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Original Article

Occupational Stress and Strain in Relation to Personal Protective Equipment of Japanese Firefighters Assessed by a Questionnaire

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Abstract: The purpose of the present study was to elucidate differences in actual work environments, mobility and satisfaction between firefighters wearing aluminized and non-aluminized personal protective equipment (PPE), and to suggest a proper standard test method for Japanese firefighters' PPE. A survey from two cities in Japan (City A: aluminized PPE; City B: non aluminized PPE) was undertaken. A total of 525 firefighters from City A and 757 from City B participated. Firefighters spent 22.5 min (City A) and 27.3 min (City B) on average firefighting with the full set of PPE in one incident, but the heat strain experienced among firefighters from City A was twice that of firefighters from City B (57.5% and 28.4%). Firefighters spent 65.9 min on one incident and 24.2 min for suppression of fire with the full set of PPE on average. The toughest task that caused physical strain in City A was 'stair climbing' and in City B was 'drawing up a hose filled with water'. The most restricted body region due to PPE was the knee for both groups. Evaluations revealed that the aluminized fire jacket had worse ventilation and mobility than the non-aluminized, while the non-aluminized one received with more unfavorable evaluations for water resistance and maintainability.

Key words: Firefighter, Personal protective equipment, Questionnaire, Actual work environment, Physical strain, Wearer mobility, Aluminized fire jacket

Introduction

Firefighting involves physical work in a superheated environment that is physiologically and psychologically stressful. In particular, Japan has areas prone to earth tremors, earthquakes, typhoons, tsunamis, and volcanic activity. These natural disasters may lead to huge damage. Consequently, Japanese firefighters' assignments are not only related to fire suppression, but also include relief work during natural disasters. In response to the unpredictable nature of disasters, the operations of firefighters have become more diverse, leading to increased strain on firefighters.

Although personal protective equipment (PPE) aims to protect firefighters from physical and chemical harm, firefighters can become fatigued by impeded movement due to the weight and bulky shape of PPE in such diverse harsh environments. Many studies have reported that firefighters were subjected to physiological strain when they performed simulated firefighting activities wearing PPE in hot and humid environments[1–3], which is attributed to the insulating properties of PPE[4, 5] and heavy self-contained

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breathing apparatus (SCBA)[6]. In particular, there are studies reporting the physiological strain on wearers of PPE of different materials (aluminized and non-aluminized).The studies, which examined the effects of PPEs on firefighters during exercise[7], reported that firefighters experienced the greatest feeling of hotness and most discomfort while wearing aluminized protective clothing, and their thermoregulatory and cardiovascular responses were more aggravated in the aluminized PPE than in typical PPE. However, the study reported experimental results in a climatic chamber, providing no information on the effects of PPE material while actually fighting a fire. In Japan, the characteristics of PPE selected for Fire Departments vary by locality. In practice, not many fire departments in Japan provide aluminized PPE (jacket only) for firefighters. In this regard, a survey on the different types of firefighter PPE is worthwhile for elucidating differences in work environments, wearer mobility and satisfaction as well as heat strain of firefighter.

In addition, according to interviews with firefighters, wearers should keep wearing PPE until any remaining fire has been extinguished in order to minimize injuries[8]. The Puerto Rico Fire Department's administration reported that 57% of 638 firefighters always wear complete PPE, but14% of firefighters did not wear PPE due to its limited mobility[9]. Tochihara and colleagues reported that 41% of 796 firefighters responded that their mobility was restricted while they were working on the fire scene[10]. In this context, the mobility of firefighters in relation to PPE (wearer mobility) is regarded as an important requisite for firefighters, as well as protective functions. In general, range of motion (ROM) is applied for wearer mobility[11–15]. For example, 13.7% of the mean ROM of the whole body was restricted and wearer comfort and mobility deteriorated sharply with a 10 kg SCBA[15].While several studies reported that significant ROM decreases while wearing PPE were found in the shoulder, knee and/or trunk[11, 13], relatively few studies have investigated PPE wearer mobility compared with the number of studies on physiological strain. There is still no standard test method for the evaluation of wearer mobility for firefighters. Without a standard test method for assessing the heat strain and mobility of a subject wearing PPE, the comparison of each result obtained from different research groups may lead to inaccurate interpretations. As a first step to developing a standard test method, it is necessary to collect basic information on firefighter's work environments, physical strain and mobility during firefighting, which could be impaired by heavy PPE.

For the investigation of firefighter's actual work environments, physical strain and wearer mobility, self-report methods are suitable. Several reports have documented the results of surveys on a firefighter`s work situation. In a recent survey, a total of 796 Japanese firefighters were asked about the importance of protective clothing for safety, ease of movement, and comfort[10]. Japanese firefighters ranked ease of movement higher than comfort, protection, and safety. Huang and colleagues carried out a survey on experiences of trouble and injury and subjective evaluation of PPE for Chinese firefighters[16]. Bos and colleagues compared the work demands, health complaints, and disabilities of firefighters to office workers[17]. However, recent surveys on firefighter mobility in relation to PPE were not found. Also, there were virtually no questionnaires considering personal protective accessories, such as SCBA, boots, mask, and rope.

Therefore, the purpose of the present study was to 1) to investigate differences in work environments, physical strain, wearer mobility, and satisfaction between Japanese firefighters wearing the aluminized and the non-aluminized PPE; and 2) to provide basic information for the development of a standard test method to evaluate heat strain and mobility of firefighters' PPE.

Methods

Anthropometric characteristics of firefighters from two cities

A questionnaire was distributed to Japanese professional firefighters working in City A and B in September and October, 2010. The two cities were chosen because each city is the major city of its respective province in Japan, and because each city's firefighters officially use different PPE from the other one. For the most past, each city's firefighting involves structural firefighting, and a number of callouts in 2011 are 365 and 5,341 for City A and B, respectively. From the 2,500 questionnaires distributed, a total of 1,282 male participants were subjected to data analysis (525 firefighters from City A; 757 firefighters from City B). Anthropometric data of participants from City A were as follows: age, 42.9 ± 12.3 yr; working period, 22.4 ± 12.8 yr; height, 171.8 ± 4.7 cm; weight, 70.3 ± 8.1 kg; and body mass index (BMI), 23.8 ± 2.6. Anthropometric data of participants from City B were as follows: age, 36.7 ± 11.7 yr; working period, 15.9 ± 13.1 yr; height, 171.4 ± 5.4 cm; weight, 68.4 ± 7.5 kg; and BMI, 23.3 ± 2.1.The age and working periods of firefighters were significantly different between the two groups (p<0.001). City A fire-

fighters (N=525) consisted of 0.2% in their teens, 23.4% in their 20s, 14.3% 30s, 23.8% in their 40s, 35.2% in their 50s, and 3.0% in their 60s. City B firefighters (N=757) consisted of 1.8% in their teens, 34.2% in their 20s, 27.5% in their 30s, 16.1% in their 40s, 19.6% in their 50s, and 0.8% in their 60s. Firefighters were asked to fill out the questionnaire based on their ordinary firefighting experiences for the last year.

Questionnaire construction

The questionnaire was designed to obtain information on firefighter activities, physical strain, actual work environment, and wearer mobility while wearing PPE. The questionnaire consisted of four sections: 1) General information including anthropometric data, firefighting work history, and PPE configurations; 2) Information about mobility and physical strain suffered during actual firefighting, which included questions about postures/tasks causing muscle fatigue (a maximum of three possible choices were allowed), body regions that suffer muscle fatigue and burns (multiple choice), and the effects of several types of PPE (wet-PPE, SCBA without a face mask, and SCBA with a face mask) on wearer mobility (Questions asked how participants felt about wearer mobility using a 5-point scale ranging from 1-neutral to 5-extremely deteriorated); 3) The satisfaction/dissatisfaction of firefighters in relation to PPE (firefighters expressed their satisfaction/dissatisfaction about mobility, physical strains, and comfort imposed on them while wearing PPE using 5-point scales); and 4) Suggestions and demands for improving wearer mobility and comfort of PPE (open questions). Prior to undertaking this survey, the validity of the questionnaire was examined by having it pre-reviewed by selected proficient firefighters from two cities in Japan.

PPE construction

PPE for general fire suppression currently in use by Japanese firefighters consisted of nine items for both cities. PPE of City A consisted of a fire jacket (2,200 g for Size L), fire pants (1,200 g for Size L), a helmet (950 g), rubber boots (2,100 g for 265 mm length), a safety belt (1,300 g), gloves (200 g), flashlight (200 g), a fire hood (670 g), and SCBA (4,100 g for the strap system and 6,700 g for the cylinder). PPE of City B consisted of a fire jacket (1,790 g for Size L), fire pants (1,200 g for Size L), a helmet (1,010 g), rubber boots (2,170 g for 265 mm length), a safety belt (750 g), gloves (180 g), a flashlight (190 g), fire hood (850 g), and SCBA (3,810 g for the strap system and 7,130 g for the cylinder). For both cities, firefighters wore office work uniforms under their own PPE. The office work uniform consisted of T-shirt (133 g), work shirts (333 g), and work pants (327 g). The total weight of PPE for City A and B were 19.62 kg and 19.08 kg, respectively. The main difference in PPE between City A and B was the materials used. The fire jacket of City A's PPE was laminated with aluminum. However, the fire jacket of City B's PPE had a non-aluminized surface. More details on PPE are summarized in Table 1.

Statistics

Results were expressed as the mean value and standard deviation (mean ± SD). Responses to each question were also expressed as frequencies and percentage. Differences between City A and B or among categories were statistically analyzed using the chi-square test (SPSS *v.*18.0). For anthropometric differences between City A and B firefighters, response frequencies were tested with a *t*-test. Significance was set at $p<0.05$.

Results

General information

For the duration time of an incident (from sounded alarm to operation finished), City A firefighters (N=478) took 56.6 ± 28.2 min and City B firefighters (N=249) took 83.7 ± 47.1 min. The duration time of firefighting with the full set of PPE (a condition where all equipment was worn) per incident in City A (N=420) and B (N=226) were 22.5 ± 14.2 min and 27.3 ± 18.7 min, respectively. On average, Japanese firefighters wore PPE for 65.9 ± 38.0 min (N=727) per incident and were exposed to the fire scene with the full set of PPE for 24.2 ± 16.1 min (N=646) of their firefighting time. A total of 64.9% of Japanese firefighters finished their fire operations within 30 min with the full set of PPE (66.2% of 420 City A firefighters and 62.4% of 226 City B firefighters).

Physical strain and injuries

Regarding the question about their experiences of heat strain on duty for the last year, 57.5% of City A firefighters (N=517) and only 28.4% of City B firefighters (N=742) experienced heat strain. For firefighters who experienced heat strain, it was experienced mostly in July (City A: 29.9%, City B: 25.9%) and August (City A: 53.2%, City B: 45.5%) between 2 and 3pm (City A: 34.0%, City B: 28.9%). For firefighter activity types when heat strain was experienced, City A firefighters (N=297, 57.5% of 517) ranked outdoor practice (43.1%), indoor practice

Table 1. Specifications of firefighter clothing used in City A and B

		City A	City B
Clothing property			
Fire jacket	Base material	Aromatic polyamide 280 g·m^{-2}	Aromatic polyamide 250 g·m^{-2}
	Thickness	Over 0.50 mm	Over 0.45 mm
	Garment weight	2,200 g	1,790 g
	Surface coating	Aluminum	–
Fire pants	Base material	Aromatic polyamide 280 g·m^{-2}	Aromatic polyamide 250 g·m^{-2}
	Thickness	Over 0.45 mm	Over 0.45 mm
	Garment weight	1,200 g	1,200 g
	Surface coating	–	–
	Suspenders	without	with
Total PPE*weight (PPC** + SCBA***)		19.62 kg (8.82 kg + 10.80 kg)	19.08 kg (8.14 kg + 10.94 kg)

*PPE=Personal protective equipment, **PPC=Personal protective clothing, ***SCBA=Self-contained breathing apparatus.

(20.2%), outdoor work (19.9%), and indoor work (14.1%) in order. City B firefighters (N=211, 28.4% of 742) chose outdoor work (35.5%), outdoor practice (30.8%), indoor work (28.0%) and indoor practice (5.2%), in order. For the symptoms of heat strain, tiredness and boredom (36.1%) ranked highest, followed by numbness of limbs (16.4%), dizziness (14.5%), and nausea (14.0%) for City A firefighters. For City B firefighters, tiredness and boredom (37.1%) also ranked highest, followed by dizziness (20.4%), numbness of limbs (16.2%), and nausea (10.8%). Over half of Japanese firefighters from each city reported that they continued and finished their work even when they felt heat strain.

A total of 38.5% of City A firefighters (N=202) and 15.5% of City B firefighters (N=117) reported experience of 343 and 194 injuries cases, respectively. For City A firefighters, injuries of the hand (22.7%) ranked highest, followed by the waist (19.5%), ankles and feet (14.6%), and head (10.8%) (Fig. 1). For City B firefighters, ankle and foot injuries (24.7%) ranked highest, followed by the hand (17.5%), waist (17.0%) and head (9.8%). The body region in which muscle fatigue was the most frequently experienced in firefighting service was the waist (17.0%), followed by the thigh (11.9%), arm (11.7%), shoulder (11.6%), and neck (7.2%) for City A firefighters (Fig. 1). For City B firefighters, the waist (18.4%) also ranked highest, followed by the shoulder (16.6%), arm (12.2%), thigh (11.1%), and calf (9.0%) in order (Fig. 1). Many responded that the causes of muscle fatigue and injury were falls, slips, trips, and external pressure due to the weight of SCBA.

Table 2 shows the firefighting activities causing the greatest physical strain. Regarding the toughest firefighting activity, City A firefighters experienced the greatest physical strain when 'stair climbing' (22.2%), followed by 'carrying a heavy object or person' (19.0%), 'drawing up a hose filled with water' (14.0%) and 'advancing whilst squatting' (12.9%). For City B firefighters, 'drawing up a hose filled with water' (19.9%) ranked as the toughest task. 'Stair climbing' (19.4%), 'carrying a heavy object or person' (18.9%), and 'advancing whilst squatting' (14.1%) ranked second, third and fourth, respectively.

Subjective evaluations for wearer mobility with PPE

Table 3 shows the countermeasures that would improve the mobility of firefighters in relation to PPE. A total of 23.1% of respondents from both two cities had no specific countermeasures for wearer mobility. For City A firefight-

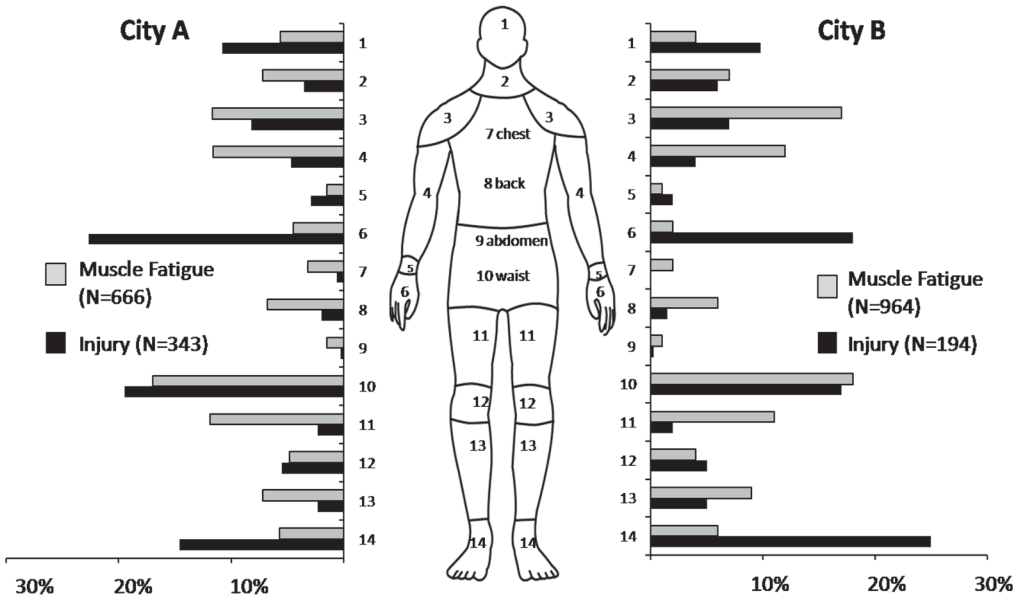

Fig. 1. Percentages of body regions that firefighters chose as areas that experienced muscle fatigue and injury when firefighting.
Values (N) are expressed as the sum of cases (1-head; 2-neck; 3-shoulder; 4-arm; 5-wrist; 6-hand; 7-chest; 8-back; 9-abdomen; 10-waist; 11-thigh; 12-knee; 13-calf; and 14-ankle and foot).

Table 2. Firefighting activities causing the greatest physical strain

Q. Please choose a tough firefighting activity that causes you physical strain with PPE. (A maximum of three possible choices were allowed)

	City A	City B
Hose rolling and dragging	139 (9.3)	127 (5.8)
Drawing up a hose filled with water	209 (14.0)	436 (19.9)
Stair climbing	332 (22.2)	426 (19.4)
Going down stairs	12 (0.8)	28 (1.3)
Advancing whilst squatting	192 (12.9)	309 (14.1)
Crawling	72 (4.8)	89 (4.1)
Stepping over obstacles	119 (8.0)	149 (6.8)
Climbing up a ladder	83 (5.6)	89 (4.1)
Climbing down a ladder	10 (0.7)	12 (0.5)
Carrying a heavy object or person	284 (19.0)	408 (18.6)
Spraying watering	19 (1.3)	106 (4.8)
Others	23 (1.5)	14 (0.6)
Sum of cases	1,494 (100)	2,193 (100)

Values are expressed as cases (%); χ^2=86.921, p<0.001 for differences between cities.

Table 3. Countermeasures that would improve the mobility of firefighters wearing PPE

Q. What countermeasures do you use for improving mobility with PPE? (Multiple choices were allowed)

	City A	City B
None	169 (23.1)	227 (23.1)
Use suspenders	188 (25.6)	15 (1.5)
Wear PPE that fits	150 (20.5)	360 (36.7)
Wear oversized PPE	92 (12.6)	123 (12.)
Wear compression clothing under PPE	4 (0.5)	19 (1.9)
Adjust boot laces	114 (15.6)	213 (21.7)
Others	16 (2.1)	24 (2.5)
Sum of cases	733 (100)	981 (100)

Values are expressed as frequency (%); χ^2=257.736, p<0.001 for differences between cities.

ers, 'use suspenders' (25.6%) ranked highest, whereas 'wear PPE that fits' (36.7%) was selected most frequently by City B firefighters.

Regarding body regions that were most restricted by PPE during firefighting, the knee as ranked highest (15.1%), followed by the wrist (12.7%), shoulder (12.6%), and elbow (9.9%) for City A firefighters (Table 4). For City B firefighters, the knee (16.2%) also ranked highest, followed by the buttocks and thigh (14.7%), shoulder (12.6%), and elbow (8.6%) in that order. A total of 63.9% of all responses from City A firefighters were distributed on the upper body.

The sum rates of 'bad' and 'a little bad' in the subjective evaluation of personal protective clothing (PPC)'s functional characteristics are shown in Figure 2. Six of 14 functional items (ventilation of PPC, mobility while wearing PPC, easiness of raising leg, easiness of raising arm,

Table 4. The most restricted region due to PPE while firefighting

Q. Please choose the most restricted region due to PPE while firefighting. (A maximum of three possible choices are allowed)			
		City A	City B
Upper Body	Collar of PPE coat	134 (9.5)	143 (6.8)
	Shoulder	177 (12.6)	263 (12.6)
	Elbow	139 (9.9)	180 (8.6)
	Wrist	178 (12.7)	132 (6.3)
	Pockets and zippers across the chest	52 (3.7)	115 (5.5)
	Lower part and pockets of PPE coat (front)	65 (4.6)	118 (5.6)
	Back	27 (1.9)	41 (2.0)
	Armpits of coat	107 (7.6)	140 (6.7)
	Lower part of PPE coat (back)	20 (1.4)	73 (3.5)
Lower Body	Waist and belt of trousers	85 (6.0)	171 (8.2)
	Buttocks and thigh	132 (9.4)	308 (14.7)
	Knee	212 (15.1)	338 (16.2)
	Ankle	49 (3.5)	47 (2.2)
	Others	29 (2.1)	22 (1.1)
	Sum of cases	1,406 (100)	2,091 (100)

Values are expressed as frequency (%); χ^2=104.809, p<0.001 for differences between cities.

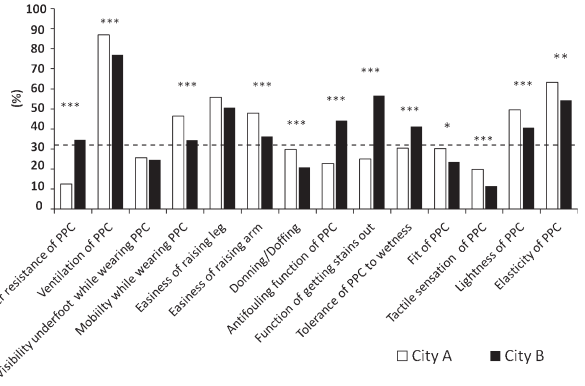

Fig. 2. Sum rates of 'bad' and 'a little bad' in subjective evaluation of PPC's functional characteristics (Significant differences between City A and B, *p<0.05, **p< 0.01, ***p< 0.001).

lightness of PPC, and elasticity of PPC) were rated as 'a little bad' or 'bad' by more than one third of respondents for both cities. Except for two functional items (visibility underfoot while wearing PPE and easiness of raising leg), there were significant differences between the two cities. Aluminized PPE had worse ventilation and mobility than non-aluminized PPE, while the non-aluminized one had more unfavorable evaluations for water and stain resistances.

Satisfaction/dissatisfaction for PPE's design and function

Table 5 shows responses to dissatisfaction with PPE. City A firefighters complained that 'it is difficult to take off rubber boots after firefighting' (19.4%), 'helmet and mask obstructs the field of vision' (18.4%), 'SCBA is too heavy' (9.8%) and 'wet gloves cause decreases in wearer mobility' (9.6%). For City B firefighters, 'helmet and mask obstructs the field of vision' (24.2%) was ranked highest and 'it is difficult to take off rubber boots after firefighting' (16.9%), 'wet gloves cause decreases in wearer mobility' (15.4%) and 'helmet bumped against SCBA' (12.0%) were ranked in order. Most firefighters from both cities (68.0%) demanded improvements in PPE. A total of 81.0% of City A firefighters had demands for improvements in their equipment such as SCBA and other accessories, and 74.5% of City B firefighters demanded improvements in equipment such as SCBA and other accessories.

Discussion

Work duration per incident

Our questionnaire contains questions to provide basic information on the time duration of a trial for developing a standard test method. City A firefighters spent 56.6 min on average on an incident and were fully equipped and exposed with PPE for 22.5 min. For City B, firefighters wore the full set of PPE for 27.3 min of a total of 83.7 min

Table 5. Responses of dissatisfaction with PPE

Q. Please choose items describing your dissatisfaction with the current firefighter PPE. (Multiple choices are allowed)		
	City A	City B
Personal tools, including a belt and a rope, are obstacles against moving	114 (8.1)	93 (4.4)
Wet gloves cause decreases in wearer mobility	134 (9.6)	326 (15.4)
Helmet and mask obstructs the field of vision	258 (18.4)	512 (24.2)
Helmet bumps against SCBA	64 (4.6)	254 (12.0)
SCBA is too heavy	138 (9.8)	88 (4.2)
Weight of SCBA causes backache (lumbago)	84 (6.0)	109 (5.1)
Weight of SCBA causes shoulder pain	93 (6.6)	195 (9.2)
Weight of rubber boots cause an uncomfortable feeling while walking	111 (7.9)	86 (4.1)
Rubber boots cause sweating of the feet	79 (5.6)	60 (2.8)
It is difficult to take off rubber boots after firefighting	272 (19.4)	359 (16.9)
Others	56 (4.0)	38 (1.8)
Sum of cases	1,403 (100)	2,120 (100)

Values are expressed as frequency (%); χ^2=214.163, p<0.001for differences between cities.

on average. It is likely that area specialty and PPE features resulted in such differences in the total working time per incident. City B is a more spacious and complicated urban than City A. City B firefighters wear the non-aluminized PPE, while the Fire Department of City A provides aluminized PPE. For those reasons, City B firefighters might spend a longer time for one incident. On average, Japanese firefighters spent 65.9 min on an incident and 24.2 min was required for the suppression of a fire with the full set of PPE. Also, 64.9% of Japanese firefighters (419 of 646 responders) finished fire suppression within 30 min with the full set of PPE. These results indicate that experimental protocols of a standard test method need to be designed that include about 20–30 min of exercise when evaluating firefighters wearing the full set of PPE. Over 30 min of exercise with a full set of PPE is not necessary.

Subjective heat strain

The month and time zones in which heat strain was most frequently experienced were August and between 2 and 3pm for both cities. Mean air temperature and relative humidity around 2–3 pm in August were 33.2 ± 1.7°C and 57 ± 9% RH and 32.2 ± 1.7°C and 57 ± 7% RH for City A and B, respectively[18], with no significant differences between cities. However, our survey reported that City A firefighters (57.5%) experienced more heat strain than City B firefighters (28.4%). Such differences are not explainable by climate differences in summer or work duration per incident between the two cities. It is likely that the difference in the experience of heat strain is partly attributable to the different design and materials of PPE between City A (fire jacket covered with aluminum) and City B (non-aluminized jacket).

Wearer mobility

For Japanese Fire Departments, each district can choose their own PPE. PPEs chosen by City A and B differ from each other in design, color, combination of materials, and fluorescent tape trimmings. As described Table 1, a big difference in PPE between City A and Bwas whether or not the fire jackethadaluminum lamination. Our survey showed that the aluminized jacket of City A, which was originally laminated to protect wearers from radiant heat and flames to avoid burns, provided better water resistance, donning/doffing, antifouling function, function of getting stains out, and tolerance to wetness. In particular, City A fireifghetrs were satisfied with its water and stain resistance of their aluminized PPC, but complained of low ventilation and more restricted mobility. City A Firefighters stated that the poor flexiblity of the aluminized firejacket most likely causedrestricted mobility (Fig. 2). In other words, our survey showed that the aluminized PPC causedreduced wearer mobility due to its poor flexibility as well as more aggravated heat starin, when compared to the non-aluminized PPC.

Muscle fatigue and injury related to PPE

The present study found that frequently-fatigued body parts were the ‘waist’, ‘shoulder’, and ‘arm’. It has been reported that the waist and low back are the most discomforted and fatigued body regions due to exposure to workload with PPE[19]. We also found that the ‘hand’, ‘waist’,

and 'ankle and foot' were frequently injured body parts (Fig. 1). The causes of such muscle fatigue and injuries were falls, slips, and trips according to personally appended comments in the questionnaire. Karter and Molis mentioned that over 20% of injuries in the US commonly occurred due to deteriorations in balance ability such as falls, jumps, trips, and slips[20, 21]. Recently, Adams evaluated balance ability using a postural test method at rest and in working conditions with three different types of PPE[22], and found significant differences in balance variation with different types of PPE. Son and colleagues investigated the effects of different weights and designs of SCBA on balance ability using a postural and functional test[23]. They found that over 10 kg of SCBA impaired balance ability. Both firefighters of City A and B responded their dissatisfaction with obstructed fields of visions. An obstructed field of vision decreases balance ability. Previous studies reported that sway length and area in an 'eyes closed' condition would be wider and longer than results in an 'eyes open' condition[19, 23, 24]. Therefore, balance ability of firefighters should be maintained at a good level while firefighting with PPE and more studies about balance ability with PPE are required for firefighter safety. Also, our survey strongly suggests that the assessment of balance ability with PPE should be accepted as a measurement for the standard of firefighter mobility.

Restricted body parts due to PPE

Both firefighter groups of City A and B appealed that the knee and arm (shoulder, elbow and wrist) ranked highest for being terribly restricted (Table 4), and as parts that experience muscle fatigue due to PPE while firefighting (Fig. 1). According to Kincl and colleagues, the discomfort response rate of the lower body was high when wearing PPE[19]. Huang and coworkers found that over 60% of firefighters (N=1,177) chose 'difficulty of movement' as their main problem and the most restricted parts due to PPE were the thigh, knee, and arm[16]. Activities while firefighting requires a wide ROM and a lot of joint motion in the arms and legs and PPE resulted in more restricted mobility and intensified physical strain. Restricted body parts, which were reported in the present study, are considered to be unfavorable combined effects of PPE`s weight, design, and various activities with a wide ROM.

Mobility countermeasures

There was a clear difference in PPE regulations for mobility countermeasures between the two cities (Table 3). City B firefighters were officially allowed to wear suspenders in the field, whereas City A firefighters were banned from wearing suspenders during firefighting activities. It has been reported that wearing suspenders increases ventilation[25]. The present study investigated whether suspenders improved a firefighter's mobility or not. A quarter of CityA firefighters wished to use suspenders to improve their mobility, whileCity B firefighters answered that 'wear PPE that fits' was the best countermeasure for improving wearer mobility (because their PPE are already equipped with suspenders). It is likely that suspenders or the fit is related to responses on restricted body regions due to PPE. City B firefighters responded that they had more experience of restricted body regions due to PPE in the lower body than City A firefighters, as shown in Table 4. These differences suggest that suspenders, worn as a countermeasure to improve mobility, may perform a role in restricted mobility, especially, in the lower body.

Conclusions

The present study aimed to investigate differences in work environments, physical strain, wearer mobility, and satisfaction between Japanese firefighters wearing aluminized and non-aluminized PPE. We ascertained that aluminized PPE is related to reduced wearer mobility as well as more aggravated heat strain, which is attributable to the worse ventilation and poorer flexibility of the aluminized jacket. Secondly, Japanese firefighters spent 65.9 min on one incident and 24.2 min for suppression of fire with the full set of PPE on average, which is applied for the development of a standard test method to evaluate the heat strain of firefighters' PPE. These results signify that about 20–30 min of exercising in a hot environment is recommended for chamber experiments to evaluate the physiological and physical strains of firefighters wearing PPE. Further, when recruiting any aluminized PPE for the standard test, it should be considered that the work duration was shorter for the City A firefighters wearing the aluminized PPE. Thirdly, we suggest that a standard test method to evaluate wearer mobility should be created. This test should be distinguishable from the test methods for heat strain, considering muscle fatigue/restricted body parts, the field of vision, the use of suspenders and the degree of PPE fit, in terms of ROM, balance tests and proper rating scales for firefighting motions and activities. Fourthly, it is important to remember that the data in this study was collected from Japanese firefighters. When developing a standard test method internationally applicable, more investigations through international collaboration are

needed in order to study a broader range of international subjects.

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