prototype II	24	4.54	0.72		
31. The vest fits well in the left mid back.	Prototype I	24	4.54	0.66	-2.598	0.016*
	Prototype II	24	4.83	0.38		
32. The vest fits well in the right mid back.	Prototype I	24	4.50	0.72	-2.598	0.016*
	Prototype II	24	4.79	0.41		
35. The vest fits well in the left lower back torso.	Prototype I	24	3.38	1.06	-3.635	0.001**
	Prototype II	24	4.08	0.88		

36. The vest fits well in the right lower back torso.	Prototype I	24	3.42	1.06	-4.623	0.000**
	Prototype II	24	4.13	0.95		

N=24 (3 raters x 8 subjects)
The prototype which acquired higher ratings is marked in bold type.
On a 5-point response scale with 1= Strongly Disagree, 2 = Disagree, 3= Neutral, 4=Agree, 5= Strongly Agree
*p = 0.05 **p= 0.01

In the twisting position (Table 6), a significant difference was found for 12 of the 36 (33%) segments including the front neckline, front shoulder, front waist, front lower torso, left side under arm, right side midriff and side lower torso area. For nine of the 12 segments, the three independent raters rated the fit of prototype II significantly better than prototype I. For three of the 36 segments, the raters rated the fit of prototype I better than prototype II. These included the same areas as the ratings from the bending position, the front waist area (left and right) and the left side underarm area. Examination of the 72 means (36 for each prototype) showed 34 or 47.2% were or at or above 4.0, 32 (44.4%) were between 3.0 and 3.99, and 6 (8.3%) were below 3.0. It is interesting, but not surprising, that the mean fit ratings tended to be lowest in the twisting position.

Table 6. Significant T-test Results for the Twisting Position by the Expert Panel's Evaluation

Question	Prototype	N	M	SD	t	p
1. The vest fits well in the front right neckline.	Prototype I	17	3.00	1.00	-3.108	0.007**
	Prototype II	17	3.47	0.87		
2. The vest fits well in the front left neckline.	Prototype I	19	2.95	0.91	-3.012	0.007**
	Prototype II	19	3.53	1.02		
3. The vest fits well in the front right shoulder.	Prototype I	20	3.40	1.43	-3.000	0.007**
	Prototype II	20	4.15	0.81		
4. The vest fits well in the front left shoulder.	Prototype I	18	3.67	1.37	-2.149	0.046*
	Prototype II	18	4.22	0.81		
13. The vest fits well in the front right waist.	**Prototype I**	21	4.67	0.48	3.873	0.001**
	Prototype II	21	3.95	0.92		
14. The vest fits well in the front left waist.	**Prototype I**	21	4.67	0.48	3.873	0.001**
	Prototype II	21	4.10	0.77		
15. The vest fits well in the front right lower torso.	Prototype I	21	2.62	1.16	-2.968	0.008**
	Prototype II	21	3.43	1.05		
16. The vest fits well in the front left lower torso.	Prototype I	20	2.75	1.16	-5.294	0.000**
	Prototype II	20	3.80	1.01		
18. The vest fits well in the right side midriff.	Prototype I	21	3.57	1.12	5.123	0.000**
	Prototype II	21	4.57	0.75		
20. The vest fits well in the right side lower torso.	Prototype I	21	2.95	0.87	-6.971	0.000**
	Prototype II	21	4.24	1.00		
21. The vest fits well in the left side under arm.	**Prototype I**	21	3.76	1.41	3.202	0.004**
	Prototype II	21	3.23	1.55		
24. The vest fits well in the left side lower torso.	Prototype I	21	2.71	0.78	-8.113	0.000**
	Prototype II	21	4.48	0.93		

N=24 (3 raters x 8 subjects)
The prototype which acquired higher ratings is marked in bold type.
On a 5-point response scale with 1= Strongly Disagree, 2 = Disagree, 3= Neutral, 4=Agree, 5= Strongly Agree
*p = 0.05 **p= 0.01

Table 7 summarizes the significant differences for both prototypes in the three body positions. Overall, the expert panel found prototype II fit better than prototype I in the standing, bending and twisting positions.

Table 7. Summary of Visual Fit Evaluation Using Significant T-test Results

	Front Body Area	Prototype which received higher rating	**Side Body Area**	Prototype which received higher rating	**Back Body Area**	Prototype which received higher rating
Standing Position	front shoulder	Prototype II**	side right waist	Prototype I*	back neckline	Prototype II**
	front upper chest	Prototype II**	side lower torso	Prototype II**	back right armscye	Prototype II**
	front midriff	Prototype II**			back left shoulder blade	Prototype II**
	front lower torso	Prototype II**			mid back	Prototype II**
					back torso	Prototype II*
Bending Position	front neckline	Prototype II**	left side under arm	Prototype I**	mid back	Prototype II*
	front shoulder	Prototype II**	side midriff	Prototype II** (right)/ *(left)	back torso area	Prototype II**
	front armscye	Prototype II**	side lower torso	Prototype II**		
	front waist	Prototype I*				
	front lower torso	Prototype II**				
Twisting Position	front neckline	Prototype II**	left side under arm	Prototype I**		
	front shoulder	Prototype II** (right)/ *(left)	right side midriff	Prototype II**		
	front waist	Prototype I**	side lower torso	Prototype II**		
	front lower torso	Prototype II**				

If right or left is not specified, it means both right and left area. For example, front shoulder includes right and left shoulders.
This table includes items which showed significance at the 1% or 5% levels.
* indicates an item which showed significant difference at the 5% level.
** indicates an item which showed significant difference at the 1% level.

<u>Intraclass Reliability</u>

To evaluate the reliability among the three independent ratings for the visual fit, the intraclass correlation coefficient (ICC) was analyzed using SPSS. The intraclass coefficient assesses rating reliability by comparing the variability of different ratings of the same subject to the total variation across all ratings and all subjects. The particular model and definition of agreement selected was a two-way mixed model and consistency among raters. The two-way mixed model indicates that all judges of interest rate all targets (which is a random sample) and consistency indicates definition of agreement among raters. This is a mixed model since the judges represent a fixed effect and the targets represent a random effect. The underarm side area and the lower torso for prototype II were not included in the analysis since these areas were problematic for raters. The procedure to modify the fit of prototype II resulted in a slight horizontal protrusion at the side underarm area and a small protrusion at the lower back torso area. Manifolds were removed at the lower center back area to insert a back stretch panel, resulting in a protrusion due to the stretch fabric accommodation of the manifolds. The underarm protrusion was caused by cutting vertically up the sides and inserting a V-shaped stretch panel. Two of the three raters considered the protrusions to be due to prototype construction rather than fit and therefore gave higher ratings than the third rater.

In general, the ICC results were lower than desired (slightly less than 10% were above 0.6). There are potential reasons for this. Different experiences and expectations of fit characteristics among the raters would be one source of low ICCs. Some (but not all) of the raters had observed the poor fit of currently available liquid cooled vests, and this previous experience could have affected their evaluation of the prototypes. Some raters ignored the protrusion areas cased by the modification process, recognizing that the protrusion would not be present when the pattern was properly developed, but some evaluated it as a poor fit. Second, the specific areas listed for response on the instruments developed for the evaluation may have contributed to rater variability. For example, when inadequate fit in a section of the garment was assessed by a rater confusion as to which or how many specific areas to mark down could contribute to rater variation. Third, image loss of the visual scans in some body areas could have resulted in difficulties for some raters during evaluation. Since the 3D body scanner does not capture horizontal surfaces, there was image loss, especially in the shoulder area, for all three body positions, and image loss in the back and chest areas for the bending and twisting positions.

Conclusions and Implications

Prototype vests I and II are similar in that they both cover the torso area and use identical fabric and tubing. However, they are quite different in terms of design features, tubing attachment techniques and characteristics of the tubing composite. Since sizing for both cooling vests was developed based on analyses from a 1988 army anthropometric study the relationship between the army personnel measurement data and the test group's measurement data were examined. The T-test analysis indicated no significant differences between the body measurements of the two groups, thus, suggesting that the army anthropometric database was a good proxy choice for measurement data for first responders in this study.

T-test results of the wearers' perceptions for prototypes I and II showed no significant differences in regard to perceived comfort, flexibility, tightness, movement restriction, and ease of adjustment. The subjects found donning and doffing prototype I (which required pulling the garment over the head) more difficult than donning and doffing prototype II (which zipped up the front). Additionally, the tubing webs inside the prototype was perceived as fragile by the participants.

The T-test analyses of the visual scan data found significant differences between the prototypes for many body segments and positions. Prototype II achieved significantly higher marks for 19 of 36 segments in the standing position, 16 of 36 segments in the bending position and 9 of 36 segments in the twisting position; a total of 40.7% of the segments assessed overall. Prototype I achieved significantly higher marks for 1 of 36 in the standing position, 3 of 36 in the bending and 3 of 36 in the twisting position; a total of 6.5% overall. These results suggest that even though prototype II used a 3-layer composite fabrication method, the prototype provided adequate flexibility to maintain good fit in the bending and twisting positions. It is noteworthy that the body segments for which prototype I acquired better ratings were front right waist in the standing position, front waist and left side underarm in the bending position and front waist and left side underarm in the twisting position. It appears that the stretch waist belt helped hold the vest tight around the waist area while the subjects were bending or twisting. Overall, the experts' visual fit ratings for both prototypes for most body segments in three different positions were quite high, suggesting that the fit of both prototypes was quite good and that the use of an anthropometric database was appropriate for achieving tight fit for a mass produced garment.

The 3D body scanner, although designed as a measurement tool, was a useful tool for fit evaluation. There were several advantages of using the 3D body scanner for fit evaluation including convenience and accuracy. The visual fit evaluation process was not limited by time, place nor subject availability. At any time, the expert panel could evaluate the fit of any subject by looking at the scanned files in detail as many times as they desired without concerns about subject fatigue. Since the scans were viewed as a neutral monochromatic image the subtle changes in shape were not obscured by variation in color. Additionally, the zooming function enabled specific body areas to be seen in detail and it allowed the raters to evaluate fit more precisely. This study demonstrated that the 3D body scanner could be used as a fit evaluation tool. The results of the inter rater reliability suggest that more emphasis should be placed on training the expert panel and developing the evaluation instrument and response scale to improve reliability.

However, the 3D body scanner equipment had certain disadvantages as well. The 3D scanner only captures information about the surface of the garment. For this study the thickness of both prototypes and the irregularity of the surface of prototype I resulted in some difficulty in evaluating the fit by visual evaluation. Complementary cross sectional data that examined the actual distance from the skin to the inner fabric of the prototype would help solve this problem.

Generally the scanner proved to be a valuable tool for objectively rating and comparing the fit of the cooling vests. This tool can be a valuable addition to analysis procedures for other functional apparel items.

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