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Effect of Different Types of Firefighter Station Uniforms on Wearer Mobility using Range of Motion and Electromyography Evidence

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Abstract: This study analyzed and compared wearer mobility for different types of clothing that also included the potential to develop firefighter station uniforms using range of motion (ROM) and electromyography (EMG). This study focused on a comparison of wearer mobility affected by different materials and shapes of the station uniforms worn under firefighter turnout gear. Japanese standard uniform (UNI), stretch-wear (ST), and compression-wear (CP) were used as station uniforms for the experiment. This study analyzed wearer movements and quantified ROM and EMG. In addition, the subjective evaluation of wearer mobility and comfort were assessed for comparisons. Nine healthy male students participated in the experiment. Wearer mobility was analyzed using ROM and EMG data obtained by measuring five motions; in addition, subjective evaluations were also obtained. As compared with the standard station uniform, ROM increased 6.8 % and 7.2 % due to stretch-wear and compression-wear. The benefits of wearing stretch material or compression material to improve muscle performance (such as reduced percent of maximum voluntary contraction) were not proven. Differences between materials and designs influenced subjective wearer comfort. In particular, the wearing of compression materials was shown best in terms of wearer comfort that may also allow greater wearer mobility.

Keywords: wearer mobility, range of motion, subjective evaluation, firefighter station uniform, compression wear

1. Introduction

Due to the physical demands when firefighting in hot areas with insufficient rest periods, firefighters are exposed to fatigue and risk of injury (Gregory et al., 2008). The fatigue also occurs due to the need for firefighting activities such as forcible entry, ceiling breaches and pull-down components, mannequin drags, and stair climbing. The performance of such motions when fatigued can negatively alter spine posture and trunk muscle activation patterns during highly demanding firefighting tasks (Gregory et al., 2008).

Firefighter turnout gear is designed and manufactured to protect workers from the extreme heat and occupational hazards present when firefighting. Additionally, this gear consists of a solid fabric that undergoes chemical treatment to endure high temperature. However, the firefighter turnout gear also causes physiological strain and discomfort due to its weight and poor ventilation. To reduce such problems with the firefighter turnout gear, over the last several years, research on personal protective clothing has been done to improve worker safety and health regarding occupational hazards.

First, study results about physiological responses during firefighting activities in high temperature, humid environments were obtained (Chou et al., 2008; Eglin et al., 2004; Holmer, 1995; McLellan & Sellirk, 2004). Second, the results from many studies were used to investigate the physiological strain caused by wearing firefighter turnout gear and other personal protective equipment, as well as the strain that occurs due to the weight and heat insulating properties of the protective clothing (Graveling & Hanson, 2000; White et al., 1989). Moreover, research about the physiological and psychological effects of self-contained breathing apparatus (SCBA) was also reviewed (Hooper et al., 2001; Bakri et al., 2012).

There were also studies that discussed the comfort of firefighter turnout gear. According to survey results from Tochihara et al.(2005), the half of Japanese firefighters answered that they realized restricted movement while firefighting (41%) with full set of firefighter gear. More than that, the respondents answered that what they want the most for working with full set of firefighter turnout gear is the ease of movement and comfort. Many firefighters from all over the world desire lighter and more comfortable next-generation firefighter turnout gear. However, it is not easy to improve

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and develop new materials that are light and capable of fully protecting firefighters from thermal and chemical harm. Firefighters from the United States of America, Korea, and Japan have commented that wearer mobility and thermal stress issues occur when wearing the current combinations of firefighter turnout gear. This includes a station uniform, firefighter jacket and pants, and personal protective equipment (Lee et al., 2015). Japanese prefectures have chosen different types of firefighter turnout gear to satisfy the needs of their firefighters. The aluminized and non-aluminized firefighter jackets were compared for wearer satisfaction, and the physical and physiological responses to wearing these two types of fire jackets were compared as well. Currently used firefighter uniforms are made of aramid fibers that lack elasticity and decrease wearer comfort (Japanese Fire Disaster Management Agency, 2005). The Japanese Fire Disaster Management Agency initiated the project of improving firefighter turnout gear, including the station uniform and firefighter jacket and pants. However, large improvements to the station uniform and firefighter jacket/pants were not suggested; thus, the commonly used gear have been employed so far. It may be necessary to improve these through new function of the materials or by novel design of the clothing. Although new aramid fibers have been developed with enhanced elasticity, they have not been applied to firefighter station uniforms. Therefore, it is felt to be necessary to provide an improved station uniform to be worn between a worker's body and firefighter turnout gear.

Several studies have been published about firefighter turnout gear that involve such as the surface characteristics of the inner-layer fabrics suitable for firefighter turnout gear (Troynikove et al., 2012), phase change material in firefighter turnout gear (McCarthy & Marzo, 2012), and performance tests of firefighter turnout gear (Watanabe, 2010). However, those studies focused only on the exterior firefighter jacket and pants, which have multiple flame-resistant layers. So far, only a few studies have reported effects from different designs of the firefighter station uniforms worn under the jacket and pants. Those studies reported on the physiological responses from wearing different designs of firefighter station uniforms. For example, by wearing short pants and T-shirts under the turnout gear, it was possible to reduce the thermal stress of firefighters (Chou et al., 2008; Malley et al., 1999; McLellan & Selkirk, 2004). Moreover, Mugie et al.(2014) contributed a report on the effects of undershirts that consisted of different materials, but found that there were no physiological or psychological differences when wearing cotton shirts, Merino wool blended shirts, and sport compression shirts. Moreover, previous studies also reported on the following subjects: mechanical and comfort performance of materials, a satisfaction survey, and proposal of a new design for a firefighter station uniform (Kim & Kim, 2014; Kwon et al., 2007; Seok et al., 2006). However, it was difficult to find studies that measured wearer mobility when using firefighter station uniforms.

There have been several studies on the measurement and analysis of wearer mobility. In these previous studies, wearer mobility was evaluated by measuring range of motion (ROM) with video cameras or goniometer, by subjective evaluation, using sensory evaluation, and dress/undress time (Ishigaki & Inomata, 2007; Iwasaki et al., 2006; Nakahashi et al., 2003; Shimosaka et al., 2008a; Shimosaka et al., 2008b; Watanabe et al., 2009). The human body had to use significantly more muscular effort when the clothing was poorly designed (Nakahashi et al., 2003), and this effort was measured by electromyography (EMG). For the analysis of wearer mobility due to the difference of design, certain elements such as crotch ease, sleeve cap height, and ease of clothing were measured using ROM. The results indicated that low sleeve cap height had an influence on increased wearer mobility of the shoulder and arm. The difference in wearer mobility due to the use of different materials was also presented in relation to increase and decrease in the ROM (Huck, 1991; Kim, 2002, 2009).

According to a previous questionnaire study (Son et al., 2013), Japanese firefighters were using compression-wear for their wearer mobility benefits. Compression-wear is widely used in sports and rehabilitation fields to improve muscle function. The compression-wear employed functional fabrics (providing such as elasticity, resilience, permeability, water resistance, etc.) and the Kinesio taping method (muscle activation and ergonomic design). The use of compression wear was effective in increasing muscle performance for male users during high-intensity exercise (Koo, 2011). Beneficial effects from using compression wear, such as injury prevention and performance enhancement, were reported (Argus, 2005; Doan et al., 2003). It may be that not only physiological effects from compression wear but also a psychological placebo effect might be expected to increase exercise performance. Therefore, evaluation of the application of compression-wear to firefighter turnout gear as a station uniform might also involve the positive effect of better wearer mobility. The use of compression-wear is considered an alternative option for a firefighter station uniform.

The Japanese firefighters had their own countermeasures that would improve wearer mobility when they working at the fire scene with firefighting turnout gear (Son et al., 2013). They answered that changing a firefighter jacket and pants, and station uniform for their preference fit, using compression wear, and so on. However, the studies related to the evaluation of those countermeasures for improving wearer mobility were not performed sufficiently. It was also pointed out that the current station uniform is inferior in wearer mobility since its low elasticity. Therefore, improvement project regarding firefighter station uniform has been processing (Fire prevention news, 2018). The firefighter station uniform typically should have worn under the firefighter jacket and pants as the inner layer (Park & Langseth-Schmidt, 2016), the increase of friction caused by multiple layers of station uniform with firefighter jacket and pants burdens the firefighters' movement (Son et al., 2010).

The aim of this study was to analyze and compare the wearer mobilities of different types of clothing; further, the possibility for developing firefighter station uniforms using ROM and EMG information was suggested with focus on improving wearer mobility.

2. Methods

2.1. Subjects and anthropometric data

Basic data was collected for the nine healthy male students that participated in this study as subjects: (*M*(*SD*): Age 26 (1) yr, Height 174 (2.8) cm, Weight/Mass 67.3 (4.5) kg, Body fat 18.9 (2.8) %). All subjects were functionally right-handed. Before they participated in the experiments, the details of the experiments and recording processes were explained to the subjects. Body fat was automatically calculated using a bioelectrical impendence analyzer and digital weight scale (KARADA Scan 362, HBF-362). This experimental protocol was approved by the Institutional Review Board of the Kyushu University.

2.2. Experimental ensembles

Three clothing conditions were created for this experiment (Fig. 1) and were labelled UNI, ST, and CP. For the UNI condition, the subjects wore firefighter turnout gear (3 kg) with personal protection equipment that consisted of self-contained breathing apparatus (SCBA, 11.0 kg), helmet (1 kg), boots (2.2 kg), gloves (0.1 kg), and belt (0.1 kg). As used in Japan, there was also underwear (0.1 kg) and Japanese station uniforms (short sleeved undershirt and long trousers, 0.4 kg). For the ST condition, subjects wore firefighter turnout gear, SCBA, helmet, boots, gloves, belt, underwear, socks, and stretch-wear (short sleeves shirts and long trousers from ®Wacoal, 0.3 kg). For the CP condition, subjects wore firefighter turnout gear, SCBA, helmet, boots, gloves, belt, underwear, socks and compression wear (long sleeves tops and long tights from ®Skins, 0.2 kg). Three measurements of each clothing condition were performed on same day, randomly. The present study primarily focused on the ergonomic analysis and comparison of wearer mobility, and not on proposing the prototype station uniform. Therefore, existing manufactured goods were chosen for ST and CT as a firefighter station uniform.

2.3. Data collection and processing

This study was conducted using a 3D motion Analysis system. Joint-angle and surface EMG data were obtained for the calculation of ROM and percent maximum voluntary contraction (%MVC). Infrared reflective markers (26) and a motion analysis program were used for data collection. All of the markers were attached to the firefighter protective jacket and pants, helmet, gloves, and boots instead of to human skin. For analysis of the ROM data, a method was used that involved establishment of two vectors for the shoulder motions and hip joint motions. To obtain a ROM measure, an active joint angle had to be acquired.

Surface EMG sensors were placed at five muscle points: middle deltoids, biceps brachialis, triceps, rectus femoris, and semitendinosus. Subjects wore short pants and a sleeveless shirt during the measure of MVC. The MVC data were recorded five times and the three most consistent data were selected and used to calculate the average %MVC. The ROM and EMG data were acquired as absolute values; however, the aim of this experiment was to clarify the distinction between UNI and the other conditions. Therefore, all data was converted to relative values with the UNI condition as the

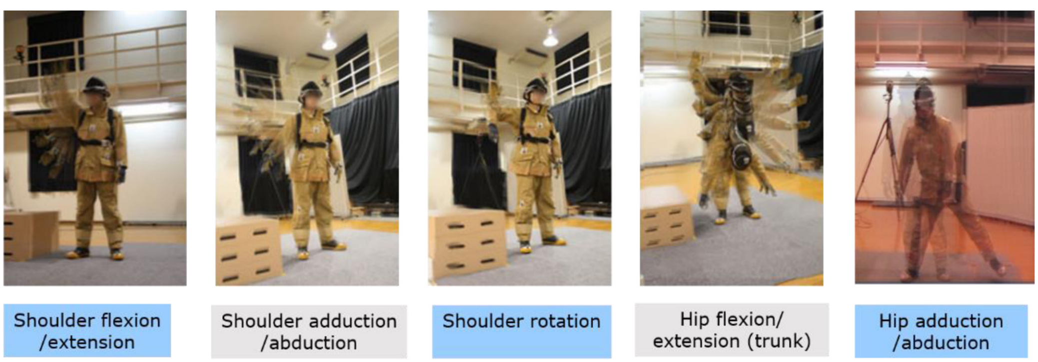

Fig. 1. The five experimental motions studied.

Table 1. Photographs and detail information of each clothing condition

	UNI	ST	CT
			
Design and material properties of undershirts	Set-in sleeve undershirts circular knitting over fitted design Polyestere 50% + Cotton 50%	Raglan short sleeves undershirt circular knitting slightly fitted design Polyestere 100%	Raglan long sleeves top warp knitting, skintight design Nylon Microfibre 76%+ Elastane Roica 24%
Undershirts sleeve circumference	36.0cm	31.2cm	13.6cm
Undershirts armhole circumference	54.0cm	50cm	32cm
Undershirts hem circumference	43.4cm	98.8cm	77cm
Design and material properties of trousers	One tuck trouser, weaving, Polyestere 20% + Meta aramid 75% + Para aramid 5%	No tuck trouser, circular knitting Polyestere 100%	long sleeves tights, skintight design, warp knitting, Nylon Microfibre 76% + Elastane Roica 24%
Trouser abdomen circumference	84cm	84.0cm	70cm
Trouser hip circumference	101.0cm	98.0cm	74..6cm
Trouser hem circumference	52.4cm	49.8cm	22cm
Total weight	0.4kg	0.3kg	0.3kg

The detail information used the L size of each clothing as a criterion.

baseline (the UNI value was 100 %). After measuring five motions, subjects answered a set of questionnaires. The questionnaires used were the same as those used by Son et al.(2010). A part was added about the donning and doffing. The questionnaires were constructed with two parts: wearer mobility and wearing comfort. The mobility section included nine inquiries about the head & neck, arms, elbows, wrists, waist, thighs, knees, ankles, and hip & pelvis. For these subjective responses, a seven point scale was used. The questionnaire for the wearer comfort section included eight questions: Fit - How does the clothing fit?, Bending body- How well can you bend your body with this ensemble?, Moving well- How about the mobility of movement in this ensemble? Was it comfortable?, Moving feet- How well can you lift your legs?, Moving arms: How well can you lift your arms?, Bulky- How about your thinking? Was this ensemble bulky?, Heavy- How about your thinking? Was this ensemble heavy?, Donning and doffing- How did you feel the donning and doffing of this ensemble?. A seven point scale was also used for the subjective evaluation of the wearing comfort. Participant responses closer to one indicated that the subject perceived discomfort and difficulty in moving. Conversely, a score closer to seven indicated greater comfort and ease of movement.

2.4. Procedures

The experiments were conducted at the Experimental House for Living Space Design at Kyushu University (Fukuoka, Japan) during summer. The experimental conditions were maintained at 26 ^{o}C and 50 % RH. Three measurements of each clothing condition were performed on the same day and the execution sequence of clothing conditions was random. Participants were asked to perform five motions: shoulder flexion/extension, shoulder adduction/abduction, shoulder rotation, hip flexion/extension (trunk), and hip adduction (Fig. 1). The participants came to the experimental location, and then had some time to relax and adapt to the experimental environment. In advance of starting to measure the experimental motions, the MVC tests were performed. After the MVC tests, the subjects wore the experimental ensembles and the firefighter turnout gear to which were attached the 26 infrared markers. Participants practiced two cycles of experimental motions. An audial metronome set at 70 beats per minute (BPM) was used to synchronize the speed of motion performance and decrease difference among individuals. Participants were asked the posing three times per one experimental motion. The mean values of those three data were used for analysis of ROM and %MVC. After the motions were performed, subjective evaluations of the mobility and wearing comfort were obtained from each subject. Every participant was asked to answer the subjective evaluation every time they finished a different clothing condition.

2.5. Statistical analysis

Statistical analysis was undertaken using the Statistical Package for the Social Science (SPSS version 17.0). The effects by means of uniform material differences to ROM and %MVC were examined using one-way analysis of variance (ANOVA). A non-parametric test (Kruskale–Wallis test) was used to analyze the subjective evaluation results. Tukey post-hoc tests were used to assess significant main effects using ANOVA. Statistical significance was set at p<.05.

3. Results and discussion

3.1. Range of motion

In this experiment, the ROM results for the ST and CP conditions did not reveal any striking differences from the UNI condition. The ROM results of the three conditions were compared, for which the UNI condition was established as the control. The ROM results for all motions and the values of relative increase are summarized in Table 2. All data were converted to relative values with the UNI condition as the baseline (the relative value of the UNI condition was 100 %). Except for the shoulder flexion/extension, most of the ROM values for the ST and CP conditions were higher than for the UNI condition. For three of the five motions (shoulder adduction/abduction, hip flexion/extension (trunk), and hip adduction/abduction) the ST and CP results were significantly higher than for the UNI condition. Fig. 2 shows the time course graph of the shoulder adduction/abduction and hip flexion/extension (trunk). As shown the Table 2, the relative values of ROM were greater for the ST and CP conditions than for the UNI condition. All the motion results for the ST and CP conditions were 6.8 % and 7.2 % higher, respectively, than for the UNI condition. According this

Table 2. Summary of the ROM data

	UNI (a)	ST (b)	CP (b)	*F*-value	*p*	
Shoulder flexion/extension (unit = degree)	176.0±35.2	166.2±28.3 (–0.9%)	162.4±27.8 (–1.5%)	0.793	0.459	
Shoulder adduction/abduction (unit = degree)	123.7±8.4	134.3±10.7 (8.6%)	135.8±11.6* (9.8%)	4.162	0.027	a < c
Shoulder rotation (unit = degree)	124.9±17.4	137.3±15.3 (8.9%)	136.2±15.2 (7.5%)	2.916	0.064	
Hip flexion/extension (trunk) (unit = degree)	110.6±10.0	119.6±8.9* (8.1%)	120.3±7.5** (8.8%)	5.265	0.009	a < b, c
Hip adduction/abduction (unit = cm)	77.5±7.1	84.7±7.1 (9.3%)	86.4±12.9* (11.4%)	3.992	0.025	a < c
Mean relative increased value	-	6.8%	7.2%			

Numerical values in parentheses means the value of relative increase of ROM when compared with UNI. The unit of degree means joint angle, and the unit of cm means distance of hip joint movement. Significant differences between UNI and the other conditions (*p<.05, **p<.01).

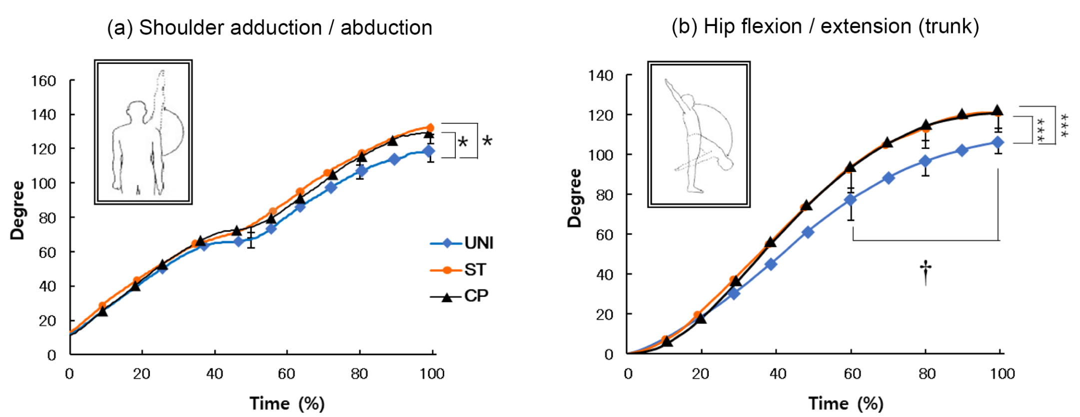

Fig. 2. Time course graph of shoulder adduction/abduction (a) and hip flexion/extension (b). X-axis means relative value of operating time (0 % and 100 % mean start and finish point of each motion), Y-axis means the angle of joint. (*p<.05, ***p<.001, The "†" mark indicated the part of the time course graph at which significant differences were revealed).

and CP) had similar effects.

For the shoulder flexion/extension, the UNI condition had the highest ROM value compared to the ST and CP conditions. The ROM variation from that of UNI was observed to be lowest in the ST condition. However, there were no significant differences. For this motion, the right arm was located upwards as far as possible (shoulder flexion) and pushed backwards as far as possible (shoulder extension). For the flexion section, the variation of ROM had similar values among the three conditions (UNI: 32.7±13.3º, ST: 27.7±13.0º, CP: 31.6±11.4º). Also, similar variation of ROM was found for the shoulder extension section (UNI: 132.3±23.3 degree, ST: 138.4±21.6º, CP: 130.8±18.3º). For the results of shoulder flexion/extension, the UNI condition had the most increased ROM value. In the experimental ensemble, the elements of shirts design (e.g., short sleeve and round neckline) had differences among the three conditions. The uniform shirt (UNI condition) had the widest armholes and sleeve circumference. From those design elements, it was considered that the ROM result of the UNI condition was higher than the other conditions for shoulder flexion/extension. This was based on the opinion that a wider armhole increased the ease of clothing and thereby, the ROM (Huck, 1991; Kim, 2009).

For the shoulder adduction/abduction, the results for the ST and CP conditions were significantly higher than for the UNI condition (p<.05). Relative to that for UNI, the ROM increased 8.9 % and 7.5 % with stretch-wear and compression-wear, respectively (Table 2). Time course result of shoulder adduction/abduction revealed minuscule differences until 40 % of the cycle phase (Fig. 3). After 40 %, the variation of values in the ST and CP conditions show intense increase in the ROM. From 80 % of motion performance time to 100 %, the results for the UNI condition are significantly lower than for the other conditions (p<.05). For the shoulder adduction/abduction, the right arm was at shoulder height in the 40 % motions. After 40 %, in other words, when the right arm was raised up more than 90 degrees, significant differences among the three materials were revealed in the ROM results. In this motion, the values of the stretch-wear (ST) and compression-wear (CP) were higher than for the normal station uniform (UNI). It is concluded that the materials with softer tactile sensations (stretch and compression wear) increased arm mobility. Moreover, the fitted sleeve of the undershirt design for ST and decline of frictional resistance due to the skintight clothing design for CT, might lead to increase in ROM (Doan et al., 2003; Im et al., 2011). Due to the results of the shoulder motions, it was regarded that the circumference of the armhole and sleeve had influence on the shoulder flexion/extension. In contrast, differences in the materials were more effective for allowing greater ease in raising the arm on the frontal plane, as in shoulder adduction/abduction. The significant differences in the ROM according to the three conditions were not shown for shoulder rotation, despite that ROM was relatively increased when participants wore stretch-wear and compression-wear (8.9 % and 7.5 %).

For the hip flexion/extension (trunk), the ROM results for the ST and CP conditions were significantly higher than for the UNI condition (p<.05): 8.1 % and 8.8 %, respectively. Fig. 2 indicated the time course graph of the UNI, ST, and CP conditions for hip flexion/extension (trunk). From the time of 20 % of motion, the ROM variation values of the ST and CP conditions increased more extremely than did the UNI rate. After 60 % of motion, the UNI condition was significantly lower than for the ST and CP conditions. The 60 % point was when a subject bent his upper body forward at 90 degrees. For the three kinds of experimental clothing, the ease of clothing had different values even when the size was the same. The ease of clothing value of the ST and CP condition was

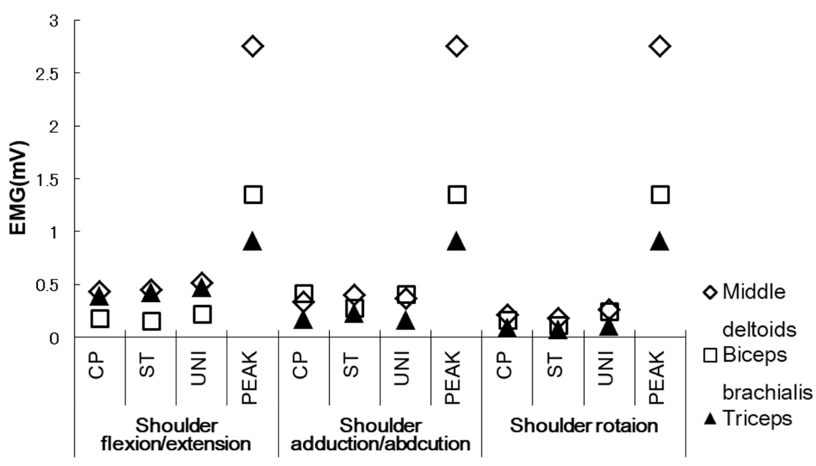

Fig. 3. EMG results for the shoulder motions and the peak data of each muscle.

lower than that of the UNI condition, because of the fitted design. Compression wear had the least ease of clothing value. Ease of clothing is necessary for the comfort and thermal insulation of the wearer; however, too much of it can occasionally interfere with the wearer mobility (Yamato et al., 2010). In cases of too much ease of clothing, when the upper body bent forward, multiple layers were formed. Those multiple layers caused the reduction of ROM. Therefore, it was considered that the slightly fitted undershirt which is worn under the firefighter turnout gear is required for the trunk. The ROM data for hip adduction/abduction had trends similar to that of hip flexion/extension (trunk). When the participants wore compression-wear, the ROM was significantly higher than for the UNI condition; however, there was no significant difference between UNI and ST conditions.

The ROM result considered how the different designs, materials, and functions of station uniform affect wearer mobility. The stretch-wear and compression-wear will have positive effects on mobility, especially when fulling up the arm and bending or folding at the waist.

3.2. Percent MVC determined using electromyography

All the experimental motions were performed in the standing position. Therefore, the EMG results showed no noticeable differences for the lower body muscles. Fig. 3 shows the EMG results for the upper muscles during the three shoulder motions. Table 3 indicates the percent MVC of the upper body muscles during the shoulder motions.

For the shoulder flexion/extension and shoulder rotation, the UNI condition had a slightly higher %MVC value than for the ST and CP conditions. However, differences in the results for the shoulder joint motions showed no statistical significance. Moreover, no trends in muscle reaction were demonstrated for the different uniform materials and designs.

According to Ishigaki and Inomata (2007), the EMG amplitude decreased in clothing of stretch material and this was reported many times by the younger subjects. However, in the present stretch-wear group, EMG was similar or slightly decreased. This was due to decrement of muscle activity according to the decreased ROM for the non-stretch clothing (UNI). It was considered that the variation of ROM increased in the stretch-wear condition and that the experimental motions were too static for effective analysis of EMG. Nakahashi and Yoshida (1997) described how mobility when wearing clothing was affected by the material, ease of clothing, and design. For an experiment with cotton jeans and training pants, there were differences of amplitude when comparing two conditions. The cotton jeans had ease of clothing close to zero. In contrast, training pants had sufficient ease of clothing even though the size of clothing used in the two conditions was the same.

The compression-wear was expected to provide an improvement in wearer mobility according to its softness and function. The effects of compression-wear, such as injury prevention and performance enhancement, have been reported many times (Argus, 2005; Doan et al., 2003). Doan et al.(2003) reported that the skin temperature warm-up speed increased more and at a faster rate when wearing compression shorts. Moreover, muscle oscillation decreased significantly in jump-and-landing exercise. The time to reach the muscle warm-up temperature was also decreased when the compression-wear was on. It was described that wearing fitted compression shorts might have an effect on long-jump distances. The lower-body compression garment might provide benefit in terms of reduced tissue injury and enhanced performance in jump exercises (Doan et al., 2003). Born et al.(2014) reported increased exercise performance and improved muscle activity due to the use of compression-wear. Reduced EMG with compression-wear was also mentioned (Koo, 2011). Moreover, Tamura (2004) mentioned

Table 3. Percent MVC results* for shoulder motions

		Middle deltoids	Biceps brachialis	Triceps
Shoulder flexion/extension	UNI	23.3±8.7	23.4±7.1	46.8±8.3
	ST	23.5±12.8	23.4±4.6	43.3±9.1
	CP	23.4±22.9	23.4±23.0	41.9±15.9
Shoulder adduction/abduction	UNI	17.5±6.0	31.5±10.4	19.0±6.3
	ST	17.7±5.8	22.0±5.1	26.0±8.3
	CP	17.2±5.7	32.3±10.8	19.7±5.9
Shoulder rotation	UNI	13.5±6.1	19.3±6.9	13.1±6.9
	ST	9.6±5.4	9.0±2.2	8.4±2.1
	CP	11.5±7.0	12.2±3.0	10.1±2.6

*These values were calculated by following a numerical formula: *%MVC = (each condition EMG value/ EMG peak mean value)*×100. For this experiment the %MVC results had no significant differences among the conditions compared.

that compression clothing or compressive belts decreased the burdens of wearers. In active exercise, muscle activity decreased with compression-wear compared to without it. On the other hand, increase in EMG was reported in passive exercise. In this study, those physiological effects were not demonstrated, and compression-wear showed results similar to those with stretch-wear. The present result of personal EMG data had wide variation in each condition. Accordingly, the analysis of muscle activity was difficult in the shoulder motions: flexion, extension, rotation, adduction, and abduction. The unrecognized burden or fatigue due to wearing 20 kg of firefighter turnout gear and equipment influenced wearer mobility, as indicated by measures such as ROM and EMG.

3.3. Subjective evaluation

For the subjective evaluation results for mobility, the CP condition (with a long sleeved fitted shirt and tights) had the highest value in most arrangements. In particular, participants felt high wearer mobility with compression-wear on arm, elbow, waist, and thigh. These results demonstrated that the soft fabric and fitted design of compression-wear improved the perception of greater wearer mobility. On the other hand, the UNI condition provided better mobility than the other two conditions did for the mobility of head and neck. For the wrists, the three conditions got similar evaluations of mobility. Overall, the CP condition had the lowest evaluations for head and neck, and wrists. Those low evaluation values of the CP condition were due to the long sleeves and a too tightly fitted neckline designed with a small hem. However, these differences in evaluation values were not significant (Fig. 4). For the perception of wearer mobility, participants responded that they did not feel good mobility with stretch-wear, but the ST condition had a slightly better evaluation for waist motion. It seems that the subjective evaluation of waist mobility reflected better ROM of hip flexion/extension (trunk).

The UNI condition had the lowest evaluation values in most of the wearing-comfort arrangements. The CP condition also had high

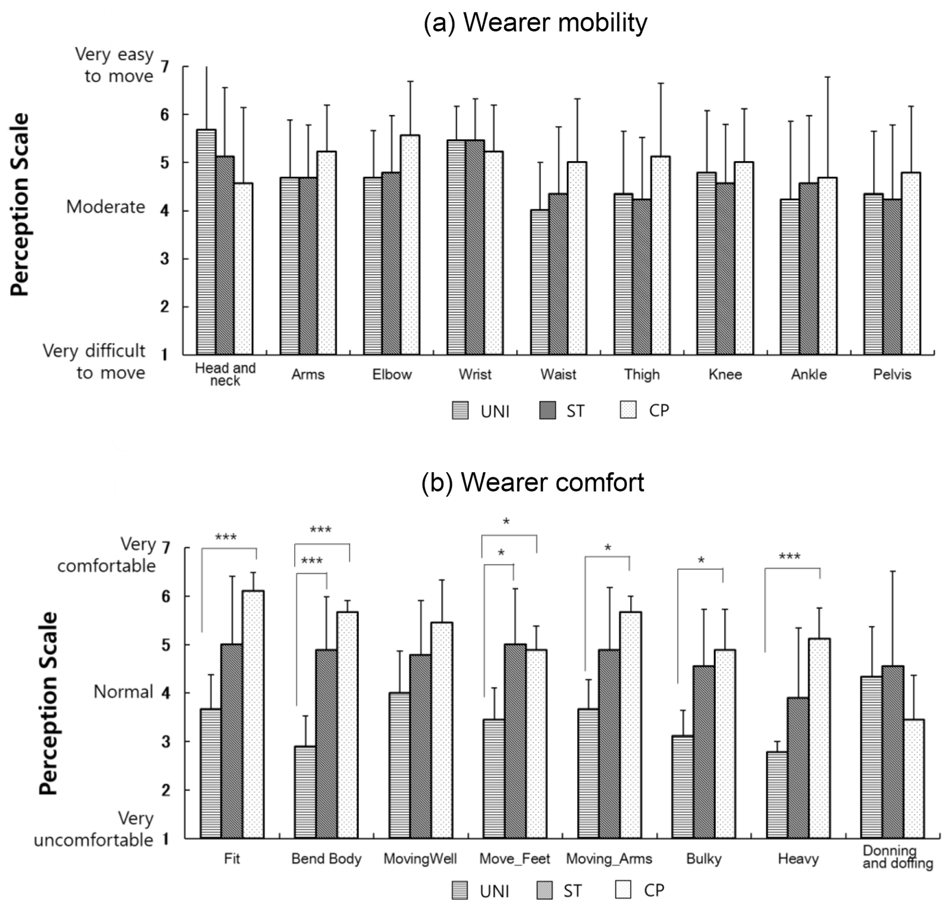

Fig. 4. These graphs indicate the results of subjective evaluation. (a) and (b) represent wearer mobility and wearer comfort, respectively. (*p<.05, ***p<.001)

evaluations in most arrangements except “wearing”. The bottom graph in Figure 4 presents the results of subjective evaluation for wearing comfort. For some of the questions (fit, moving feet, moving arm, bulky, and heavy), the results of the UNI condition were significantly lower than for the other two conditions. In contrast, for the questions about changing the clothes (donning and doffing), the compression were worn in the CP condition had the lowest value. It was considered that CP condition have a skintight design for whole body such as long sleeves, and too fitted neckline which was designed a small hem. For the wearing comfort evaluations, the normal station uniform had the lowest values when compared with the other two conditions. The compression wear also had high values in most arrangements for wearing comfort. These results demonstrate why clothing of relatively rough fabrics and clothing with an ease of clothing factor that is too high, are not recommended.

The differences of uniform material had no obvious differences for the physical responses among these three conditions. However, this study verified that the softer the clothing material is, the more comfortable and easier to move wearer realized more comfortable and easier for movement. The differences of uniform design affected to the wearers’ subjective evaluations. Therefore, it is necessary to consider changing uniform fabrics and design to consider stretch ingredients; also it is important to change the uniform design to fitted to the body and to have an easy to move design. Those effects are likely to provide stability and satisfaction to the firefighters that wear them.

4. Conclusions

In this study, the focus was the comparison of effects on wearer mobility from different types of clothing of the station uniforms worn under firefighter turnout gear. The present study focused on the ergonomic analyzing and comparing the wearer mobility, not for proposing the prototype of station uniform. The main approach used in the study was to analyze wearer movements quantitatively using ROM and EMG. In addition, subjective evaluations of wearer mobility and comfort were performed for comparison.

Relative to the standard station uniform, ROM increased 6.8 % and 7.2 % using stretch-wear and compression-wear, respectively. It is concluded that ROM variations depend on design elements such as the ease of clothing, and the circumference of armholes and sleeves under different conditions. Wider armholes and sleeve circumference result in wider ROM at the shoulder flexion/extension. This result was based on the opinion that wider armholes provided greater ease of clothing and increased ROM. Form most of the experimental motions, the ROM values of stretch-wear and compression-wear were higher than for the normal station uniform. The differences in materials made some more effective for raising the arms in the frontal plane. It is concluded that the materials that provide soft tactile sensation and compress the body, also increase arm mobility, and that the stretch-wear and compression-wear will have positive effects on mobility. This is especially so when raising the arms in the frontal plane and with bending or folding of materials at the waist. The multiple layers of the firefighter turnout gear plus station uniform cause reduction of ROM. Therefore, relatively tight fit clothing is required for better wearer mobility. In the present study, no benefits from stretch-wear and compression-wear for improving muscle performance (such as reduced %MVC) were proven.

The differences between materials and designs influence subjective wearer comfort. Because the uniform made from stretch-wear and compression-wear are soft and comfortable, those options are preferred over general station uniforms. In particular, compression-wear was found to be the best in terms of wearer comfort in the present experiment. Compression-wear may allow better wearer mobility for firefighters, resulting in more efficient performance during actual firefighting. For this reason, compression-wear is proposed as an alternative to the current general station uniforms.

There are some limitations to the present study. First, the wearer mobility depends on the type of clothing that is worn under the firefighter turnout gear. However, the manufactured goods were chosen for ergonomic analysis and comparison of wearer mobility, and each clothing condition was not fully controlled with respect to the design or materials used. Second, actual firefighting environment was not simulated in this study. Actual firefighting tasks in hot environments, especially during rescue activities and firefighter training, involve a wide range of shoulder motions, and improved muscle performance may be necessary. Therefore, the results of this study should be interpreted carefully only about wearer mobility, and the analysis of wearer mobility while doing active movements with a full set of firefighter turnout gear is required for future studies.

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