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# Anthropometric fit evaluation of firefighters' uniform pants: A sex comparison

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ABSTRACT

This study identified anthropometric fit issues associated with a female firefighter's uniform pants. Eighteen firefighters (nine females and nine males) participated in a multidimensional fit assessment protocol, consisting of a subjective comfort survey, 3D body scanning, and exit interview. Mann–Whitney *U* tests were performed to compare sex differences in the survey and 3D scan data, along with descriptive and qualitative analyses. Female firefighters showed significantly lower survey ratings on overall satisfaction, perceived comfort, and performance of their turnout pants. Three-dimensional body scan data affirmed anatomical sex differences in baseline body measurements, and determined specific landmark areas that caused discomfort in female firefighters while wearing station and turnout pants. Interview data supported the findings from the quantitative measures. Results demonstrated that female firefighters experienced poorer fit and a higher level of discomfort with their uniform pants than male firefighters. The outcomes of this study suggest scientific evidence of the anthropometric fit problems associated with firefighter PPE, which is anticipated to help policymakers and the manufacturing industry enhance occupational safety regulations and improve fit and sizing systems especially for female firefighters who wear uniforms designed based on the male physique.



## 1. Introduction

Firefighting is a necessary, critical, and challenging occupation that requires firefighters to perform physically demanding tasks in hazardous environmental conditions (Broorady et al., 2013a). In contemporary society, firefighters' occupational safety has become at higher risk than before, as modern construction materials burn at higher temperatures and speed (Hasenmeier, 2008), and they are expected to go deeper and stay longer at a burn site with improved firefighting tactics (Broorady et al., 2013a). Given the evolving trends, wearing appropriate personal protective equipment (PPE) is crucial to protect firefighters from the occupational hazards. While PPE provides essential protection, added layers of thermal and respiratory protective equipment result in extra weight and bulkiness, which negatively affect firefighters' physical and physiological performance and, thus, their occupational functioning and efficiency (Bakri et al., 2012; Bruce-Low et al., 2007; Carlton and Orr, 2014; Young et al., 2014).

The demographic of firefighters also has changed and the field of firefighting has become a career path for women. Based on statistics from the National Fire Protection Association (NFPA, 2015), the number of women serving as structural firefighters in the United States has increased from 1700 (1%) in 1983 to 10,000 (3.4%) in 2012, with a peak in 2007 of 15,000 (5.2%). Despite the increased number of female firefighters, firefighting is still a male-dominant occupation, and, as a result, female firefighters wear uniforms designed for men (Broorady et al., 2013b). While most PPE studies have focused on thermal protection and heat stress (e.g., Holmér, 1995; McLellan and Selkirk, 2004; Raimundo and Figueiredo, 2009) and the impact of a self-contained breathing apparatus (SCBA) on stability, balance, and job performance (e.g., Park et al., 2010; Sobeih et al., 2006), few studies have addressed the fit issues of PPE that female firefighters experience (e.g., Bakri et al., 2012; Coca et al., 2011). Previous studies are predominately descriptive in nature, based on interviews, surveys, and questionnaires of firefighters (Broorady et al., 2013a,b; Hulett et al., 2008; Shuster, 2000; Sinden et al., 2013). However, these approaches only represent the participant's subjective evaluations of fit and comfort, and narrative expressions of female firefighters, without scientific evidence, are often considered as complaints, not

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legitimate arguments.

To date, no empirical research has been conducted to evince occupational concerns of female firefighters associated with the fit of PPE, based on objective scientific data. Therefore, this study aimed to (a) identify fit issues of the female firefighter's uniform and (b) determine specific areas on the uniform that cause fit issues, based on a comprehensive anthropometric fit analysis using 3D body scanning technology, as well as the survey and interview methods. The ultimate goal of this study was to demonstrate the necessity of sex-specific uniform designs to facilitate better fit and comfort for female firefighters.

Firefighter PPE is a combination of multiple clothing and accessory items, including turnout jacket, turnout pants, boots, gloves, helmet, face mask, hood, and a self-contained breathing apparatus (SCBA). Additionally, firefighters typically wear a station uniform under the turnout jacket and pants as the inner layer of the protective clothing ensemble. To set a parameter of the experiment, the firefighter's pants were selected for this study as a particular PPE item to investigate. According to a recent report on firefighter injuries issued by NFPA (Haynes and Molis, 2015), in 2014, approximately 63,350 firefighters were injured in the line of duty, and 42.6% of the injuries occurred on the fireground. Muscle strains or sprains accounted for 52.6% of moderate and severe injuries, followed by wounds, cuts, bleeding, and bruises (13.6%). Slips, trips, and falls were the most leading cause (28.7%) of firefighter injuries. These statistical data indicate that firefighters are particularly vulnerable to slips, trips, and falls on uneven or slippery surfaces, which are probable consequences of lack of lower body motion. In previous studies (Hulett et al., 2008; Broorady et al., 2013b; Park and Hahn, 2014; Sinden et al., 2013), female firefighters have mentioned turnout pants as a specific PPE item that often causes mobility problems while performing firefighting tasks such as climbing ladders, dragging hoses, entering/exiting emergency vehicles, etc. (Guidotti, 1992). For example, in Broorady et al.'s (2013b) focus group study, female firefighters commented on the uniform pants, saying the length was too long and the waist was too large. In the study, female firefighters described the wearing experience of the uniform pants as “terrible.” In another qualitative study (Sinden et al., 2013) based on phone interviews with four female firefighters, it was acknowledged that the critical elements of the firefighting PPE, especially pants, were too large, fitted loosely, and better suited for males. Furthermore, according to Park & Hahn (2014), which conducted online surveys with 516 US and Canadian firefighters, female firefighters showed significantly lower satisfaction with the pants' length while walking and bending, and reported significantly lower satisfaction with the pants' fit around the crotch, hips, and waist, relative to their male counterparts. These findings from the previous studies lend a strong justification to the selection of uniform pants, including turnout and station pants, as the focus of this study.

## 2. Methods

### 2.1. Study participants

Structural firefighters of both sexes, who had a minimum of 12 months of firefighting experience and had no musculoskeletal problems, were recruited. To control the variance of the uniform size between the sexes, the matched-sampling strategy was employed. Stuart and Rubin (2007) suggested the matching method as an effective means for a small case-control sample to replicate, as closely as possible, the ideal of randomized experiments. The pants' waist was chosen as the matching variable because it is the most common measurement in determining pants' fit (Keiser and Garner, 2012). That is, with Institutional Review Board (IRB) approval from the researchers' university, firefighters were recruited through fire departments located in the Western region of the United States, as well as a website for female firefighters (FireWomen.org). An e-mail was first sent to the contact representative at a fire department to introduce the scope of the study and request assistance in forwarding a recruitment letter to firefighters. The recruitment letter provided details about the project and contact information of the researchers. Ten female firefighters contacted the researchers, expressed their interest in the study, and scheduled an appointment to visit the research lab. Except for one firefighter, who declined her participation due to a personal reason, nine female firefighters ($N = 9$) actually participated in this study. Male firefighters were recruited as a control group. The mean and median ($50^{th}$ percentile) of the female pants size were used for sample matching. The mean pants' waist of the recruited female firefighters was 32 in. ($SD = 3.16$), and the median was also 32 in. Nine male firefighters ($N = 9$) were recruited, whose mean pants' waist was 32.8 in. ($SD = 1.45$) with 32 in. at the $50^{th}$ percentile of the waist measurement. In total, 18 firefighters (nine females and nine males) were recruited, and they represented five different locations within the region, including diverse urban/rural settings from a metropolitan city to a small, rural town. All participating firefighters were asked to bring their own station pants and turnout pants to their scheduled visit.

Table 1 summarizes the demographics and firefighting experience of the participants. The average age of the recruited female firefighters was 42.6, while that of male firefighters was 33.3. The average physical profiles of female participants, based on the self-reported height and weight, were 65.8 in. in height (5 feet 5.8 in., 167.1 cm) and 145. 7 lbs. (66.1 kg), while the male participants were 71 in. tall (5 feet 11 in., 180.3 cm) and 183.9 lbs. (83.4 kg). The average body mass index (BMI) for females was 23.6 kg/m$^2$ and that of males was 25.8 kg/m$^2$. All nine female firefighters were career firefighters, while seven male firefighters were career and two were volunteer firefighters. The female firefighters' average years of firefighting service were 16 years and 3 months, and those of male firefighters were 7 years and 5 months. All participants were Caucasian Americans.

### 2.2. Experimental design and procedure

This study explored a multidimensional measurement protocol to evaluate current fit issues associated with female firefighters' uniform pants in the form of (a) subjective evaluations via a survey, (b) 3D body scanning, and (c) exit interviews. Qualitative and quantitative data collection methods were used to gain a holistic understanding of the fit and comfort perception of their uniform pants among the participants. The participants' body dimensions were captured using a 3D body scanner. Three-dimensional scan data were analyzed by comparing body measurements of the male and female participants wearing various levels of their uniform pants. The participants were encouraged to openly comment on their uniform pants during the experiment and at an exit interview. Each participant participated in an hour-long experiment total.

#### 2.2.1. Subjective evaluations

The survey questionnaire, developed for this study, was administered to evaluate the firefighter's experience of wearing their current uniform pants. The questionnaire included a total of 54 questions asking about their subjective evaluations of the current uniform pants as well as demographic and occupational background (i.e., sex, age, height, weight, clothing/shoe size, type of firefighter, job title, department name, and years of service). Additionally, the survey asked about the age and alteration history of the uniform pants that the participants have made. Participants