Comparative Analysis between 3D Visual Fit and Wearers' Subjective Acceptability

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Abstract

The purpose of this study is to evaluate pants fit of current firefighter gear through 3D visual fit analysis in various active positions to determine ways for improving firefighter gear. Ten male firefighters were recruited through contacting fire stations in Midwestern cities of the United States. Each participant wore his own firefighter gear for the study. Participants were scanned wearing their firefighting pants and in form fitted clothing in two different positions (i.e., standing upright and stretching a bent right leg forward) using a [TC]^2 white-light NX-16 3D body scanner. In addition, each completed a wearer acceptability survey. Survey items related to the gear fit, mobility, comfort level, and demographic information, including height and weight. Visual analysis of 3D scan data was completed using Rapidform 2006 software, a 3D modeling program. Scanned images of the firefighter in each position, both in form fitted clothing and wearing turnout pants, were overlapped to determine the ease between the pants and the body. Cross-sectional profiles at the knee, thigh, and crotch levels were taken for data analysis, and the distance between the pants and human body was measured for each participant in the two different positions. Survey results revealed that firefighters were uncomfortable with their current gear due to poor fit and restricted mobility. 3D visual analysis compared with the results of wearer acceptability survey showed that decreased pants ease amounts resulted in increased complaints regarding pants fit. This indicates that firefighters may need greater ease amounts in their pants to allow for proper fit and mobility. The ease variation at the crotch level was especially important for firefighters. In the standing position, the crotch ease has to be low, but when in the bending position the ease value has to increase to improve apparel fit and mobility. A relationship was identified with decreased wearer acceptability and greater participant's weight as well as shorter participant's height. This research provides fundamental information to develope firefighter gear with high wearer acceptability in ergonomic terms by quantifying sensory data such as wear acceptability into numerical data associated with ergonomic pattern designs. Further research should be conducted focusing on the gear fit in relationship with firefighter's various body shapes using this technology.

Keywords: 3d body scanning, ease, fit, firefighter gear

1. Introduction

1.1. Background

Much of protective clothing research has focused on the protection of people from severe situations/environments while neglecting ergonomic functions of the clothing. Protective clothing research for firefighters has also focused on protection, particularly qualities of the thermal protective materials [1]. Identifying how the protective clothing allows the wearer to achieve various working positions will provide essential information for making design improvements to increase the worker's performance in those severe environments. For firefighters, it is critical that their clothing should not restrict their mobility or not interfere with the firefighter's ability to accomplish critical task-related activities [2,3]. Ensuring proper fit of a garment is one way to allow the wearer's maximum mobility. Researchers have examined the factors that affect apparel fit using objective or subjective methods. An objective assessment of apparel fit alone is not enough to represent human perceptions, therefore it is necessary to use both objective and subjective assessments of apparel fit. The purpose of this study is to evaluate pants fit of current firefighter turnout gear through 3D visual fit analysis in various active positions comparatively with subjective data to determine areas for design improvements. Specific research objectives are to: 1) Examine the wearer acceptability of current firefighter gear, 2) analyze the distribution and ease variation between the body and clothes through 3D visual fit analysis, and 3) explore the relationship between the wearer acceptability and the clothing ease of current firefighter gear. The results of this study will provide future suggestions for distribution and ease variation of turnout gear pants.

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1.2. Literature Review

1.2.1. Research on Protective Clothing for Firefighters

Protective clothing is designed to protect a human body from one or more hazards and may be worn in addition to or in substitution of ordinary clothes [4,5]. If worker mobility is limited by inappropriate fit or design of protective clothing, their task efficiency and protection will be reduced [1,6]. Protective clothing should provide both protection and comfort [7]. Huck and Kim conducted a series of studies to develop design modifications to improve the functionality of firefighter gears [6,8,9]. In evaluating the effect of firefighter gear on wearer mobility, Huck found firefighter gear design affected the range of shoulder and trunk motion [6]. Design modifications were implemented for prototype testing and found to increase mobility and wearer acceptability [8,9]. In sum, previous research has identified the ways to enhance firefighter gear through changing materials and design elements of existing gear, but have not fully considered ergonomic functions when creating new designs. This study uses 3D scan data to measure the ease of turnout gear pants related to subjective wearer perceptions to analyze turnout gear pants design for improvements.

1.2.2. Apparel Fit and Ease

Erwin and Kinchen defined apparel fit as the combination of the following five elements: ease, line, grain, balance, and set [10]. Ease is needed in clothing as it wraps around circumferential parts of a human body to allow for body movements, creating a difference between clothing measurements and body measurements [11]. Suggested ease amounts vary for different areas of the body, and ease preferences vary from person to person. Ashdown and Delong also found that each person's perception of ease can vary from one area of the body to another. The ease of apparel is an important element to increase customer satisfaction [12], but few researchers have investigated factors affecting consumer preference related to garment ease values.

Evaluation of apparel fit is accomplished through subjective and objective assessments [13]. Subjective assessments allow an individual to evaluate his/her apparel fit. Usually the wearers evaluate how fit their clothes are through analyzing the form of their clothes projected on the mirror [12]. Subjective fit assessments can vary considerably depending on the evaluator's preferences, abilities, bias, and mood at the time of the evaluation. The results are not reproducible and cannot be expressed absolutely but only compared in relative figures. Objective assessments of apparel fit utilize methods such as moiré topography, which determines how closely a garment conforms to the human body. With the recent commercialization of 3D human body scanners, many researchers have began to utilize 3D visual images as indicators of apparel fit and extracted cross-sectional profiles of the human body and clothing to measure ease values.

1.2.3. Pants Complexity

Pants have a more complex shape than other garments as they must fit an area comprised of a human body's abdominal region, buttocks, and crotch where legs are divided [14]. The ease of pants should be set at an appropriate amount for the shape of the body to allow for proper movements. Pants must have adequate ease at the waist, hip, knee, and crotch, as well as throughout the legs [14]. Fig. 1 describes a lower human body and the basic prototype of pants designed for the body. One component of good pants fit is determined by proper ease amounts and distribution.

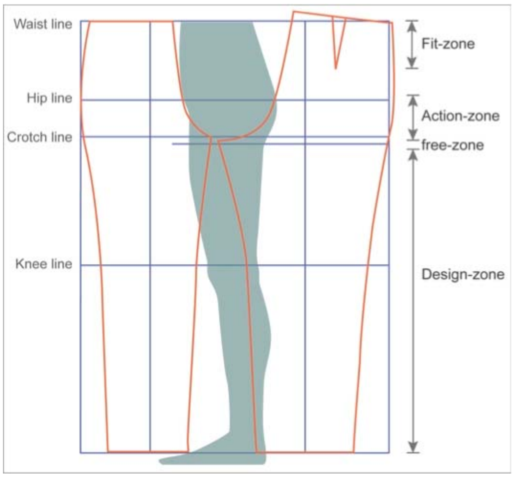

Fig. 1. The relationship between the lower body shape and the basic pants prototype.

As can be seen in Fig. 1, when the pattern of pants is designed, the surface of a body shape can be divided, according to its ease, into fit-zone, action-zone, free-zone, and design-zone which are defined as a part of human body where the clothing pressure is the greatest since it is a tightly-fit to the human body and upholds the weight of clothes, the field where changes are made during body movements, the space where the crotch is freely molded for patterns, and the space where molding for pants length and shape is made, respectively [15]. Among those, the free- and design-zones are the particular areas where ease 1) is designed, 2) may or may not be set up, and 3) can be appropriately observed. To evaluate the fit of current firefighter gear, this study employs a subjective assessment method to investigate the wearer acceptability of the gear and an objective assessment method to measure the ease distribution over specific parts between the body and clothing using 3D scan data.

1.2.3. Apparel Fit using 3D Scan Data

3D body scan data provides precise 3D space coordinates so that an assessment of apparel fit, which has previously depended on human evaluators, may be quantified. A 3D body scanner provides a vast amount of data, including anthropometric measurements, 3D visual images of a human body with and without clothing, cross sectional forms, and gaps between the body and clothing when overlapping two scan images of the body in the same positions, with and without clothing [13]. Researchers have used 3D body scan data to 1) measure garment ease, a contributing factor to apparel fit, and 2) assess garment appearance, often considered as an indicator of apparel fit [16,17,18,19].

Ashdown et al. has developed a program in which apparel fit can be evaluated from a computer screen which has uploaded images of the front and back of scanned conditions of the minimum dressing and the pants wearing [17]. This method offers advantages for researchers evaluating garment fit over traditional methods of using a fit model, such as the ability to repeatedly review the fit images to ensure accurate assessments are made. Loker et al. used a similar method to analyze the appearance of pants on the body, as a determinant of garment fit [19]. Daanen et al. also utilized 3D scan data to measure the volume of air between the body and clothing [18]. Four men were scanned while seminude, wearing a T-shirt, and wearing a coverall. Scan data of seminude subjects were extracted from scan data of the subjects wearing T-shirts and coverall to measure volume values of the clothes reliably. Apeagyei and Otieno also utilized 3D scan data to analyze the space between the clothing and the skin through cross sectional shapes of the waist and hips [16].

2. Research Methods

Comfort of a current firefighter gear was assessed using 3D body scanning technology (objective fit measure), and wearer acceptability questionnaire (subjective fit measure). Ten firefighters were scanned with and without wearing their own firefighter gear in two different positions using a 3D body scanner and then filled out the survey questionnaire.

2.1. Subjects

Ten male firefighters were recruited from fire stations in Midwestern cities of the United States. Table 1 presents the general characteristics of the subjects such as their age, and body weight. The average age was 38.2, with an age range of 25 to 43. The average height, body weight, and waist circumference were 1747.11mm, 101.15kg, and 997.98mm, respectively.

Table 1. Characteristics of the firefighters in this study (n=10).

Variable	Mean	S.D.
Age (years)	38.20	5.55
Height (mm)	1747.11	55.68
Weight (kg)	101.15	18.12
BMI	33.22	6.36
Waist circumference (mm)	997.98	119.53
Hip circumference (mm)	1093.25	101.75
Crotch circumference (mm)	918.13	99.60
Thigh circumference (mm)	534.09	39.49
Knee circumference (mm)	412.83	21.33

Note. Body Mass Index (BMI) is defined as the individual's body weight divided by the square of his or her height (kg/m^2).

2.2. Data Analysis Procedure

2.2.1. Wearer Acceptability Survey of Firefighter Gears

Survey items comprised of a total of 25 questions related to sizing acceptability (fit of firefighter gear), mobility acceptability (fit for firefighting-related movements), and demographic information, including height and weight (see Table 2). A 5-point Likert type scale, ranging from “1” (strongly disagree) to “5” (strongly agree), was used for all items excluding demographic information. The survey data were analyzed using descriptive statistics, Pearson's correlation, One-Way ANOVA, paired *t*- test, and linear regression using SPSS, a statistical analysis software.

Table 2. Wearer acceptability survey items.

	Sizing acceptability items		Mobility acceptability items
S1	Overall, my pants fit well.	M1	I have trouble moving quickly in my gear.
S2	My pants are too big for my body.	M2	My movement is restricted when wearing my pants.
S3	The length of my pants is too long.	M3	It is easy to move in my pants.
S4	The size range of pants offered is appropriate.	M4	I am able to move my legs freely when wearing my gear.
S5	The waist on my pants is too tight.	M5	I have trouble lifting my legs up high when wearing my pants.
S6	The waist is too big on my pants.	M6	It is easy to lift my legs in my pants.
S7	My pants have an acceptable crotch length.	M7	The pants make it difficult to crawl on the ground.
S8	The crotch on my pants is too loose.	M8	The knee is too tight and makes it difficult to bend my leg.
S9	The crotch is too low on my pants.	M9	My pants are easy to put on and take off.
S10	The crotch is too tight.		
S11	The crotch is ripped out on my pants.		

2.2.2. 3D Visual Fit Analysis of Firefighter Gears

A [TC]^2 NX-16 white-light 3D body scanner was used in this study. 3D scan data were then transferred to RapidForm 2006 software, a 3D modeling program, to complete the visual analysis. This study defined “ease” as the space between a human body and its clothes determined by the visual analyses using 3D scan data. Ease values are an indicator of garment fit. Ten male firefighters participated in 3D body scanning and completed the wearer acceptability survey in the summer of 2009. Participants brought their own firefighter gear to wear for the scanning. Participants were scanned wearing their firefighting pants and in form-fitted clothing in two different positions (i.e., standing upright and stretching a bent right leg forward), as shown in Fig. 2.

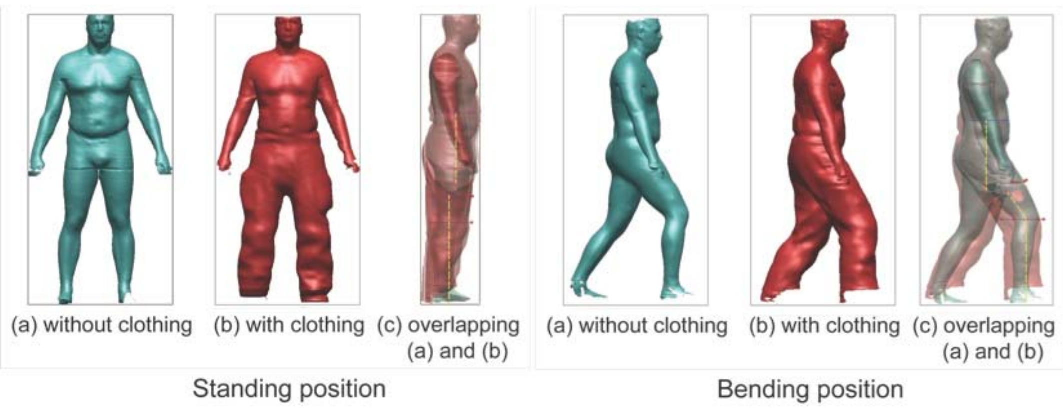

Fig. 2. 3D scan pose – Standing upright and bending.

Scan images of the firefighter in each position, both in form-fitted clothing and wearing firefighting pants, were then overlapped to determine the ease between the pants and the body. Cross-sectional profiles at the knee, thigh, and crotch levels were taken for data analysis, and the distance between the pants and the body was measured for each participant in the two different positions. Examples of the cross-sectional profiles are shown in Fig. 3.

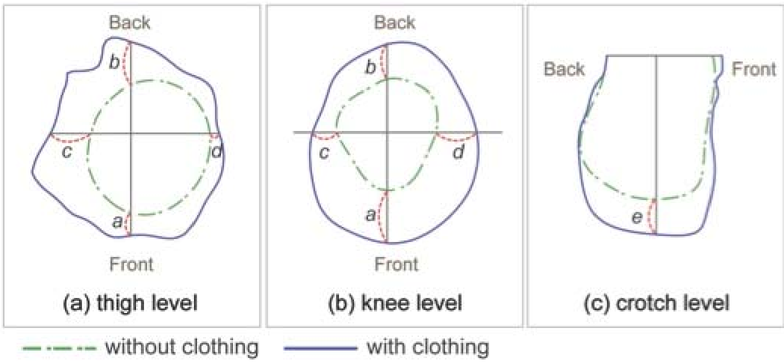

Fig. 3. Cross-sectional analysis between firefighter turnout pants and human body.

In this study, a total of 47 dimensions from the 3D visual data were analyzed, including ease of standing position (ES), ease of bending position (EB), ease variation (EV), height proportion (HP), and circumference. In Table 3, “ease of standing position (ES)” and “ease of bending position (EB)” refers to the ratio of the ease of each section in relation to the sum of ease *a, b, c,* and *d* that were shown in Fig. 3. “Ease variation (EV)” represents the change in ease values between the standing and bending positions, which was calculated using the following equation:

$$EV = \left|\frac{(EB - EA)}{ES}\right| \qquad (1)$$

“Height proportion (HP) ” is the ratio of the height of the lower body in relation to the overall height of the body.

Table 3. Dimensions of 3D visual data analysis.

	Measurement
Ease of Standing position (ES)	ES_Thigh_a
	ES_Thigh_b
	ES_Thigh_c
	ES_Thigh_d
	ES_Thigh_total
	ES_Knee_a
	ES_Knee_b
	ES_Knee_c
	ES_Knee_d
	ES_Knee_total
	ES_Crotch_e
Ease of Bending position (EB)	EB_Thigh_a
	EB_Thigh_b
	EB_Thigh_c
	EB_Thigh_d
	EB_Thigh_total
	EB_Knee_a
	EB_Knee_b
	EB_Knee_c
	EB_Knee_d
	EB_Knee_total
	EB_Crotch_e

	Measurement
Easy Variation (EV)	EV_Thigh_a
	EV_Thigh_b
	EV_Thigh_c
	EV_Thigh_d
	EV_Knee_a
	EV_Knee_b
	EV_Knee_c
	EV_Knee_d
	EV_Crotch_e
Height Proportion (HP)	HP_Waist height
	HP_Waist height_omphalion
	HP_Hip height
	HP_Crotch height
	HP_Thigh height
	HP_Knee height
	HP_Calf height
	HP_Minimum leg height
Circumference	Waist circumference
	Waist circumference_omphalion
	Hip circumference
	Crotch circumference
	Thigh circumference
	Knee circumference
	Calf circumference
	Minimum leg circumference

A one-way ANOVA was used to verify the statistical significance of an average change between four groups: the ease of *a, b, c*, and *d*, depending upon measurement areas. A paired *t*-test was also conducted to examine the statistical significance of an average change between two groups depending on position changes from a standing position to a bending position.

2.2.3. Analyses of the Relationship between the Wearer Acceptability and the 3D Visual Fit

This study examined the relationship between wearer acceptability survey data and 3D visual fit analysis results. From the results of wearer acceptability survey, the items that had the high scores of dissatisfaction on the measure of sizing acceptability and mobility acceptability were extracted and then linear regression was made of 3D visual eases of pants related to these dissatisfaction items to explore the effect of pants ease on the subjective fit of firefighter gears. In this research, survey items (subjective assessment) and ease measurements (objective assessment) were set as independent variables and dependent variables, respectively.

3. Results and Discussion

3.1. Wearer Acceptability Survey of Firefighter Gears

Fig. 4 shows the results of the wearer acceptability survey for firefighter gear. Survey results revealed that firefighters were uncomfortable with their current gear due to poor fit and restricted movements. Concerning the sizing acceptability, the wearers were highly dissatisfied with the length of their pants (S3) followed by the crotch fit (S10) and waist fit (S5). Participants indicated their pants affected their mobility the most when crawling (M7) and bending (M8).

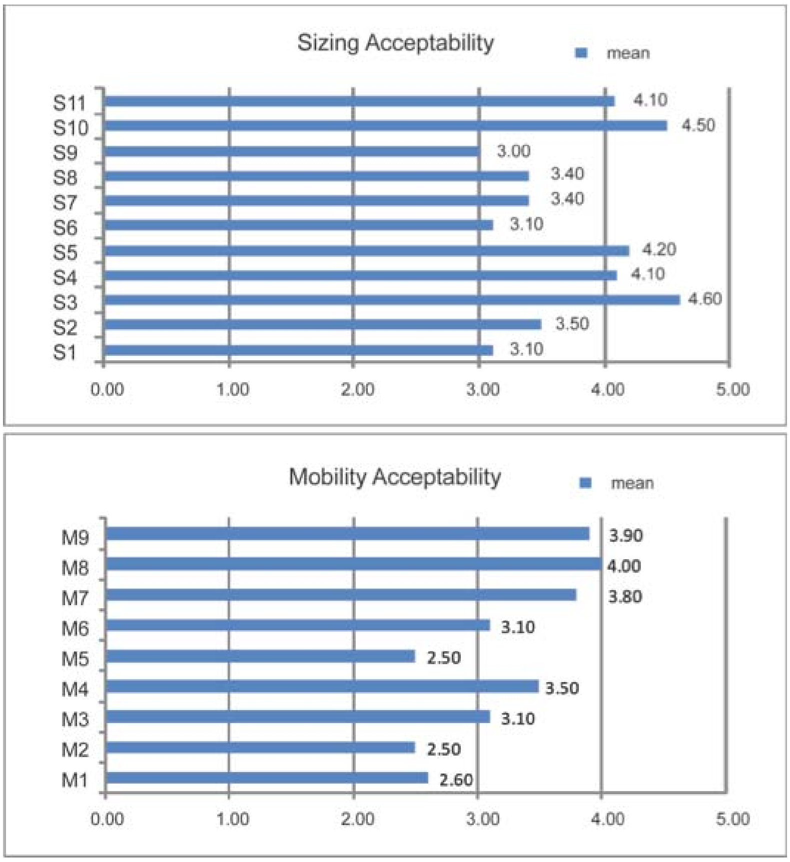

Fig. 4. Summary of firefighters' sizing and mobility acceptability for their gears.

Note. 5-point Likert type scale ranges from 1=strongly disagree to 5=strongly agree.

Table 4 presents the result of correlation analyses between the five questionnaire items that had high dissatisfaction scores and the rest of items. Those who expressed the discomfort of their pants length (S3) considered their pants were overall larger than their body (S2) and were dissatisfied with their waist fit (S6). In addition, those who thought their waist was too tight (S5) felt their crotch areas were also tight (S11). Those who considered the length of crotch was too tight (S10) felt uncomfortable when bending their legs since their knee area was also tight (M8). In other words, the wearers were highly dissatisfied with the fit of their waist, crotch, and knee areas. Those who were highly dissatisfied with the size also felt uncomfortable with their mobility.

One unexpected result was that those who felt uncomfortable while crawling (M7) still considered their pants size was appropriate (S4). Those who felt uncomfortable while bending (M8) also considered that their pants size was appropriate (S1 and S4) and felt that it was not too uncomfortable to move freely (M3); however they noted the tightness of their pants at the crotch level (S10). In other words, it is remarkable that many of those whose mobility acceptability was not high were satisfied with their pants size. These results imply that firefighter gear may not be too uncomfortable to perform ordinary activities, but may become much problematic during firefighting work or duties which require much more dramatic body movements than ordinary activities in severe environments.

Table 4. The results of Pearson's correlation analysis.

		Variable	Pearson Correlation
Sizing Acceptability	Pants length (S3)	S2	0.730 *
		S6	0.728 *
	Waist size (S5)	S11	0.854 **
	Crotch size (S10)	M8	0.676 *
Mobility Acceptability	Crawling (M7)	S4	0.700 *
	Bending (M8)	S1	0.692 *
		S4	0.900 **
		S10	0.676 *
		M3	0.712 *

Note. * $p<0.05$ (2-tailed), ** $p<0.01$ (2-tailed).

Survey results also revealed that the sizing acceptability had close correlations with mobility acceptability. In particular, those who were dissatisfied with their pants size were uncomfortable while moving and those who were dissatisfied with the mobility tended to be satisfied with the pants size. They considered their pants size was appropriate but felt uncomfortable while moving because the functionality of mobility was a more important element than the size of firefighter gears. This finding is important to aid the development of ergonomic pattern designs of firefighter gears taking into account the functionality of mobility. It is also demonstrated that crotch and knee areas play an important role in pants satisfaction for the wearer acceptability of firefighter gears.

3.2. 3D Visual Fit Analyses of Firefighter Gears

As the results of a one-way ANOVA, Table 5 showed that the average values of four groups were significantly different. The results showed that the significance probability in all cases was no more than p=0.000, which implies that the average difference is statistically significant among the groups. Duncan's post-hoc test was also applied to understand in detail that in which groups there is a difference. For a standing position, ease *c* of thigh part was measured as the largest followed by *b*, *a,* and *d*. Ease *a* of knee part was measured as the largest followed by *c, b,* and *d*. For a bending position, ease *b* of thigh part was measured as the largest followed by *c, d,* and *a*. Ease *b* of knee part was measured as the highest followed by *c, a,* and *d*. In sum, ease *a* and ease *c* had large values at a standing position, while ease *b* presented a large value at a leg bending position.

Table 5. The results of one-way ANOVA on the measurement parts at standing and bending positions.

		Ease *a*		Ease *b*		Ease *c*		Ease *d*		F	Sig.
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.		
Standing position (S)	Thigh	24.54 B	7.39	26.12 B	10.42	38.72 A	15.39	10.63 C	4.61	12.54	0.000
	Knee	35.82 A	4.94	22.01 B	7.19	31.60 A	9.69	10.55 C	6.31	24.05	0.000
Bending position (B)	Thigh	9.94 C	5.66	42.26 A	9.36	32.88 B	11.31	14.91 C	7.88	29.65	0.000
	Knee	8.01 C	4.06	56.87 A	10.18	27.96 B	9.60	7.17 C	5.21	90.81	0.000

Note. A, B, and C indicate the grouping by Duncan tests ($p<0.05$).

The results of a paired *t*- test are presented in Table 6. A significant change of the average value was identified from eases *a* and *b* of thigh, eases *a* and *b* of knee, and ease *e* of crotch. As legs were bending, the average value of eases *a* and *e* has been decreasing while that of ease *b* was increasing.

Table 6. The results of a paired t-test on the scan posture.

		Standing position (S)		Banding position (B)		t
		Mean	S.D.	Mean	S.D.	
Thigh	Ease *a*	24.54	7.39	9.94	5.66	6.34*
	Ease *b*	26.12	10.42	42.26	9.36	-2.92*
	Ease *c*	38.72	15.39	32.88	11.31	1.07
	Ease *d*	10.63	4.61	14.91	7.88	-1.40
Knee	Ease *a*	35.82	4.94	8.01	4.06	15.75*
	Ease *b*	22.01	7.19	56.87	10.18	-9.61*
	Ease *c*	31.60	9.69	27.96	9.60	0.86
	Ease *d*	10.55	6.31	7.17	5.21	1.28
Crotch	Ease *e*	69.54	38.12	29.01	18.57	2.95*

Note. * Significant difference ($p<0.05$).

3.3. Analyses of the Relationship between the Wearer Acceptability and the 3D Visual Fit

From the results of the wearer acceptability survey of firefighter gears, five items that had high dissatisfaction scores were selected and used as independent variables, especially items S3, S5, and S10 for sizing acceptability and items M7 and M8 for mobility acceptability. Forty-seven measurement items were considered as dependent variables. Then, a linear regression was performed by employing a stepwise method (see Table 7).

The analysis results revealed that the items that had an effect on the fit of pants length (S3) are EV_Thigh_d, EB_Crotch_e, and ES_Knee_c. As the value of ease variation *d* of thigh was less and as the value of ease *e* of crotch was less at the bending position, the level of dissatisfaction with the pants length was higher. As the value of ease *c* of knee was larger at the standing position, the level of dissatisfaction with the pants length was also higher. The results presented that the measurement items that had an effect on the fit of waist part (S5) were ES_Knee_b and ES_Crotch_e. As the value of ease *b* of knee and the value of ease *e* of crotch were greater at the standing position, the wearers felt their waist was too tight.

The items that had a significant effect on the fit of crotch part (S10) were EV_Crotch_e, ES_Knee_a, and EB_Thigh_b. As the value of ease variation *e* of crotch was small, the wearers felt their crotch was too tight. As the value of ease *a* of knee was less at the standing position and as the value of ease *b* of thigh was larger at the bending position, the fit of crotch part was decreased. EV_Crotch_e, Waist circumference, and ES_Knee_total had a significant effect on the crawling function (M7). As the value of the ease variation *e* of crotch was less, as waist circumference measurements have increased, and as the total of ease amounts of knee was less at the standing position, there were more difficulties of body movement with wearing pants when crawling. Lastly, the items that had a significant effect on the knee bending function (M8) were HP_Waist height, ES_Crotch_e, HP_Knee height, and EB_Thigh_b. As the waist height proportion and the knee height proportion were lower, as the value of ease *e* of crotch was larger at the standing position, and as the value of ease *b* of thigh was less at the bending position, the wearers felt that the knee areas of their pants were too tight, which led the wearers be difficult to bend their legs.

The analysis results of the relationship between the wearer acceptability and 3D visual analysis are summarized as follows:

When a body position has changed from a standing to a leg bending, the level of dissatisfaction with the pants fit is higher if ease variation has been decreased. Less ease variation causes clothes to limit the wearer's mobility. In contrast, larger ease variation implies that ease of clothes is changed along with the mobility, which contributes to the excellent mobility acceptability of a wearer. Of ease variations, ease variation *e* of crotch and ease variation *d* of thigh are especially valued. This fact should be reflected in the future when developing ergonomic patterns of firefighter gears.

Ease of knee is important at a standing position. As the total of ease amounts of knee is less, the fit is more lowered. Therefore, it is desirable to secure enough ease for knee part at a standing position but to reduce the value of ease *b* and *c* of knee and to sufficiently procure the value of ease *a*. The ease at the crotch level was especially important for firefighters. In the standing position, the crotch ease has to be low, but when in the bending position the ease value has to increase to improve pants fit and mobility. Since crotch is critically important to the pants fit, continuous research is needed focusing on an appropriate ease of crotch depending on a different active positions.

The results of linear regression also revealed that factors associated with body shape were important in apparel fit that was related with mobility. Relationships were identified with decreased wearer acceptability and greater participant weight as well as shorter participant height. Further research should be conducted focusing on a gear fit in relationship with firefighter's various body shapes as well.

Table 7. The results of a linear regression analysis.

		Variable	Unstandardized Coefficients		Standardized Coefficients	t
			B	Std. Error	Beta	
Sizing Acceptability	Pants length (S3)	(Constant)	5.234	0.075		69.633***
		1 EV_Thigh_d	-0.625	0.027	-1.0251	-23.165***
		2 EB_Crotch_e	-0.013	0.001	-0.498	-15.486***
		3 ES_Knee_c	0.007	0.002	0.203	4.527**
		$R^2 = 0.996$, Adjusted $R^2 = 0.993$, F = 341.168, p = 0.000				
	Waist size (S5)	(Constant)	2.216	0.246		9.024***
		1 ES_Knee_b	0.062	0.011	0.645	5.676**
		2 ES_Crotch_e	0.009	0.002	0.525	4.624**
		$R^2 = 0.946$, Adjusted $R^2 = 0.922$, F = 42.581, p = 0.001				
	Crotch size (S10)	(Constant)	6.706	0.465		14.412***
		1 EV_Crotch_e	-2.062	0.144	-0.985	-14.296***
		2 ES_Knee_a	-0.046	0.009	-0.408	-5.376**
		3 EB_Thigh_b	0.016	0.004	0.299	4.507**
		$R^2 = 0.988$, Adjusted $R^2 = 0.978$, F = 105.928, p = 0.000				
Mobility Acceptability	Crawling (M7)	(Constant)	3.517	0.328		10.716***
		1 EV_Crotch_e	-2.932	0.133	-1.006	-22.085***
		2 Waist circumference	0.004	0.000	0.652	14.757***
		3 ES_Knee_total	-0.007	0.002	-0.202	-4.353**
		$R^2 = 0.994$, Adjusted $R^2 = 0.989$, F = 207.873, p = 0.000				
	Bending (M8)	(Constant)	96.903	2.111		45.899***
		1 HP_Waist height	-1.213	0.0387	-0.808	-31.307***
		2 ES_Crotch_e	0.0244	0.001	0.732	28.719***
		3 HP_Knee height	-0.0246	0.002	-0.574	-14.969**
		4 EB_Thigh_b	-0.0267	0.004	-0.184	-6.110**
		$R^2 = 0.999$, Adjusted $R^2 = 0.998$, F = 728.413, p = 0.000				

Note. ** p<0.05, *** p<0.001.

4. Conclusions

This study aimed to understand the relationship between a subjective assessment and an objective assessment of pants fit for firefighter gears, specifically the relationship between sensory data such as the individual subjective assessment of pants and objective numerical data such as pants ease, with a view to provide fundamental information for ergonomic pattern designs that could increase a wearer's mobility adaptability. In order to analyze the fit of firefighter gears, a subjective assessment method was employed for a wearer acceptability survey to the firefighters wearing their current gears. 3D scan data were used as an objective assessment method to measure the distribution of ease over a specific part of a human body and its clothes. This study found that firefighters felt their gears were uncomfortable since their gears were not agreeable to their body measurements and limited their mobility during firefighting duties. In particular, the mobility functionality was found to be a more important element than the pants size, and crotch and knee areas played an important role for the level of their pants satisfaction.

The relationship between the wearer acceptability and the 3D visual fit was also analyzed. When a wearer's position has changed from a standing position to a leg bending position, if the easy variation was less, the pants fit was more dissatisfied. In addition, as the total of ease amounts of knee was less, the fit was more dissatisfied at a standing position; therefore, it is important to secure the sufficient ease at the knee level at a standing position and arrange an appropriate ease to each part of the knee. The results of this study should be reflected on the future development of ergonomic patterns for firefighter gears. This study also found that crotch area was a critical element for the fit of firefighter gears, here especially pants. Therefore, intensive research needs to be continuously conducted to examine appropriate eases and their distribution according to different body shapes in order to improve the wearer acceptability of their firefighter gears. Furthermore, a research emphasis should be given both the range of actual eases of clothes and the range of eases acceptable to consumers.

Protective clothing must consider both "protection" and "comfort" at the same time [7]. Protective clothing research has been usually focused on "protection" and heavily dealt with the physical properties and effects of clothing materials while practically neglecting their ergonomic functions, which do not hinder the mobility of the wearers but make them to feel comfortable while doing their duties in severe situations. It is hard to conclude that a human body can be fully protected from external dangers when wearing any type of protective clothing which only considers the properties of up-to-date new materials since problems related to the safety of workers are identified from inappropriate fit of protective clothing. Shortly, resolving such problems requires ergonomic pattern designs that can minimize clothes' limits of wearers' mobility. This study is significant in that it has quantified sensory data such as the wearer acceptability of firefighter gears into numerical data associated with ergonomic pattern designs and provided fundamental information to produce better firefighter gears with well-fitting size and great mobility acceptability in ergonomic terms.

This study only focused on the upright and bent-leg positions of a firefighter's lower body. Therefore, it is not recommended to generalize the results of this study to the entire population of firefighters. Further research with a large sample size is needed to generalize this study. In addition, different body positions associated with firefighter's task-related activities such as crawling need to be incorporated in the future research. Pattern development of a firefighter gear is another area that should be further explored to improve firefighters' mobility and function in a variety of severe situations. In fact, firefighters run into a fire only after they have put on the entire set of a gear such as firefighter gear, gloves, helmet, safety shoes, and air respirator. Consequently, in order for these equipments to minimize their limits to the wearers' mobility at the scene of a fire, the research emphasis should be given to the ergonomic design and development of firefighter gears as well as that of associated equipments.

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References

1. Coca, A., Williams, W. J., Roberge, R. J., Powell, J. B., (2010): "Effects of fire fighter protective ensembles on mobility and performance", Applied Ergonomics, Vol.41, No.4, pp.636-641.
2. Huck, J., (1991): "Restriction to movement in firefighter protective clothing: evaluation of alternative sleeves and liners", Applied Ergonomics, Vol.22, No.2, pp.91-100.
3. NFPA, (1971, 2007), "Standard on protective ensembles for structural fire fighting and proximity fire fighting", National Fire Protection Association.
4. NFPA, (1977, 2005), "Standard on protective clothing and equipment for wildland fire fighting", National Fire Protection Association.
5. Adams, P. S, Slocum, A. C., Keyserling, W. M., (1994), "A model for protective clothing effects on performance", International Journal of Clothing Science and Technology, Vol.6, No.4, pp.6-16.
6. Huck, J., (1988), "Protective clothing systems: A technique for evaluating restriction of wearer mobility", Applied Ergonomics, Vol.19, No.3, pp.185-190.

7. Parsons, K., (1994), “Fifth international symposium on performance of protective clothing: Improvement through innovation”, Applied Ergonomics, Vol.25, No.4, pp.257-259.
8. Huck, J. and Kim, Y. H., (1997), “Coveralls for grass fire fighting”, International Journal of Clothing Science and Technology, Vol.9, No.5, pp.346-359.
9. Kim, Y. H., (1996), “Fire fighter coverall: A study in functional apparel design”, Doctoral thesis, Kansas State University, Manhattan, Kansas.
10. Erwin, M. D. and Kinchen, L. A., (1969), “Clothing for moderns, 4th ed”, Macmillan, New York.
11. MacDonald, N. A., (2002), “Principles of Flat Pattern Design”, Fairchild Publications, New York.
12. Ashdown, S. P. and Delong, M. R., (1995), “Perception testing of apparel ease variation”, Applied Ergonomics, Vol.26, No.1, pp.47-54.
13. Yu, W., (2004), “Subjective assessment of clothing fit”, in: Fan, J., Yu, W., Hunter, L. (Eds.), Clothing appearance and fit: science and technology. Woodhead Publishing, Cambridge, pp. 31-42.
14. Armstrong, H. J., (1995), “Pattern making for fashion design”, Hopper Collins, New York.
15. Nakazawa, S., (1996), “Clothing and Body shape” Bunka Pub., Tokyo.
16. Apeagyei, P. R. and Otieno, R., (2007), “Usability of pattern customising technology in the achievement and testing of fit for mass customization”, Journal of Fashion Marketing and Management, Vol.11, No.3, pp.349-365.
17. Ashdown, S. P., Loker, S., Schoenfelder, K., Lyman-Clarke, L., (2004), “Using 3D Scans for Fit Analysis”, Journal of Textile and Apparel, Technology and Management, Vol.4, No.1, pp.1-12.
18. Daanen, H. A. M., Hatcher, K., Havenith, G., (2005), “Determination of clothing microclimate volume”, in: Tochihara, Y., Ohnaha, T. (Eds.), Environmental Ergonomics. Elsevier, Amsterdam, pp. 361-368.
19. Loker, S., Ashdown, S., Schoenfelder, K., (2005), “Size-specific Analysis of Body Scan Data to Improve Apparel Fit”, Journal of Textile and Apparel, Technology and Management, Vol.4, No.3, pp.1-15.