Applied Ergonomics 45 (2014) 1019–1027

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Comparison of firefighters and non-firefighters and the test methods used regarding the effects of personal protective equipment on individual mobility

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ARTICLE INFO

Article history:
Received 11 April 2013
Accepted 23 December 2013

Keywords:
Personal protective equipment
Test methods
Mobility

ABSTRACT

The aims of this study were 1) to evaluate the current pilot test method and ascertain reliable measurements for a standard test method of mobility with personal protective equipment (PPE), such as physical performance and balance ability tests; 2) to compare two participant groups (firefighters versus non-firefighters) and to investigate whether non-firefighters are appropriate as a standard participant group in the field of PPE or not. Totally, 18 participants (nine professional firefighters and nine untrained males) performed the current pilot test method consisting of a balance test, completed prior to and after a performance test. Significant differences were found between PPE conditions and CON (the control clothing ensemble: T-shirt, shorts, and running shoes) for the functional balance test, physical performance test, heart rate, and subjective evaluations in firefighters group. Therefore, the present pilot test method is valid as a standard test method for assessing mobility while wearing PPE. Moreover, the present result shows that firefighters are more reliable than non-firefighters in testing of PPE with current test methods.

1. Introduction

Firefighting is one of the most hazardous occupations and is associated with exceedingly high rates of injuries. Average of 38,660 American firefighter injuries occurred at the fire site (Karter, 2012). Therefore, firefighters require not only good physical capabilities but also sufficient mobility in their active work while firefighting at a high temperature and humidity with heavy personal protective equipment (PPE). PPE, which is composed of personal protective clothing (PPC) and accessories such as a self-contained breathing apparatus (SCBA), helmet, mask, gloves and boots, is necessary to protect firefighters from various occupational hazards such as fire on the high-storied and sealed buildings. In this regard, the assessment of PPE in terms of wearer mobility, as well as protective functions, is required. Although PPE aims to protect firefighters from physical and chemical harm, firefighters can become fatigued by impeded movement due to the weight and bulky nature of the multiple layers.

Therefore, studies into firefighter PPE are performed frequently. Previous studies have reported that firefighters experienced physiological strain when performing at a simulated fire site and during firefighting activities with PPE in hot and humid environments (Griefahn et al., 2003; Bakri et al., 2012). However, relatively few studies have reported on mobility with different designs and weight of PPE during firefighting activities, and Range of motion (ROM) and subjective evaluations are generally used to assess mobility in previous studies. According to previous studies, ROM of each body part was changed due to PPE designs (Coca et al., 2008, 2010; Huck, 1988, 1991), and decreased by weight of PPE and friction of wet PPE (Son et al., 2010).

There are several international standards for evaluating firefighters' PPE, but these standards are merely assigned to the heat, flame, and water resistant properties of PPE (CEN TC 162, 2002; EN 469, 2005; ISO 11613, 1999). Furthermore, few test methods for assessing mobility while wearing PPE have been established (BS 8469, 2007; CEN TC 162, 2002). Without a standard method for mobility, the comparison of several types of PPE from different research groups may lead to inaccurate interpretations. Therefore, research on a standard method for assessing the mobility of PPE is required.

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http://dx.doi.org/10.1016/j.apergo.2013.12.006

From the 1970s, many studies have been performed on firefighting drills which consist of dynamic movement such as ladder drill, pulling a hose, rescue, forcible entry, and stair climbing. These are carried out as essential movements for firefighting (Gledhill and Jamnik, 1992; Smith et al., 2001; Williford et al., 1999). However, the previous research groups have merely studied the demands on firefighters using these movements. They reported the physiological responses of PPE wearers such as heart rate (HR) and metabolic demands. The mobility during firefighting drill was not evaluated in previous studies. Referring to survey of Japanese firefighters from Son et al. (2013), a large number of firefighters suffered injuries and restricted mobility due to failures in balance control (slips or falls) while wearing PPE. According to previous research, many firefighters have been injured by failing to control their balance (Karter, 2012). These reports suggest that a balance test with PPE is necessary. Therefore, for a standard method to evaluate mobility with different types of PPE, a combination of the physical performance test and functional balance test is required.

Previous studies on PPE recruited firefighters as participants (Bos et al., 2004; Coca et al., 2010; Plat et al., 2010; Smith et al., 1997; Williford et al., 1999). Also, non-firefighters were asked to perform the experiment as subjects (Huck 1988, 1991). However, the physical demands and abilities of firefighters and untrained volunteers are not same, and firefighters are more used to working with PPE than untrained subjects. Therefore, the results of previous studies could not be compared absolutely. Regarding this, we were curious as to whether untrained males, especially students are appropriate to study of standard test method for mobility with PPE. To resolve this, comparison or evaluation of participant groups is also required.

The pilot test method consisted of several measurements such as a physical performance test which was composed of a general physical fitness test and simple firefighting drills and the balance ability test, made for developing a standard test for assessing the mobility while wearing PPE in the present study. The aim of this study was to evaluate the current pilot test method and ascertain reliable measurements for developing a standard test method of mobility with PPE. The other aim was to compare two participant groups (firefighters versus non-firefighters) and to investigate whether non-firefighters are appropriate as a standard participant group in the field of PPE or not.

2. Methods

2.1. Physical characteristics of participants and clothing conditions

Nine healthy Japanese professional firefighters (FFT) and nine healthy males (NFT) untrained for firefighting, performed physical performance and balance tests in this study. Participants of both groups had similar physical characteristics. For FFT, age, height, body mass, and body mass index were28.6 ± 2.4 yrs, 172.4 ± 5.9 cm, 69.4 ± 5.1 kg, and 23.4 ± 1.4 kg m^{-2}, respectively (Mean ± SD). The age, height, body mass, and body mass index of NFT were 26.6 ± 4.3 yrs, 173.6 ± 6.1 cm, 69.2 ± 7.6 kg, and 22.9 ± 1.6 kg m^{-2}, respectively (Mean ± SD). There were no significant differences in anthropometric data between FFT and NFT.

Participants undertook physical and balance tests using three types of PPE and a control condition (CON) wearing a T-shirt, shorts, and running shoes (total weight was 1.0 kg). According to Son et al. (2013), firefighters are working on the fire scene with the full set of PPE. Therefore, three types of full structural firefighting PPE sets, not wild land, rural or bushfire PPE sets, were used in the present study. Table 1 summarizes the specifications of the three types of PPE, and shows figures for PPEs. Type A comprised an aromatic polyamide upper fire coat and aromatic polyamide long pants in addition to a helmet, boots, gloves, belt, underwear, socks, and normal uniform. PPC for Type A was treated with a flame retardant. Type B comprised an aromatic polyamide upper fire coat and aromatic polyamide long pants in addition to a helmet, boots, gloves, belt, underwear, socks, and normal uniform, and PPC was also treated with flame retardant. However, the surface of type B's fire jacket was coated with a layer of aluminum. Types A and B were developed and used in Japan. Type C comprised an upper fire coat and long pants in addition to a helmet, boots, gloves, belt, underwear, socks, and normal uniform. Hainsworth TITAN and Gore-tex were used for the fire coat and pants. The fire pants of type C had suspenders, thus the wearer could control their fit. Type C was developed and is used in Europe. 11 kg of SCBA was worn for all PPE conditions.

Table 1
Specifications of three types of PPE.

Clothing and equipments properties		Type A	Type B	Type C
Upper	Base material	Aromatic polyamide	Aromatic polyamide	Hainsworth TITAN and Gore-tex
	Weight	1.5 kg	1.9 kg	1.5 kg
	Surface coating	–	Aluminum	–
Lower	Base material	Aromatic polyamide	Aromatic polyamide	Hainsworth TITAN and Gore-tex
	Weight	1.2 kg	1.0 kg	1.5 kg
	Surface coating	–	–	–
	Suspenders	No	No	Yes
Helmet weight		0.9 kg	0.9 kg	1.4 kg
Boots weight		2.2 kg	2.2 kg	2.8 kg
Gloves weight		0.12 kg	0.12 kg	0.3 kg
Total PPE[a] weight (PPC[b] + SCBA[c])		19.2 kg (8.2 kg + 11.0 kg)	19.4 kg (8.4 kg + 11.0 kg)	20.8 kg (9.8 kg + 11.0 kg)
				

[a] PPE=Personal protective equipment.
[b] PPC=Personal protective clothing (with station uniform: 0.7 kg, short: 0.2 kg, T-shirts: 0.2 kg, socks: 0.05 kg, belt: 0.1 kg, rope: 1.0 kg).
[c] SCBA= Self-contained breathing apparatus.