〔보 문〕

Journal of the Korean Society
of Clothing and Textiles
Vol. 26, No. 12 (2002) p.1739~1748

A Functional Design of Fire Fighter Coveralls
소방용 coverall의 기능적 디자인 연구

Dept. of Fashion design, Duksung women' s university
Younghee Kim

덕성여자대학교 의상학과
김 영 희

(2002. 6. 28 접수)

Abstract

본 연구의 목적은 소방용 coverall의 디자인이 소방수들의 동작기능성에 어떤 영향을 주는지에 관하여 고찰하여, 보다 기능적인 coverall을 개발, 궁극적으로 작업자의 노동력을 향상시키고, 보다 안락한 환경속에서 작업할 수 있도록 도와주는데에 있다.

미국 캔사스 지역의 전문 소방수를 대상으로, interview 및 video analysis를 통하여, 그들이 현재 사용하고 있는 current coverall의 동작기능면에서의 문제점을 조사, 분석한 후, 이를 바탕으로 prototype coverall을 개발하였다.

prototype coverall의 동작기능성을 객관적으로 측정하기 위하여 10가지 실험동작 (shoulder adduction/abduction, shoulder flexion/extension, trunk flexion/extension (standing), hip flexion/extension (knee), hip flexion/extension (trunk), upper leg flexion, trunk lateral flexion, hip adduction, trunk flexion/extension (sitting), upper leg flexion)을 선택하여 이의 관절각도 (range-of-motion)를 Leighton flexometer, goniometer, computer-aided method를 이용하여 측정하였으며, 착용자의 주관적 평가를 위하여서는 23 항목의 wearer acceptability scale를 사용하였다.

ANOVA (Analysis of Variance)와 LSD (Least Significant Difference)를 이용한 통계처리 결과, prototype coverall이 current coverall에 비해 동작기능성 (특히 crotch, torso, hip movement)에 있어서 우수함을 보이고 있다.

Key words: Functional design, Fire fighter coverall, Range-of-motion;
기능적 디자인, 소방용 coverrall, 관절각도

I. Introduction

An important function of apparel is to protect the human body. Personal protective clothing enables people to work in hazardous environments, but can have detrimental effects on worker performance. For example, the protection afforded by apparel may result in decreased mobility. Ideally, protective clothing should not only offer adequate protection from environmental hazards, it should also be comfortable. Clothing comfort is influenced by a number of factors and can be evaluated at several levels, including thermal aspects, ease of movement, fit, pressure on the body, tactility and propensity to generate static electricity (Rosenblad-Wallin, 1985).

According to model developed by Adams, four

causal factors, (i.e., Clothing Properties, Task Requirements, Worker Characteristics, Environmental Conditions) influence two functional events, changes in garment form and thermal imbalance. These functional events affect immediate effact(i.e., movement capability, physiological balance with the environment and sensory feedback.) Finally, these immediate effects cause reduced productivity, physiological strain and low level of comfort (Adams, 1993).

Changes in garment form restrict wearer movement, and finally, this effect reduces worker productivity. When movement is compromised, the wearer' s accuracy and speed in performing tasks decreases, and exertion is increased. Also, range-of-motion (distance of angle movement) is decreased (Adams, 1993).

Ease of movement is closely related to the perceptions of overall clothing comfort. For example, in a study of fire fighters' protective clothing, 31.8 percent of all complaints for turnout gear is involved with the restriction of movement (Kinderknecht, 1994).

Relatively few studies have focused on ease of movement based on clothing design and task movement contributing to worker productivity. Until now, most research dealing with the effects of protective clothing on the wearer has focused on fabric properties and their effects on heat stress, tolerance time and worker acceptance. Although, such studies answer specific questions of garment preference and suitability, the results are often not transferable to workers wearing other clothing systems or performing dissimilar tasks (Adams, 1993).

Therefore, in this study, the relationship between clothing design and body movement was focused. The purpose of this study was to develop prototype coveralls for fire fighting, with a special emphasis on the relation between clothing design and ease of movement to maximize wearer comfort and mobility, and finally to improve worker efficiency.

II. Methodology and Procedure

This part was organized analysis of current coveralls, subject, design of prototype coverall, and evaluation of coveralls.

1. Analysis of current coveralls

To analyze problem and complaints of current coveralls and to determine the restricted body area with the current coverall during fire fighting task, fire fighters were interviewed and video captured. Fire fighters were interviewed the problem and satisfaction of current coveralls. Also, the types of movements during fire fighting job in a real situation were video captured to determine the representative movement and the restricted body area with current coveralls. The fire fighter was asked to don his current coverall over the jean pants and T-shirts provided to him by researcher and demonstrate the types of activities he would use in a real fire fighting situation. These movements were captured by video camera and analyzed later.

Notes about the design, fabric and styling of fire fighters' current coveralls were investigated (Figure 1) and the measurements of current coveralls were reported (Table 1). The current coveralls which possessed by fire fighters were actually little different in aspect of fabric and style because fire fighters bought their own coveralls in the market. However, all current coveralls were similar in aspect of fabric and style except detail. The fabric hand and appearance of current coveralls were indistinguishable.

As a results of analysis of the video tape and

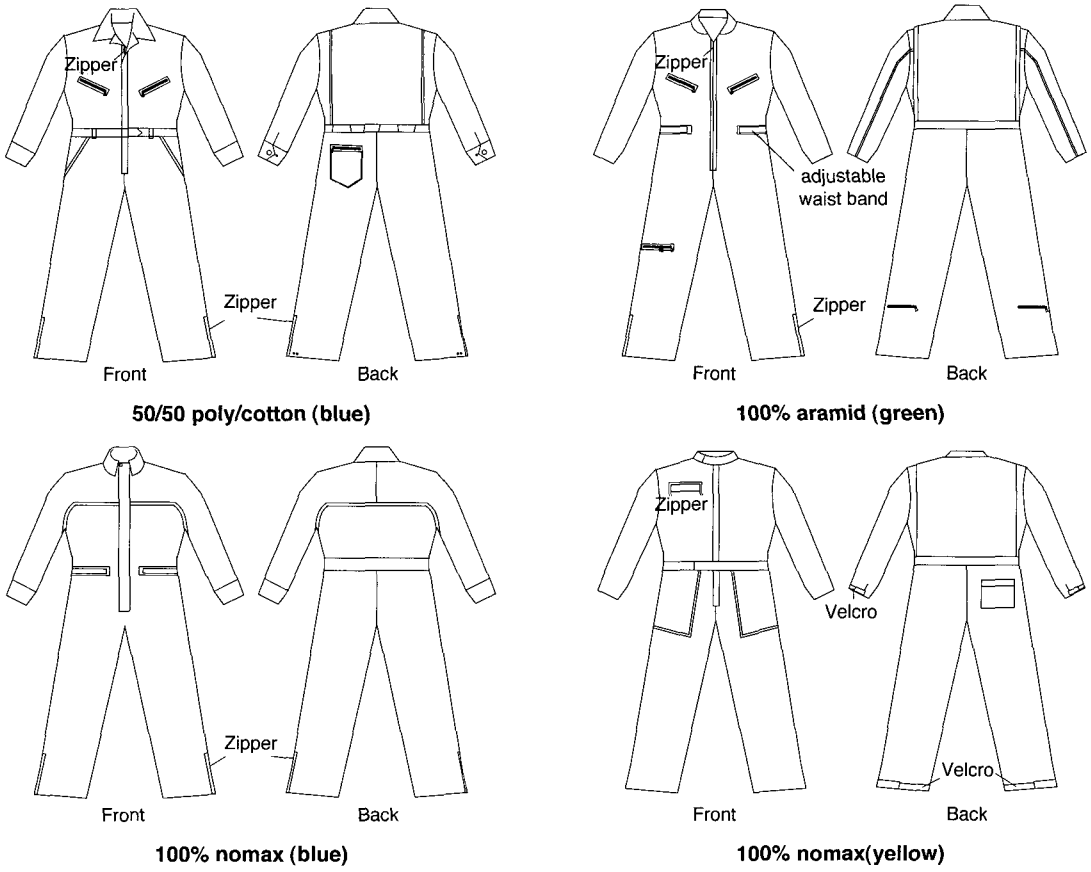


Fig. 1. current coverall designs

Table 1. The measurements of current coveralls

Measurement	Mean (cm)	S.D. (cm)	Min. (cm)	Max. (cm)
Chest circumference	120.1	9.7	101.6	137.2
Waist circumference	107.2	12.2	87.6	127.0
Back waist length	51.1	2.3	48.3	53.3
Shoulder length	18.8	1.0	17.3	20.3
Hip circumference	120.9	11.2	104.0	142.2
Vertical trunk circumference	173.0	7.9	164.8	189.2
Full pants length	106.9	7.4	94.0	119.4
Sleeve length	60.5	3.0	55.9	66.0

n=10

interview with fire fighters, the general types of movement during fire fighting task with current coveralls were walking, spraying, jumping from the truck, slapping the fire, crawling over the fences, driving the trunk, pulling, dragging, climbing onto the trunk, carrying a water tank, bending,

running, sweeping, raking, pumping the spray, climbing the truck, squatting down, carrying hose, climbing the ladder.

According to the interview, most fire fighters complained problem with crotch area. They felt crotch area of current coveralls was too tight and not flexible to move easily. Actually, most current coverall had tearing hole in the crotch area. The crotch area of the current coveralls had been torn easily because the crotch movement was frequent and intensive.

Table 2. Fire Fighters' Physical Characteristics and Fire Service Experience

Subject No.	Age	Height (cm)	Weight (kg)	Years in fire service
1	54	180.3	77.2	14
2	42	180.3	84.8	11
3	45	172.7	86.5	6
4	29	172.7	77.2	7
5	35	177.8	113.5	9
6	33	172.7	83.9	7
7	41	175.3	72.6	5
8	44	167.6	74.9	1
9	41	182.9	113.5	10
10	29	177.8	93.1	6
Mean	39.3	176.0	87.6	7.6
Std.	7.8	4.6	14.9	3.6

Also, fire fighters complained problem with the back of the current coveralls. They felt restriction and tightness in the back of the current coverall when torso was bending forward. They suggested the back of the coverall needed more room and flexible in order to bend torso forward easily.

2. Subjects

Ten male fire fighters from local area volunteer fire departments in Kansas, USA served as subjects. All subjects had experienced wearing coveralls when performing the fire fighter duties.

Subjects' physical characteristics and body measurement were reported (Table 2, 3)

3. Design of Prototype Coverall

The information derived from the interview and video tape was analyzed to design the prototype coverall by determining the problems associated with current coveralls. The results of movement analysis indicated that the crotch and the back of the coverall needed more flexibility. In order to give flexibility and improvement of the easy of movement in the crotch, the stretch fabric was attached in the crotch area of the prototype coveralls (Figure 2, 3). Also, for improving the easy

Table 3. Subjects' body measurement

Measurement	Mean (cm)	S.D. (cm)	Min. (cm)	Max. (cm)
Chest circumference	106.2	8.9	91.5	119.4
Waist circumference	105.7	11.0	91.5	124.5
Back waist length	46.5	2.5	43.2	50.0
Shoulder length	15.0	1.5	12.7	17.8
Hip circumference	106.9	6.4	97.8	119.4
Vertical trunk circumference	170.2	10.7	158.0	186.7
Crotch depth	24.4	2.3	21.8	28.7
Full pants length	100.5	4.3	93.0	108.0
Sleeve length	60.2	1.8	58.4	63.5
Crotch length	85.3	6.4	0.9	8.6

n=10

of movement of torso, back and hip, the stretch fabric was included in the back, and in the back waist area of the prototype coverall (Figure 3). Pattern was drafted based on individual body measurement (Figure 4). Each subject's prototype coverall was constructed using proper construction technique.

Prototype coverall design features included:

1) Features to facilitate comfort, mobility and utility:

- The inclusion of stretch panels in the back, the back waist area, and in the crotch area to facilitate movement of the trunk, hip and legs.
- Consistant fit of the garment over body measurements (by drafting each pattern using individual measurements).
- A panel of fabric over the stretch fabric in the upper back, designed to protect the stretch fabric and provided a cushion of fabric for the wearer using a back pack water container.
- A generously-sized inseam hip pocket, with a side seam opening in the coveralls to allow the wearer to access his jeans pockets.

2) Fastening systems:

- A center front opening consisting of a zipper and overflap of Velcro hook and loop tape.
- A band collar with Velcro hook and loop tape.
- Cuffs with Velcro hook and loop tape.
- Lower leg openings with zipper and overflap of Velcro hook and loop tape

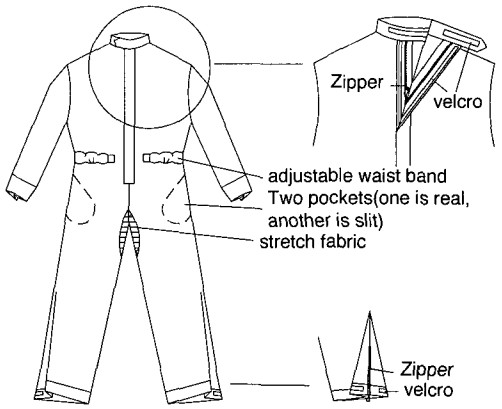


Fig. 2. Front view of prototype coverall

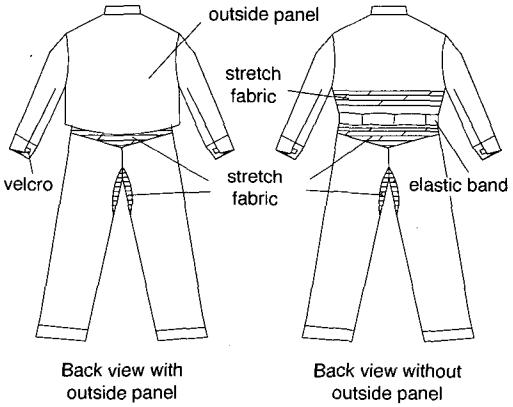


Fig. 3. Back view of prototype coverall

3) Adjustability features:

- Waist adjustability (waist elastic with tabs that could be adjusted to wearer's preference).

4) Fabric:

-Fabric of similar weight and hand that would

Table 4. Fabric characteristics of prototype coverall

Fiber content	Fabric construction	Fabric count (Warp/cm X filling/cm)	Weight (g/m^2)	Thickness (mm)	Air permeability ($cm^3/cm^2/sec$)
50/50 poly/cotton	Plain weave	22X37	150.0	1.067	200.5
50/50 poly/cotton	Rib knit	16X9	284.0	0.33	453.3

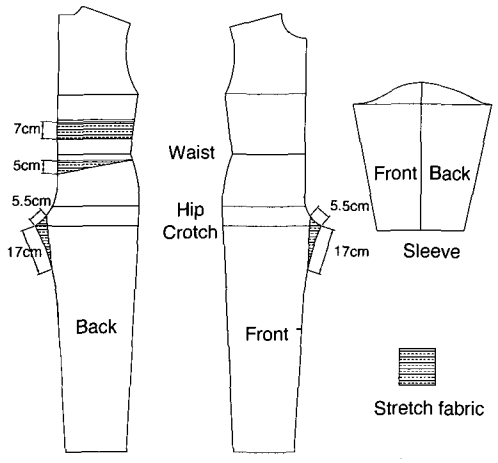


Fig. 4. The pattern of prototype coverall

meet NFPA Standard 1977 was used. This fabric was a 50/50 polyester and cotton blend with a weight of 4.4 OZ/yd^2(Table 4).

4. Evaluation of the coveralls

1) Range-of-motion evaluation

Range-of-motion of prototype and current coverall was measured for objective evaluation. Wearing T-shirts and jeans, fire fighter was asked to complete pre-exercise routine, so that his muscles were relaxed and warm. The subject was asked to don his current coverall over the T-shirts and jeans. Range-of-motion of 10 selected movements (figure 5) - shoulder adduction/ abduction, shoulder flexion/extension, trunk flexion/extension (standing), hip flexion/extension (knee), hip flexion/extension (trunk), upper leg flexion, trunk lateral flexion, hip adduction, trunk flexion/extension (sitting), upper leg flexion - was measured using a Leighton Flexometer, goniometer and computer aided-method. This procedure was repeated with prototype coverall. Order of testing was randomized.

Table 5. Exercise protocol

Walk 10 sec.
Step onto the table and jump from the table (3 times).
Imitate a pumping motion as if you were spraying (5 times).
Bend torso back and forth (3 times).
Stand with your arms spread open, bring arms back in with your palms flat against each other (3 times).
Imitate a sweeping motion (5 times).
Squat (3 times).
Imitate a raking motion (3 times).
Sit with legs together and touch your toes (3 times).
Crawl 10 sec.

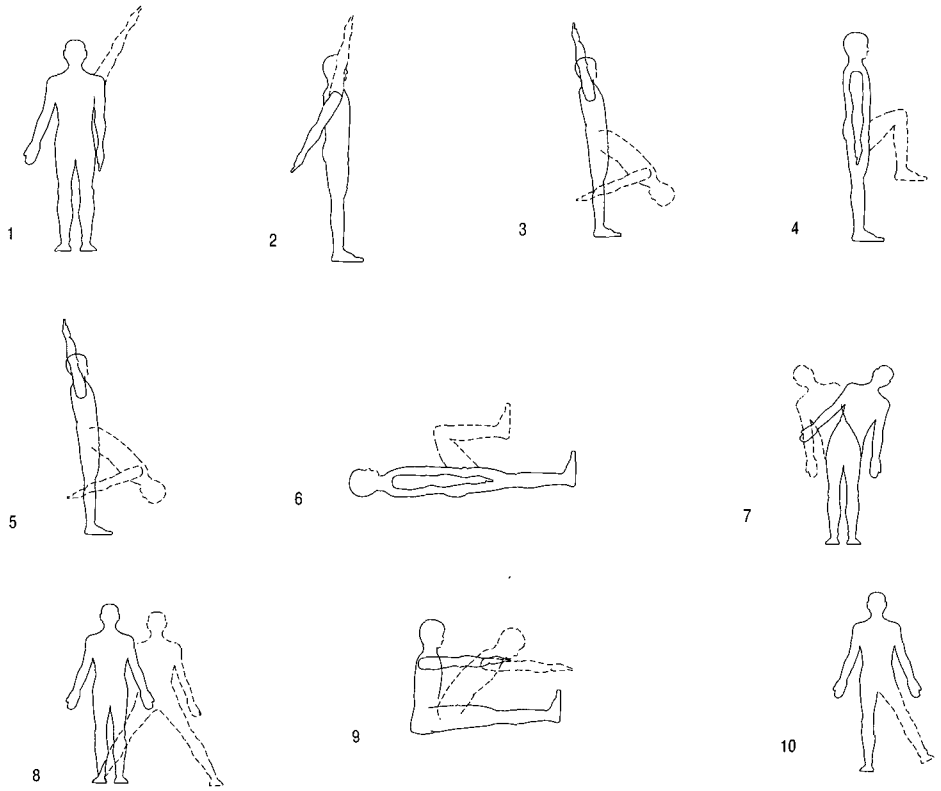
2) Wearer acceptability evaluation

Wearer acceptability was measured by 23 scale for subjective evaluation. Wearing current coverall

Table 6. Wearer Acceptability Scale

Comfortable / Uncomfortable
Acceptable / Unacceptable
Tired / Rested
Flexible /Stiff
Easy to put on / Hard to put on
Freedom of movement of arms / Restricted movement of arms
Easy to move in / Hard to move in
Satisfactory fit / Unsatisfactory fit
Freedom of movement of leg / Restricted movement of legs
Freedom of movement of torso / Restricted movement of torso
Like / Dislike
Loose / Tight
Walking (Easy to do /Hard to do)
Stepping onto the table (Easy to do/ Hard to do)
Jumping from the table (Easy to do / Hard to do)
Pumping motion (Easy to do/ Hard to do)
Bending torso back and force (Easy to do / Hard to do)
Spread and bring arms back in (Easy to do / Hard to do)
Sweeping motion (Easy to do /Hard to do)
Squatting (Easy to do /Hard to do)
Raking (Easy to do /Hard to do)
Toe touching (Easy to do /Hard to do)
Crawling (Easy to do / Hard to do)

The scale was rated from 9 to 1.
"9" was the best possible rating; a "1" was the poorest possible rating.



Solid line: initial position
Dotted line: second position (after moving)

1. shoulder adduction/ abduction
2. shoulder flexion/extension
3. trunk flexion/extension (standing)
4. hip flexion/extension (knee)
5. hip flexion/extension (trunk)
6. upper leg flexion
7. trunk lateral flexion
8. hip adduction
9. trunk flexion/extension (sitting)
10. upper leg adduction

Fig. 5. Range-of-motion movements

over the T-shirts and jeans, fire fighter was asked to complete an exercise protocol (Table 5). The exercise protocol included representative tasks which had been identified and selected from the initial interview. After completing the exercise protocol, the subject was asked to fill out a wearer acceptability scale (Table 6) to determine his perception of fit and mobility while wearing his current coverall during the exercise protocol. Wearer acceptability scale was consisted of 23 items presented in a semantic differential format with 9 choice points for each item. The scores of wearer acceptability scale (ranging from 1 to 9) for each subject were summed and calculated. This procedure was repeated with prototype coveralls. Order of testing was randomized.

III. Results and Discussion

An Anova (Analysis of Variance) procedure and

Table 7. Anova Table for Range-of-Motion by Design

Variable	Mean value current coverall (degrees)	Mean value prototype coveralls (degrees)	LSD	F-value
Shoulder abduction/adduction	131.6	136.7	AB	6.28*
Shoulder flexion/extension	190.6	192.4	AA	0.37
Trunk flexion/extension (standing)	131.3	143.9	AB	39.58*
Trunk flexion (sitting)	30.6	39.4	AB	33.24*
Trunk lateral flexion	68.3	70.6	AA	3.24
Hip flexion/extension (knee)	70.1	77.7	AB	23.09*
Hip flexion/extension (trunk)	80.9	89.2	AB	16.62*
Hip adduction	52.9	58.1	AB	14.26*
Upper leg adduction	47.1	49.7	AB	4.16*
Upper leg flexion	83.2	86.4	AA	3.96

n=10

*significant at $\dot{p}$ = 0.05 level

- AA: No significant difference between two coveralls. - AB: Significant difference between two coveralls.

Table 8. Anova table for wearer acceptability scale

Variable	Mean value current coverall	Mean value prototype coveralls	LSD	F-value
Comfortable/uncomfortable	6.8	7.6	AA	2.44
Acceptable/unacceptable	7.8	7.9	AA	0.02
Tired/rested	6.8	7.6	AA	2.44
Flexible/stiff	6.4	8.5	AB	12.06*
Easy to put on/hard to put on	6.0	6.8	AA	1.21
Freedom of movement of arms	7.1	8.1	AA	1.86
Easy to move in/hard to move in	6.8	8.3	AB	7.11*
Satisfactory fit/Unsatisfactory fit	6.3	7.8	AB	5.87*
Freedom of movement of legs	6.6	8.3	AB	6.49*
Freedom of movement of torso	7.0	8.4	AB	6.68*
Like/Dislike	7.2	7.7	AA	0.69
Loose/Tight	5.5	7.2	AB	7.63*
Walking(Easy to do/hard to do)	8.2	8.7	AA	5.0
Stepping onto the table (Easy to do/hard to do)	8.0	8.6	AB	7.36*
Jumping from the table (Easy to do/hard to do)	7.4	8.8	AB	8.65*
Pumping motion(Easy to do/ hard to do)	8.0	8.8	AA	4.24
Bending torso back and force (Easy to do/hard to do)	6.9	8.5	AB	7.58*
Spread and bring arms back in (Easy to do/hard to do)	7.2	8.7	AB	6.68*
Sweeping motion(Easy to do/hard to do)	8.0	8.6	AA	5.06
Squatting(Easy to do/hard to do)	6.4	8.3	AB	6.38*
Raking (Easy to do/hard to do)	7.8	8.7	AA	5.65
Toe touching (Easy to do/hard to do)	6.3	8.3	AB	6.43*
Crawling (Easy to do/hard to do)	7.3	8.4	AB	6.44*

n=10

"9" was the best possible rating; a "1" was the poorest possible rating. *: Significant at p = 0.05

-AA: No significant difference between two coveralls. -AB: Significant difference between two coveralls.

LSD (Least Significant Difference) were used for statistical analysis. The difference in range-of-motion between prototype coverall and current coverall was significant for seven body movements (Shoulder abduction/adduction, Trunk flexion/extension (standing), Trunk flexion (sitting), Hip flexion/extension (knee), Hip flexion/extension (trunk), Hip adduction, Upper leg adduction). Results indicated that the prototype coveralls allowed greater freedom of movement than did the current coverall. Also, for all measurements, the mean value of prototype coveralls was greater than that of current coveralls (Table 7).

It was assumed that the stretch fabric attached in the back and at the back waist area in prototype coverall allowed the wearer to move his torso and hip with less garment restriction. (i. e., trunk flexion extension (standing and sitting), hip flexion/extension (trunk)) Also, the stretch fabric attached in the crotch area helped hip, crotch and leg movement(i. e., hip adduction, hip flexion/extension (knee) and upper leg adduction).

An Anova (Analysis of Variance) procedure and LSD (Least Significant Difference) were used to test for differences in the wearer acceptability scale between prototype and current coveralls (Table 8).

According to results, prototype coveralls were significantly different from current coveralls on 13 items among 23 items. Subjects were able to discriminate between to the two coverall designs on adjectives of "flexible", "easy to move in", "satisfactory fit", "freedom of movement of leg", "freedom of movement of torso", "loose/tight", "bending torso back and forth", "squatting", "raking", "toe touching", and "crawling". Also, for all measurements, the mean value of prototype coveralls was greater than that of current coveralls. Results indicated that fire fighters would find the prototype coveralls more comfortable and acceptable than their current coveralls.

IV. Conclusions

The purpose of this research was to develop prototype coveralls for fire fighting, with a special emphasis on the relation between clothing design and ease of movement to maximize wearer comfort and mobility, and finally to improve worker efficiency. Using a functional design process, a prototype coverall was developed. The prototype and current coveralls were evaluated using objective measurements of range-of-motion for ten selected body movements and subjective measurements of wearer acceptability scale to determine subject's perceptions of comfort, fit and body mobility in both their current and prototype coveralls. Results indicated that the prototype coveralls were preferable to the current coveralls. It was concluded that there was relation between clothing design (including pattern variation) and wearer's body mobility. Appropriate clothing design factor could improve wearer's body mobility, and finally influenced worker efficiency. Further study is needed, particularly in an actual wearing condition i.e., grass fire fighting situation.

References

Adams, P. S. (1993). The effect of protective clothing on worker performance: A study and fabric weight effects on range-of-motion. Unpublished doctoral dissertation, The University of Michigan.

American Society for Testing and Materials. (1985). Annual book of Standards-part 7.01. Philadelphia, PA: ASTM.

Huck, J., Maganga, O., & Kim, Y. (1997). Protective

overalls: evaluation of garment design and fit, *International Journal of Clothing Science and Technology*, **9**(1), 45−61.

Kinderknecht, R. (1994). A statewide survey of the protective clothing used by Kansas volunteer fire departments. Unpublished master's report, Kansas State University, Manhattan, K.S.

Rosenblad-Wallin, E. (1985). User-oriented product development applied to functional clothing design. Applied Ergonomics, **16**(4), 279−287.

National Fire Protection Association, NFPA. (1977). Standard on Protective Clothing and Equipment for Wildland Fire Fighting, ANSI/NFPA 1977.