### THESIS

# ANTHROPOMETRIC FIT EVALUATION OF STRUCTURAL FIREFIGHTERS' PROTECTIVE PANTS: A GENDER COMPARISION STUDY

Submitted by

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#### ABSTRACT

# ANTHROPOMETRIC FIT EVALUATION OF STRUCTURAL FIREFIGHTERS' PROTECTIVE PANTS: A GENDER COMPARISON STUDY

This study identified fit issues associated with the female firefighter's station and turnout pants, in comparison to male firefighters. Fifteen firefighters (9 females, 6 males) participated in a multi-dimensional fit evaluation protocol; including a survey, 3D body scanning, joint angle measurement and an exit interview. Female firefighters showed, through the survey, significantly lower ratings on overall satisfaction, comfort, mobility, and performance of their protective pants. Anthropometric data, generated from 3D body scanning, confirmed a congruent trend of the fit issues to the survey data. The joint angle measurement determined decreased range of motion (ROM) for females during simulated occupational activities. Results affirmed that female firefighters experience poorer fit and a higher level of discomfort than male firefighters, while wearing uniform pants designed for the male physique. This study suggests important implications to the firefighting industry, policy makers, and researchers involved in improving protective clothing to enhance occupational safety of firefighters.

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# DEFINITION OF TERMS

Anthropometrics	The gathering and analysis of human measurement (Stirling, 2002,
	p. 5).
Comfort	Pleasant state of physiological, psychological and physical
	harmony between a human being and the environment (Slater,
	1986, p. 158).
3D Body Scan	An industrial tool to measure and compare three-dimensional
	objects at varying stages of assembly for the process of product
	development (Ashdown, et al., 2004, p. 1).
Fit	Fit usually has two aspects: comfort (decided by the wearer) and
	appearance (look, style, and fashion, as decided by the designer or
	manufacturer) (Boorady, 2011, p. 344).
Functional Ease	The need of a garment to accommodate and adapt to the user's
	movement (Broorady, 2011, p. 345).
Goniometer	The measurement of angles, in particular the measurement of
	angles created at human joints by the bones of the body." (Norkin
	& White, 2009, p.3). A goniometer is a measurement instrument
	used to determine joint angles.
PPE	Personal protective equipment, commonly referred to as PPE, is
	equipment worn to minimize exposure to a variety of hazards.
	Examples of PPE include such items as gloves, foot and eye
	protection, protective hearing devices (earplugs, muffs) hard hats,
	respirators and full body suits (OSHA).

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	Personal protective equipment for structural firefighters typically
	consists of coat, pants, boots, hood, gloves and helmet along with a
	self-contained breathing apparatus when needed (Park et al., 2011).
Range of motion	The arc of motion that occurs at a joint or series of joints. Range
	of motion is measured using a degree (0-180 or 180-0 system).
	(Norkin & White, 2009, p. 6).

- Station pants
  Traditionally a flat-front, twill pant in navy blue often coated to increase durability, flame resistance and liquid resistance.
  Firefighters wear station pants to public events, at the station and on emergency calls when their full turnout uniform is not required (O & Stull, 2014).
- Turnout uniform Firefighters' coat, pants, boots, hood, helmet and gloves that meet the NFPA 1971 standard. Turnout uniform is also referred to as bunker gear (Boorady et al., 2013).

#### **CHAPTER 1: INTRODUCTION**

#### 1.1 Background & Justification

Structural firefighting is a necessary, critical, and challenging occupation that requires the firefighter to perform several physically demanding tasks in hazardous environmental conditions (Broorady, Barker, Lee, Lin, Cho, & Ashdown, 2013a). Since its' inception, the fighting of fires, the scope of duties of firefighters, and the demographic of firefighters has evolved. The changes in the occupation have prompted scholars and designers to examine the turnout uniforms, particularly the protective coat and pants worn by firefighters, for fit and effectiveness. The turnout uniform is important as, according to studies, without the correct fit of functional garments, mobility, safety, and efficiency for the worker is compromised (Hasio, 2013; Hulett, Bendick, Thomas, & Moccio, 2008; Jahnke, Poston, Haddock, Jitnarin, Hyder, & Horvath, 2012; Mordecai & Freeman, 2012). Firefighters in particular work in demanding environments and require properly fitting turnout uniforms for their safety and also for their occupational performance affecting the safety of others (Park & Hahn, 2014).

The turnout uniform is critical because fires are more dangerous than they have been in the past. Due to the use of modern construction materials, they burn at higher temperatures and with increased speed (Hasenmeier, 2008). Firefighters use improved tactics to approach fires from within buildings, not solely attacking fires from the outside as more typical of the past (Angle, Harlow, Gala, & Lombardo, 2013). As a result, they go deeper and stay longer at a burn site (Boorady, et al., 2013a). More dangerous fires require uniforms with added thermal protection; therefore research attention has been given to increasing the thermal protection of the

firefighters' protective coat and pants (Mell & Lawson, 2000; Braker, Guerth-Schacher, Grimes, & Hamouda, 2006; Lawson, 1997; Lee & Barker, 1987).

Firefighter duties currently go beyond fighting fires. Firefighters are called upon to rescue people and animals, protect property, protect natural resources, and are "First Responders" in car accidents and hazardous material incidents. The tasks of the firefighters are performed in uniform, and depending on the emergency situation, their extended duties can require extreme physical mobility. They frequently climb ladders, drag hose, enter and exit large emergency vehicles, crouch, and crawl; thus, uniforms that allow for mobility are critical to the effectiveness of their performance and to their safety, (Guidotti, 1992). Studies suggest that the added bulk resulting from increased thermal protection could decrease the wearer's mobility needed in performing a variety of the firefighters' duties (Dorman & Havenith, 2009; Coca, Williams, Roberge, & Powell, 2010). Park and Han (2014) claim the reduced mobility in firefighters' turnout uniforms adds stress to their job, which is supported by other studies (Boorady et al., 2013a; Cocoa et al., 2010; Son, Bakri, Muraki, & Tochihara, 2014).

Finally, the demographic of firefighters has changed and it has become a chosen career path for women. Based on statistics from the National Fire Protection Association (NFPA), the number of women serving as structural firefighters has increased from 1,700 (1%) in 1983 to 10,000 (3.4%) in 2012, with a peak in 2007 of 15,000 (5.2%). These female firefighters with limited exception, currently wear protective uniforms designed for men (Broorady, Barker, Lee, Lin, Cho, & Ashdown, 2013b). According to previous research, incorrectly sized and ill-fitting PPE, most often the fit of firefighter turnout pants, affects both job satisfaction and job performance (Boorady, et al., 2013b; Hulett et al., 2008; Sinden, MacDermid, Buckman, Davis, Matthews, &Viola, 2011). Few research studies, however, specifically address the fit of

protective uniforms for female firefighters. The previous scholarly work is predominantly descriptive in nature, based on interviews, surveys, and questionnaires of female firefighters (Boorady, et al., 2013b; Hulett et al., 2008; Shuster, 1999; Sinden et al., 2011). Given the increasing numbers of females in this profession, their reported problems with ill-fitting clothing, and the lack of attention on female firefighters and their uniforms, more empirical research is needed to help them perform these significant and necessary duties efficiently and safely.

In that firefighters are critically important to the safety, health and well-being of a society, it is paramount to support their safety, effectiveness and overall satisfaction with their occupation. The evolution of firefighting to include more dangerous fires, duties beyond fighting fires, and an influx of female firefighters has created scholarly interest in their turnout uniforms. Research has supported changes in the thermal protection and prompted studies in mobility to allow firefighters to perform more effectively and safely. However, few studies have specifically addressed the particular needs of female firefighters and the fit of their protective clothing. This research considers the current protective clothing, specifically the station and turnout pants, worn by structural firefighters and compares the fit and comfort between the genders.

#### 1.2 Purpose

The purpose of this study was to (a) identify fit issues associated with the firefighter's station and turnout pants, particularly for female firefighters, and (b) determine specific areas on the uniform pants that cause the fit issues through: a participant survey, 3D body scanning, measurement of lower-body joint angles, and qualitative feedback. The ultimate goal of this study was to demonstrate the necessity of gender-specific uniform designs for firefighters to facilitate better fit and comfort to female firefighters.

#### 1.3 Research Questions and Hypothesis

The research questions that serve as the basis of this study are as follows:

# **RQ1:** What are the major fit issues and concerns associated with the firefighter's uniform pants as experienced by female firefighters?

H1: As compared to male firefighters, female firefighters experience lower satisfaction with the overall fit and comfort of their station and turnout pants.

## **RQ2:** What specific areas of firefighter uniform pants express poor fit for female

#### firefighters?

H2: As compared to male firefighters, female firefighters demonstrate poor fit in 8 identified critical measurement areas (waist, hips, upper thigh, knee, calf, ankle, inseam, pant rise), while wearing their station and turnout pants.

#### CHAPTER TWO: REVIEW OF LITERATURE

#### 2.1 Turnout Gear for Firefighters

Firefighters in the United States are required to utilize PPE that has been designed and manufactured to meet the National Fire Protection Association (NFPA) 1971 standard. PPE includes: a turnout coat, pants, boots, hood, gloves and helmet. Firefighters may also carry a self-contained breathing apparatus (SCBA) that offers an external air supply (Broorady et al., 2013a). The turnout coat and pants are typically constructed with three functional layers for increased protection: an outer shell, a moisture barrier, and a thermal liner. The outer shell is designed for protection against heat shock and is made of fire-resistant materials. The moisture barrier layer is used to minimize penetration of water from the outside environment to inside layers and is usually produced with breathable, water-resistant textiles. The thermal barrier layer serves to protect the firefighter's body from the heat intensity (Huang, Yang, Qi, Xu, Chen, Li, & Zhang, 2011). Station pants are commonly worn under the turnout ensemble as an added layer of fire-resistant protection. These pants, often made of Nomax or twill construction, offer no stretch or flexibility. Traditionally, station pants serve as a work-pant that offer a preliminary level of protection for mechanical, medical and basic duties. In addition, station pants provide a professional appearance for public engagements (O & Stull, 2014).

Firefighters are required to wear the brand and style of turnout gear as chosen by their station or department. There may be freedom for firefighters to choose their own accessories (helmet, boots, gloves, tools), but that often comes at the expense of purchasing the items themselves. With the many elements of a firefighter uniform, choosing the right combination of gear to wear may be a complex and difficult process (Boorady et al., 2013a). The National Fire Protection Association (NFPA) has developed a set of standards (No. 1971) on turnout gear to

address some of the complexity of firefighters' functional garments. These standards require availability of sizes for chest, sleeve, waist and inseam and also address the interface, or overlap, between the jacket and pants to ensure thermal protection and keep the wearer safe. However, the NFPA standards do not account for the difference in body shape, do not address gender specific issues, and do not guarantee a proper fit for each individual. Consequently, many firefighters are still donning garments with poor fit despite the NFPA standards on protective garments worn in structural firefighting (Mordecai & Freeman, 2012)

Turnout gear has advanced over the years due to increased attention from scholars and designers. The majority of changes have been focused on increasing thermal protection with the goal of protecting firefighters as they go deeper and stay longer at hazardous site. The use of modern building materials has resulted in hotter, more dangerous fires than ever before and a demand for increased fire protection. However, previous studies suggest that increased thermal protection adds bulk and weight to turnout gear, and increases firefighters' discomfort by reducing their mobility. Dorman and Havenith (2009) conducted a study that evaluated a variety of personal protective uniforms, across multiple industries, to understand the relationship between personal protective clothing (PPC) and energy consumption (oxygen consumption) during different occupational activities. They noted that the two heaviest garments they tested were the firefighting uniforms (two different structural firefighting uniform models were evaluated) and stated that a side effect of PPC is that it "adds a load on the body, reduces mobility due to stiffness bulk and poor fit" (p.1). Coca and his colleagues (2010) performed a study that evaluated change in range of motion (ROM) of participants while wearing a standard structural firefighting uniform. Their approach aimed to quantify ROM and evaluate the relationship between PPC and functional mobility of the wearer. Their sample was limited in

size, with 5 men and 3 women. Although they did not find any adverse effect in the overall functional mobility of the wearer, they did notice that the firefighter uniform limited wearer movement to some extent. Using semi-structured focus groups, Broorady et al. (2013a) explored the issues that male firefighters experience when wearing their PPE. Mobility was one of the identified main areas needing improvement. Specifically, male firefighters expressed that if their mobility was reduced, it hindered their ability to move quickly and a lack of moving quickly increased their stress. It is a daily challenge for firefighters to perform tasks while wearing a turnout ensemble and carrying equipment that commonly weights between 50 and 70 pounds while working in hazardous environments (Park & Hahn, 2014).

#### 2.2 Turnout Uniform for Female Firefighters

Overall, female firefighters have indicated more difficulty with their turnout gear than their male counterparts (Boorady et al., 2013b; Hulett et al., 2008; Shuster, 1999; Sinden et al., 2011). Female firefighters, with limited exception, currently wear turnout ensembles designed for men (Boorady et. al, 2013b). It is unrealistic to expect this gear to properly fit women due to differences in body shape and proportions between the sexes.

Results from the 1995 iWomen survey of 495 active female firefighters reported that 58% of participants function in their jobs with one or more items that did not fit properly. Of the 42% who said their gear fit, many reported that satisfaction was only achieved after voicing disapproval for an extended period of time (up to 15 years). In a 2008 study (Hulett, Thomas, & Moccio, 2008), 79.7% of female firefighters reported having experienced problems with poor fitting gear, while 20.9% of male firefighters reported so.

Turnout pants have, in particular, been identified as causing poor fit and reduced mobility for female firefighters (Hulett et al., 2008; Broorady et al., 2013b; Park & Hahn, 2014). Specific

areas that have been identified to cause dissatisfaction include pant waist, hips, crotch and leg length (Broorady et al., 2013b; Park & Hahn, 2014). Based on the iWomen survey (1995), 30% of the women whose turnout pants didn't fit, reported that they were too tight in the hips, thighs or waist. Other responses included concerns about the length of the rise being too low and it negatively affecting leg movement. Female firefighters from the 2013 (b) study conducted by Boorady et al. also reported dissatisfaction with the low crotch of their turnout pants; specifically that it hindered their ability to perform tasks that required squatting or stepping up. Congruent with previous findings, Park and Hahn (2014) also found that female firefighters showed a lower satisfaction with their turnout pants crotch, than their male co-workers. Sixty-seven firefighters (15 male, 52 female), out of 388 (F = 234, M = 154), reported that their turnout pant crotch is too low and bulky. In this same study, female firefighters reported the hip area caused discomfort, whereas no male participants reported the hip area as needing any improved development.

#### 2.3 Comfort and Fit in Firefighter Turnout Gear

Comfort is defined as "a pleasant state of physiological, psychological, and physical harmony between a human being and the environment" (Slater, 1986, p. 158). The feedback from each of the five senses, the working environment, and the attributes of textile garments may influence a sense of heightened or diminished comfort to each individual wearer. According to Akbar-Khazadeh and Bisesi (1995), individuals may experience a lack of comfort with PPE for a variety of reasons. The cause of discomfort may be a consequence of clothing adjustments due to ill-fitting garments to begin with and result in different, but continued discomfort. Discomfort can also be a result of the individual's opposition to wearing specific garments. Finally, discomfort can stem from reduced safety of the protective garment. Their study also noted that some workers demonstrated additional physical movement to compensate for their discomfort

and that their compensations affected and potentially endangered the worker's performance, efficiency, safety and expected protection.

Comfort is closely related to fit, as fit is traditionally referred to as a relationship between garment appearance and comfort. However, as fit applies to functional garments, a third aspect titled "functional ease" has been introduced (Boorady, 2011). Functional ease refers to the need of a garment to accommodate and adapt to the user's movement (Boorady, 2011). This aspect is especially important in physically demanding professions, such as firefighting, and has been of interest to a variety of researchers (Ashdown, Loker, Schoenfelder, & Lyman-Clarke, 2004; Boorady, 2011; Hsiao, 2013; Mordecai & Freeman, 2012). Fit is often analyzed and evaluated with the wearer in a static, upright position. However, according to Boorady (2011), it is important to evaluate body movement in conjunction with a functional garment and ensure that the garment allows and accommodates the movement demanded of the wearer. Functional garments, such as firefighters' turnout gear, serve a purpose that is of critical importance and that purpose may be at risk due to poor fit (Boorady et al., 2013a; Hsiao, 2013; Stirling, 2002). Boorady (2011) identifies ideal fit for functional garments when the clothing "...allows the body to function and neither restrict the wearer's movement not interfere with their required tasks" (p. 345).

#### 2.4 Body Dimensions

Determining fit, in general, is a challenge because of the diversity in human size and shape. It is particularly difficult for specific worker populations because the PPE standards for body dimensions, used in manufacturing, (e.g., NFPA standard 1971) are dated and were generated from military personnel in 1988 (Annis & McConvill, 1996). Furthermore, military populations were required to meet high fitness levels and as a result their physique reflects less

body fat than that of a general, civilian population. Recent studies report that current body dimensions, including height and weight, have changed and often increased (Routley, 2009; Stirling, 2002). The dated standards based on military personnel, and the challenge in the diversity of human size and shape pose a unique problem for fitting turn-out gear for present day firefighters.

Historically, size and shape differences between men and women have been poorly understood and overlooked in design (Annis & McConville, 1996). It was assumed that the average, or 50<sup>th</sup> percentile, females were essentially equivalent to males in the 5th percentile and that women were proportionately scaled down versions of men (Annis & McConville, 1996; Stirling, 2002). On the contrary, women are shaped significantly different than men as demonstrated in neck circumference, hip breadth, and finger length (Hulett et al., 2008, Stirling, 2002). On behalf of the Chief and Assistant Chief Fire Officer Association (CACFOA) Dr. Mary Stirling (2002) collected anthropometric data from 314 female firefighters in the UK. Anthropometric data includes measurements of body size, shape, and surface and assists in understanding a specific user population's needs. Stirling (2002) posits that if anthropometric information is taken into consideration during the design process, the end user is not constrained by having to adapt to what is provided. She notes the differences in the sexes and contends that females and males are different and that difference should be taken into account when designing turnout gear. For example, height is a measurement that is often used as a design criterion, but negates to articulate the torso length, leg length, posture, weight gain/loss or specific body positions (Ashdown et al., 2004). Although users may fit into average sized garments, the comfort and fit may be compromised especially when movement is required (Stirling, 2002). This performance compromise is supported by the Hulett et al. (2008) study of 175 female

firefighters through individual interviews and focus groups. The researchers' report 79.7% of the participants experienced difficulty with poor fitting equipment and garments. Specifically related to turnout gear were comments and complaints about gloves (57.8%), boots (46.8%), turnout/bunker coats (38.9%), and helmets (28.4%). Although pants were included in the general difficulty with poor fitting garments, no specific comments or complaints were given. Both studies (Hulett et al., 2008; Stirling, 2002) contend that the differences in males and females support the need for gender specific designs.

Also in support of gender specific design, Boorady et al. (2013b) research focused on the turnout gear needs of female firefighters. Information from 22 participants in seven focus groups across the U.S. suggested that female gear was: too long in spite of the correct circumference measurement and needed to be hiked up by suspenders, too long in the crotch because of design or stretched out suspenders, designed poorly for pocket use around female figures, too bulky and heavy which restricted range of motion, and reduced in overall comfort because of the bulk that was more easily managed by males. Another small study conducted by Sinden et al. (2013) supported these findings. The researchers interviewed four female firefighters; all commented that the equipment and garments were too large and "…better suited for their male counterparts (p. 100)."

#### 2.5 3D Body Scanning

Accounting for all of the potential variations in body shape and size poses a challenge in evaluating the proper fit of a garment (Boorady, 2011). According to Boorady (2011), the best tool to determine fit is an observational analysis of the shapes and contours of a garment in relationship to the wearer's body. Visual inspection allows the observer to see wrinkles that may indicate areas that require additional ease and loose fabric that may need to be reduced.

Although this system of live fit analysis has been traditionally effective, visual inspection can be enhanced with the use of 3D body scanning, a measuring technology that allows for threedimensional surface scanning of the human body. 3D body scans provide valuable information relating to fit, sizing, and design development (Ashdown et al., 2004). The tool strongly supports the evaluation of PPE because it provides detailed data about the complex relationship between the end-user's body and the garment, as well as the ability to see the protective ensemble as a whole or detailed view (Ashdown et al., 2004).

Current 3D body scanner models scan the whole body in seconds and rapidly produce a 3D model with over 400 measurements (Loker, Ashdown, & Schoenfelder, 2005). Body scanners use safe depth sensors to capture a surface representation of approximately 300,000 spatial data points per scan. Scanners project lasers onto the human subject and the image is then captured by a set of cameras. The resulting data is received and visually represented by a computer in the form of X, Y, Z coordinates. Scanner software assists in combing multiple camera views (data points) together to visualize and create a three-dimensional image on the computer. Scan image quality is affected by the software that aligns the data points as well as the speed and number of cameras. Current scanners utilize 2-16 cameras, where the higher number of cameras to an increased resolution (Ashdown et al., 2004).

In attempt to evaluate the effectiveness of using a 3D body scanner for a fit analysis, Ashdown et al. (2004) conducted a study comparing traditional fit methods to 3D body scans. The researchers concluded that transitioning away from live fit analysis to 3D scans increases the potential for: recording images that are easily viewed from multiple angles, rotated and manipulated for the best visual analysis; building a database of scan data to assist viewing multiple body shapes wearing a single size; evaluating the garment/body relationship in a variety

of poses; sharing scan images with others for additional analysis or evaluation. The results (Ashdown et al., 2004) support the use of 3D scanning to enhance traditional fit methods and collect additional valuable information for evaluating fit.

The Ashdown et al. (2004) and the Choi and Ashdown (2010) studies are important additions to the research on fit analysis related to turnout gear. Garment fit is a complex process where the relationship between the end-user and garment are analyzed to determine how well the clothing meets the required demands, as decided by the designer (Boorady, 2011). Traditionally, a consortium of experts conducted a live fit analysis to evaluate the issues that needed attention. The belief that human sense, as an instrument, could detect and compute complex stimuli more effectively than other measurement drove the use of live fit analysis. Especially when complex patterns were present. (Ashdown et al., 2004). 3D body scan visuals provide the same information as live fit analysis, but offer some additional benefits (Ashdown et al., 2004). The 3D images provide easy evaluation of the human's silhouette where stress folds are visible and show an area of poor fit, as well as close up and multiple views to isolate specific areas that might need attention. In addition, background information, color, and texture are eliminated and are no longer distractions from fit. Lastly, multiple scan images can be compared with the minimally clothed body to see areas that were compressing the body (Choi & Ashdown, 2010).

The 3D scan images also offer additional information that is of benefit to firefighters. In Choi and Ashdown's (2010) study, 3D scans were used to measure and analyze lower body surface changes using different active body positions. Researchers compared the traditional standing position with three different positions that mimic common postures found in daily life. The ability to customize scanning and measure specific areas of the protective wear is of critical importance to firefighters. 3D images allow the viewer to refer back to the image after the

measuring has ceased, manipulate the aspects of the image shown, and organize data for a specific population. The data received from a 3D body scanner provides valuable information for developing more versatile and effective sizing systems and ultimately protective garment patterns for female firefighters.

To conclude, the literature on turnout gear for female firefighters is limited, but suggests the importance of gender specific designs and the need for continued research. Most of the studies are focus groups and interviews with small sample sizes. A few exceptions are the Hulett et al. (2008) study that included focus groups and in depth interviews of 175 female firefighters, Stirling's (2002) collection of anthropometric data from over 300 female firefighters and Park and Hahn's (2014) study that evaluated survey data. The following summary statements can be made from the literature review:

- Firefighting, as an occupation, has evolved. Fires have become hotter and burn with increased speed due to modern construction materials, which has put a demand on increased thermal protection in current turnout uniforms. However, increasing thermal protection negatively affects job performance for firefighters, and negatively impacts mobility and comfort. (Dorman & Havenith, 2009; Coca et al., 2010; Broorady et al., 2013)
- Firefighters have hazardous jobs and the fit of their turnout gear is critically important to their job performance and to avoid health and safety risks (Hasio, 2013; Hulett et al., 2008; Jahnke et al., 2012; Mordecai & Freeman, 2012)
- Female firefighter dissatisfaction with the fit of their turnout gear has been routinely reported in interviews and focus groups. Suggestions for gender specific turnout gear

based on their reports needs more research, specifically more empirical evidence (Boorady et al., 2013b; Hulett et al., 2008; and Stirling, 2002).

 Based on solid evidence that 3D body scanning is a useful and reliable tool to enhance the traditional live fit analysis, the potential use of 3D body scanning to determine fit for female firefighters needs to be studied (Ashdown et al., 2004; Choi & Ashdown, 2010; Paquette et al., 2011 and Song & Ashdown, 2010).

#### CHAPTER THREE: METHODOLOGY

#### 3.1 Research Design

The term *fit* as it relates to functional garments encompasses aspects of the wearer's perceived physical comfort, psychological comfort, physiological comfort, mobility, performance and appearance (Slater, 2008; Boorady, 2011; Shuan, Huang, & Qian, 2012). Therefore, this study employed the use of multiple measurement methods in the form of: (a) a participant survey, (b) 3D body scanning, (c) measurement of joint angles, and (d) an exit interview. That is, this study is experimental in nature as it explores a multi-dimensional protocol to evaluate the current fit issues associated with firefighters' protective pants.

Qualitative and quantitative data collection methods were used in an attempt to gain a holistic view of the current fit issues among the participants. Survey research was used to collect quantitative data on the participants' experience with their current turnout pants. The participants' body dimensions were captured using a 3D body scanner. 3D scan data were analyzed by comparing body measurements of the male and female participants wearing various levels of their uniform pants. Joint angles were measured to understand the influence of the firefighter's uniform pants on mobility. Qualitative data were collected during the experiment and through an exit interview, in which the participants were encouraged to openly comment on their uniform pants. The following model illustrates the research design and process for this study:



Figure 1. Data collection process map (illustrated by the researcher)

#### 3.2 Participant Recruitment and Profiles

Purposeful sampling was used to recruit male and female structural firefighters who had a minimum of 12 months of firefighting experience and had no musculoskeletal problems. Purposeful sampling is used to study a specific group and is often used when a study topic is new or not feasible to do random sampling (Flyn & Foster, 2009).

With Institutional Review Board (See appendix A for IRB approval letter) approval from Colorado State University, female firefighters were recruited first. The initial group of female firefighters was recruited through the Poudre Fire Authority (PFA) in Fort Collins, Colorado. A positive, collaborative partnership has been established between the researcher's academic advisor (i.e., Dr. Park) and the PFA. An e-mail was first sent to the contact representative at PFA to introduce the scope of the present study and to request assistance in forwarding a recruitment letter to PFA female firefighters (See appendix B for E-mail to Chief and appendix C for Participant Recruitment Letter). The recruitment letter provided details about the project and contact information of the researchers. Female firefighters were also recruited though FireWomen.org, a website specifically for Colorado-based, female firefighters. The organization offers female firefighters resources in professional development, occupation-related training, and social networking. A firewomen.org representative was contacted via e-mail and a recruitment flyer (See appendix C for recruitment letter) was sent to inform interested participants about the study.

Ten female firefighters contacted the researcher, expressing their interest in the study, and scheduled an appointment to visit the research lab. Nine female firefighters actually participated in this study. The recruited female firefighters represented 5 different locations within the Front Range of Colorado.

Male firefighters were recruited as a control group. To correspond with the physical profiles of female firefighters, male firefighters were recruited who had a similar range of waist measurements to that of female firefighters; 30 – 40 inches with an average of 32 inches (the female firefighters' waist measurements were asked at the phone contacts for scheduling). Male participants were recruited through the PFA as well as through a snowballing method. The female firefighters who previously participated in the experiments were asked to prompt their male co-workers who met the inclusion criteria to participate. Ten male participants expressed interest in the study, but six were able to schedule an appointment. Male participants represented 2 different cities within the Front Range of Colorado and had waist measurements that ranged from 32-38 inches, with an average of 33.8 inches.

Two to five days prior to the lab visit schedule, a follow-up e-mail was sent to firefighters to confirm their schedule details (See appendix D for participant e-mail follow up). To help the

participants understand the 3D body scanning process, the follow-up e-mail also included a website link to a video illustrating the scanning process. This video was created by  $[TC]^2$  – the manufacturer of the 3D body scanner that this study utilized. Participants were asked to bring their personal station pants, turnout pants, station boots, turnout boots and any tools that may typically be stored in the pockets of their turnout pants. The experiments took place in the Human Body Dimensioning (HBD) Lab on the Colorado State University campus; located in the Gifford building, room 141. Each session took approximately 1-½ hours, and data collection was conducted in June and July 2014.

#### 3.3 Pilot Study

Prior to the actual data collection, a pilot study was conducted with a female graduate student in the Design and Merchandising department at Colorado State University, to improve the clarity and validity of the questions and overall organization of the data collection process. The pilot study participant donned station pants and structural firefighting turnout pants that were lent to the HBD Lab from the PFA, and experienced the data collection process. The pilot study served as an opportunity to streamline the timing and instrumentation for this study. Following the pilot study, specific survey questions were edited to increase their clarity and elicit participant information based on the primary research questions. The same researcher conducted the pilot and main study appointments in order to maintain the reliability of data.

#### 3.4 Data Collection Procedures

Upon arrival to the HBD Lab, the researcher greeted the participant, explained the purposed of the study and verbally outlined the experiment process to the participant (See appendix E for Data Protocol). Following the overview, the researcher asked the participant if

they had any questions/concerns or if they needed clarification on any part of the research process. The participant was then asked to read and sign the consent form (See appendix F for Participant Consent) and complete the survey (see appendix G for Participant Survey) before participating in 3D body scanning.

#### 3.4.1 Participant Survey

The survey took approx. 10-20 minutes for participants to complete. The survey questionnaire was designed to evaluate firefighter's experience of wearing their current station and turnout pants. The survey questionnaire included a total of 54 5-point Likert-type questions: 10 questions about demographic and occupational background, 21 questions focused on station pant fit and evaluation, and 23 questions focused on turnout fit and evaluation. The questionnaire also included an opportunity for participants to leave any additional comments on their uniform pants at the end. Participants' job-related information, i.e., type of firefighter (professional vs. volunteer), job title, department name, and years of service, as well as their demographics (i.e., sex, age, height, weight, clothing and shoe size), were collected via the survey questionnaire.

In the survey, twenty-two questions were asked that focused on station pants. The first question asked about the frequency in which the participant wears station pants under their turnout pants, 8 questions asked about an overall evaluation of the pants, including topics such as overall fit, comfort, protection, mobility and bulkiness using the 5-point Likert scale (1 = strongly disagree; 5 = strongly agree). Eight questions focused on the firefighter's fit evaluation of specific areas: waist, hips, upper thigh girth, knee girth, calf girth, ankle girth, inseam girth and pant rise using a 5-point Likert scale (1 = very tight, 3 = neutral, 5 = very loose). Each question using the Likert scale allowed the participants to comment on the details of their

perceived discomfort or dissatisfaction in an open-ended comment section. The same overall evaluation (8 questions) and specific fit evaluation (8 questions) questions were used for evaluation of turnout pants.

#### 3.4.2 3D Body Scanning

Following the completion of the survey, the participants were walked through the 3D body scanning steps by the researcher and were allowed to ask any questions prior to the start. A  $[TC]^2$ , model KX-16, scanning technology scans the whole body in seconds and rapidly produces a 3D model with over 400 measurements. Once the researcher and participant were ready, the participant was asked to stand inside the scanner and had the ability to push a start-button inside the scanner. The trigger started a music and audio prompt that gave the participant scanning directions. Participants were scanned with three different layers of clothing: 1) undergarments for baseline measurements, 2) station pants with a basic t-shirt only, 3) turnout pants worn over station pants with a basic t-shirt.

The body scanner captured 3 images in each of the positions, which took about 15-20 seconds per position. The scanning software automatically averaged the anthropometric data (3 scans in each position, and for each variation of clothing) and produced an image that was void of any outlying data (e.g., the participant moved, or data wasn't captured clearly).

#### 3.4.3 Joint Angle Measurement

The experiment employed two occupational positions that required the participants to 1) bend and lift an object and 2) pose on a step stool. The occupational positions were identified through O\*Net OnLine. The online resource categorizes the importance of job tasks for structural firefighters as follows: 93% rescue victims from burning buildings and accident sites, 93% search burning buildings to locate fire victims, 90% dress with equipment such as fire

resistant clothing and breathing apparatus, 86% position and climb ladders to gain access to upper levels of buildings, or to rescue individuals from burning structures, and 86% create openings in buildings using varied tools. Each of the tasks listed above requires the ability to coordinate two or more limbs, and considerable use of whole body movement, such as climbing, lifting, stepping and balancing while wearing a protective ensemble. Thus, in this study these were the two particular positions relevant to the firefighting occupation to further evaluate comfort and fit as it relates to the physical movement required of a structural firefighter.

For the bending and lifting task, female firefighters were instructed to stand on two markers, 14.5" apart and male firefighters stood 18.5" apart; representative of the average shoulder (Rosenberg, 2014) width for each sex. They were asked to squat and lift a box (approx. 20 lbs, 17"x 29.5" x 16") 12" off the ground – as indicated by a mark on the wall. The participants were asked to repeat the bending and lifting motion three times, without break as the researcher filmed their movement. Participants were then asked if they experienced any tension, bulk, looseness or general discomfort in any area. Feedback was recorded on the 'Active Joint angle' worksheet (See appendix H for Active Joint Angle worksheet). Participants were then asked to lift the box again, holding a static position with the box 12 inches off the ground. Joint angles: waist, knee and ankle measurements were recorded using a goniometer. The measurement of joint angles was guided by 'Joint Motion: Method of measuring and recording,' published by the American Academy of Orthopedic Surgeons (1965). To maintain consistency of the measurement protocol, the same researcher measured all joint angles. After the participant set the box back down, distance from the participant's toes to the box was also recorded. Digital photos were taken in each position as supplementary reference material and visual inspection of identified fit areas.

For the stepping movement, participants approached a 2-step stepstool and were asked to rest their right foot on the lower step (8") three times, followed by resting their right foot on the upper step (17") three times. This movement was captured on video. Again, participants were asked if they experienced any tension, bulkiness, discomfort or specific concerns in the stepping motion. Answers were recorded on the Joint Angle worksheet. The researcher then measured participant joint angles (hip flexion, knee flexion, dorsiflexion) and distance from the stepstool, at the lower step as well as the upper step, and took digital photographs. Occupational position evaluation was held for both the station pants, as well as the turnout pants (worn over the station pants).

#### 3.4.4 Exit Survey

The participant appointment finished with a short exit interview that was comprised of 5 questions. (See appendix I for Exit Interview) Two questions asked the participants to identify one thing they like about their station and turnout pants (if any); 2 questions asked the participants to identify something they dislike about their station and turnout pants (if any); and 1 question asked the firefighters what other areas they would like to see researched in the future. Interviews lasted less than 8 minutes; they were recorded and transcribed for analysis. A \$30 cash incentive was offered as compensation to the participants for their time and assistance.

#### 3.5 Data Analysis

#### 3.5.1 Subjective Evaluation

The survey data was analyzed using a Statistical Package, IBM SPSS 22.0. Independent samples t-tests along with descriptive statistics were run on all survey questions to highlight specific areas of fit concern for structural firefighters between females and males. Likert scales

reflected the participant's attitudes toward specific fit and comfort-measuring statements and each point of agreement is given a numerical value from one to five. The survey also used a subjective fit evaluation scale that asked participants to rate their current turnout pants from "much too tight" to "much too loose." This scale strived to determine how subjects felt and how they perceived the fit and comfort of their station pants and turnout pants.

#### 3.5.2 3D Scan Data

Each participant was first scanned in their undergarments (or Lycra suit) to establish their baseline body measurements by identifying landmark locations. 3D scan data at landmark locations were retrieved from all three layers of clothing, and data of station and turnout pants were compared to the baseline body (minimally clothed) measurements. Poor fit is demonstrated in scenarios where the garment was very close to the baseline body-part measurement or drastically different. For the fit areas, mean and standard deviation data were collected in order to format a table and graph summarizing the gathered information. Independent samples t-tests were performed to compare the body measurements against the opposing sex.

#### 3.5.3 Joint Angles

In the active positions, joint angle measurements were collected: hip flexion, knee flexion and dorsiflexion points using a manual goniometer. The participants were in a weight-bearing stance when their measurements were taken. Mean scores of joint angles and % difference of ROM were calculated to compare the participants' mobility wearing their uniform pants in occupational positions between the genders. Joint angles data were also used to support and further understand the participant's claims (via survey, 3D scanning, or exit interview) of poor fit or discomfort.

#### 3.5.4 Exit Interview

Participant responses were transcribed and categorized to look for patterns and themes in feedback. Participants' comments were focused around 5 main questions, 2 questions about station pants, 2 questions about turnout pants and one question about recommended areas for future research and exploration. The participants' comments, collected through the experiment, were transcribed verbatim and categorized by themes. Interview data provided supplementary information to support the findings from statistical analyses.

#### 3.5.5 Supplementary Visual Analysis

Data was also collected in the form of still images that illustrated visual representation of poor fit. Scan images were evaluated for areas that show stress folds, compression of the body, and distorted areas of the silhouette that visually identify areas of misfit (Ashdown et al., 2004). Images were also used to support and further understand the participant's claims (via survey, active position evaluation or exit interview) of poor fit or discomfort.

#### 3.6 Implications

The outcome of this study is expected to provide the apparel industry and researchers with practical guidance in advancing the development of improved fit and sizing systems for female structural firefighters; as well as provide scientific evidence of poor fit to policy makers within the firefighting industry. Three-dimensional body scanning technology offers a vital tool to generate and store accurate anthropometric data of diverse populations with various body shapes. Collecting this information is a crucial step in the development of customized garments and improved uniform size-ranges for female firefighters that specifically address differences in physical profiles, not just smaller versions of one pattern. Anthropometric and ROM data, along with descriptive accounts from the study participants, can be used to facilitate effective

communication with the manufactures of firefighter protective clothing by providing a visual, numerical and descriptive account of female firefighter's fit concerns. A multi-dimensional fit evaluation provides a comprehensive representation of the relationship between the wearer and the garment, which helps in understanding how to adjust patterns and sizing systems to better fit the female firefighter population and ultimately improve their occupational safety in the fire field.
## CHAPTER FOUR: MANUSCRIPT

## 4.1 Introduction

Structural firefighting is a necessary, critical, and challenging occupation that requires the firefighter to perform physically demanding tasks in hazardous environmental conditions (Broorady, Barker, Lee, Lin, Cho & Ashdown, 2013a). In the last 30 years, the scope of duties of firefighters has evolved due to a change in construction materials, firefighting tactics and the firefighting workforce (Angle, Harlow, Gala, & Lombardo, 2013; Guidotti, 1992). With the changing environmental needs, firefighter duties go beyond fighting fires. Firefighters are called upon to rescue people and animals and protect personal property and natural resources – that is, they are "First Responders" in emergency incidents. Their extended duties require extreme physical mobility. Thus, the correct fit and mobility of the firefighters' uniforms is critical to their safety and efficiency in the field (Guidotti, 1992; Hasio, 2013; Hulett, Bendick, Thomas, & Moccio, 2008; Jahnke, Poston, Haddock, Jitnarin, Hyder, & Horvath, 2012; Mordecai & Freeman, 2012). Fires burn at higher temperatures and with increased speed due to the use of modern construction materials; specifically the use of plastics, foams, and synthetic fibers change fire dynamics and increase toxic fumes and smoke (Angle et al., 2013; Hasenmeier, 2008). These environmental changes in fire behavior have prompted the need for new firefighting strategies and subsequently require uniforms with added thermal protection to allow firefighters to be more aggressive with their fighting tactics (Angle et al., 2013); therefore much attention has been given to the thermal protection of the firefighters' protective uniforms (Boorady, et. al., 2013a; Braker, Guerth-Schacher, Grimes, & Hamouda, 2006; Lawson, 1997; Lee & Barker, 1987; Mell & Lawson, 2000). Studies suggest that the added bulk resulting from

increased thermal protection likely decreases the wearer's mobility needed in performing a variety of the firefighters' duties (Dorman & Havenith, 2009; Coca, Williams, Roberge, & Powell, 2010).

The demographic of firefighters has also changed and it has become a career path for women. Based on statistics from the National Fire Protection Association (NFPA), the number of women serving as structural firefighters in the United States has increased from 1,700 (1%) in 1983 to 10,000 (3.4%) in 2012, with a peak in 2007 of 15,000 (5.2%). Being in the maledominant occupation, female firefighters wear uniforms designed for men (Broorady, Barker, Lee, Lin, Cho & Ashdown, 2013b). According to previous research, incorrectly-sized and illfitting personal protective equipment (PPE) affects the wearer's job satisfaction and performance (Boorady et al., 2013a; Hulett et al., 2008; Sinden, MacDermid, Buckman, Davis, Matthews, &Viola, 2011). Few studies, however, address the fit of personal protective equipment (PPE) for female firefighters. The previous work is predominantly descriptive in nature, based on interviews, surveys, and questionnaires of female firefighters (Boorady et al., 2013b; Hulett et al., 2008; Shuster, 1999; Sinden et al., 2011). Given the increasing number of females in this profession, empirical research is needed to provide scientific evidence to determine fit and performance issues associated with their PPE, thus helping them perform necessary duties efficiently and safely. To inquire the research question, this study aimed to (a) identify fit issues associated with the female firefighter's uniform pants; and (b) determine specific areas on the uniform pants that cause the fit issues. The ultimate goal of this study was to demonstrate the necessity of gender-specific uniform designs for firefighters to facilitate better fit and comfort to female firefighters. Female firefighters have indicated more difficulty with their turnout gear than their male counterparts (Boorady et al., 2013; Hulett et al., 2008; Shuster, 1999; Sinden et

al., 2011). Turnout pants, in particular, have been identified as having poor fit and caused mobility problems for female firefighters (Hulett et al., 2008; Broorady et al., 2013; Park & Hahn 2014). Therefore, firefighters' uniform pants were selected for this study as a particular PPE item.

## 4.2 Methods

## 4.2.1 Study Participants

Purposeful sampling was used to recruit male and female structural firefighters who had a minimum of 12 months of firefighting experience and had no musculoskeletal problems. With Institutional Review Board (IRB) approval from the researchers' university, female firefighters were recruited through a fire department located in the Midwestern region of the U.S., as well as a website for female firefighters (FireWomen.org). An e-mail was first sent to the contact representative at the fire department to introduce the scope of the present study and to request assistance in forwarding a recruitment letter to female firefighters. The recruitment letter provided details about the project and contact information of the researchers. Ten female firefighters contacted the researchers, expressing their interest in the study, and scheduled an appointment to visit the research lab. Nine female firefighters actually participated in this study. The recruited female firefighters represented 5 different locations within the region, representing diverse urban/rural settings from a metropolitan city to a small, rural town.

Male firefighters were recruited as a control group. To correspond with the physical profiles of female firefighters, male firefighters who had similar waist measurements to those of recruited female firefighters were invited to this study. That is, female firefighters were recruited prior to male firefighters and their waist range was added to the inclusion criteria for their male counterparts. The female firefighters' waist measurements were asked at the phone contact for

scheduling and the measurements ranged 30-40 inches (mean = 32 inches). Six male participants were recruited through the contact of the local fire department. Male firefighter waist measurements ranged from 32-38 inches, with an average measurement of 33.8 inches.

## 4.2.2 Experimental Design and Procedure

This study explored multi-dimensional measurement protocols to evaluate current fit issues associated with female firefighters' uniform pants in the form of: (a) a participant survey, (b) 3D body scanning, and (c) the measure of joint angles. 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; 3D scan data were analyzed by comparing body measurements of the male and female participants wearing various levels of their uniform pants. Joint angles were measured by the researcher, using a goniometer in two defined occupational positions, wearing 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 a 1 ½ hour-long experiment that consisted of the four parts of data collection- survey, 3D body scanning, joint angle measurement, and exit interview.

## 4.2.2.1 Survey

The survey questionnaire was designed to evaluate the firefighter's experience of wearing their current uniform pants. The questionnaire included a total of 54 questions: 10 questions about demographic and occupational background (i.e., sex, age, height, weight, clothing/shoe size, type of firefighter, job title, department name, and years of service), 21 questions focused on the station pants' fit and comfort evaluation, and 23 questions focused on turnout pants' fit and comfort evaluation. The questionnaire also included an opportunity for participants to leave

any additional comments on their uniform pants at the end. The firefighter's perceived fit and comfort were evaluated on the eight specific areas of uniform pants: waist, hips, upper thigh girth, knee girth, calf girth, ankle girth, inseam girth and pant rise, using a 5-point Likert scale (1 = very tight, 3 = neutral, 5 = very loose). Each question using the Likert scale allowed the participants to comment on the details of their perceived discomfort or dissatisfaction in an open-ended comment section.

## 4.2.2.2 3D Body Scan

Following the completion of the survey, the participants were walked through the 3D body scanning steps by a researcher and allowed to ask any questions prior to the start. Threedimensional scanning technology scans the whole body in seconds and rapidly produces a 3D model with over 400 landmark measurements. The 3D body scanner ([TC]<sup>2</sup>, KX-16®), adopted for this study, uses non-invasive depth sensors to capture a surface representation of approximately 300,000 spatial data points per scan; there are no known risks associated with the 3D body scanning procedures. Once the researcher and participant were ready, the participant was asked to stand inside the scanner and had the ability to push a start-button inside the scanner. The trigger started a music and audio prompt that gave the participant directions on how to pose within the scanner. Participants were scanned with three different layers of clothing: 1) undergarments for baseline measurements (i.e., a bra and underpants for females and underpants for males), 2) station pants with a basic t-shirt only, and 3) turnout pants worn over station pants with a basic t-shirt. Firefighters commonly wear a station uniform made of twill construction when they are at the stations. Turnout pants are a protective ensemble item, made of Nomax or Kevlar, and they are typically worn over station pants. The body scanner captured 3 images in each of the clothing layers, which took about 15-20 seconds per layer. The scanner

automatically averaged the anthropometric data (3 scans in each layer) and produced an image that was void of any outlying data.

### 4.2.2.3 Joint Angle Measurement

The experiment employed two occupational positions that required the participants to 1) bend and lift a heavy object and 2) pose on a step stool. The occupational positions were identified through O\*Net OnLine. The online resource categorizes the importance of job tasks for structural firefighters. The two particular positions relevant to the firefighting occupation were selected to evaluate comfort and fit of the firefighter's uniform pants as they are frequently required for firefighters to perform in their job field. Occupational position evaluation was held wearing the station pants, as well as the turnout pants (worn over the station pants).

For the bending and lifting task, female firefighters were instructed to stand on two markers, 14.5" apart and male firefighters stood 18.5" apart; representative of the average shoulder (Rosenberg, 2014) width for each sex. They were asked to squat and lift a box (approx. 20 lbs, 17"x 29.5" x 16" in dimension) 12" off the ground – as indicated by a mark on the wall. For the stepping movement, participants approached a 2-step stepstool and were asked to rest their right foot on the lower step (8") three times, followed by resting their right foot on the upper step (17") three times. The participants were asked to repeat each position three times, without break, while their movement was captured on video. Participants were then asked if they experienced any tension, bulk, looseness or general discomfort in any area. Feedback was recorded on the 'Active Joint Angle' worksheet. Joint angles, including hip flexion, knee flexion and dorsiflexion points, were recorded by the researcher, using a goniometer. The measurement of joint angles was guided by 'Joint Motion: Method of measuring and recording,' published by the American Academy of Orthopedic Surgeons (1965). To maintain consistency of the

measurement protocol, the same researcher measured all joint angles. Digital photos were taken in each position as supplementary reference material and visual inspection of identified fit areas.

## 4.2.2.4 Exit Interview

The experiment finished with a short exit interview. Questions asked the participants to identify one thing they like about their uniform pants, and to identify areas that they dislike about their uniform pants, if any. They were also given an opportunity to comment on what other areas they would like to see researched in the future. The exit interviews took 1-8 minutes in length.

## 4.2.3 Data Analysis

Independent samples t-tests along with descriptive statistics, using IBM SPSS 22.0, compared fit and comfort of the firefighter's uniform pants between female and male participants. The participants' comments, collected through the experiment, were transcribed verbatim and provided supplementary information to support the findings from statistical analyses.

## 4.3 Results

## 4.3.1 Demographic Information

A total of 15 firefighters (9 females and 6 males) participated in this study. All participants were Caucasian American. 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 32.5. The average physical profiles of female participants, based on the self-reported height and weight, were 65.8 inches in height (5 feet 5.8 inches) and 145. 67lbs, while the male participants were 71 inches tall (5 feet 11 inches) and 185.33lbs. The average Body Mass Index (BMI) for females was 23.6 kg/m<sup>2</sup> and that of males was 25.5kg/m<sup>2</sup>.

All nine female firefighters were professional firefighters, while four male firefighters were professional and two were volunteer firefighters. The female firefighters' average years of firefighting service were 16 years and 3 month, and those of male firefighters were 6 years and 8 months. The profiles of the study participants indicated that the female firefighters, who participated in this study were more experienced than the male participants. It may be assumed that young male firefighters who often are volunteers, and not issued custom uniforms, tend to experience more fit and comfort issues with their PPE, thus making them want to participate in this study, while all female firefighters, even experienced professional firefighters, have experienced significant issues with the fit and comfort of their PPE.

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Characteristics	Female	Male		
Age: Mean (SD)	42.6 (9.9)	32.3 (6.5)		
Height: Mean (SD)	65.8 in. (1.9)	71.0 in. (2.2)		
Weight: Mean (SD)	145.67 lbs. (20.0)	185.33 lbs. (20.3)		
BMI average: Mean (SD)	23.5 (3.3)	25.9 (3.6)		
Firefighting service:				
Career	9 ( <i>n</i> =9)	4 ( <i>n</i> =6)		
Volunteer	0 ( <i>n</i> =9)	2 ( <i>n</i> =6)		
Experience: Mean (SD)	16 years, 3 months (8.6)	6 years, 8 months (6)		

## 4.3.2 Subjective Evaluation of Fit and Comfort

Individuals have apparel fit preferences based upon aesthetic and functional expectations and ultimately the wearer determines what is considered a good fit (Ashdown & DeLong, 1995). To evaluate subjective perception of fit and comfort associated with the firefighter's uniform pants, mean scores of female firefighters had significantly lower ratings for the overall fit satisfaction, protection, and comfort for their station and turnout pants, than those of male firefighters (see Table 2). Female firefighters reported a lower level of overall fit satisfaction with their uniform pants ( $\bar{x}_{station} = 2.55$ ,  $\bar{x}_{turnout} = 2.11$ ) than male firefighters ( $\bar{x}_{station} = 4.00$ ,  $\bar{x}_{turnout} = 3.50$ ) on a 5-point Likert scale. Female firefighters also showed lower scores in perceived protection from occupational injuries or risks when wearing their station/turnout pants ( $\bar{x}_{station} = 3.00$ ,  $\bar{x}_{turnout} = 4.00$ ) than male firefighters ( $\bar{x}_{station} = 4.00$ ,  $\bar{x}_{turnout} = 4.66$ ). Female firefighters rated lower in perceived comfort ( $\bar{x}_{station} = 2.66$ ,  $\bar{x}_{turnout} = 2.55$ ) than male firefighters ( $\bar{x}_{station} = 3.60$ ,  $\bar{x}_{turnout} = 4.33$ ). Female firefighters also rated a lower score for mobility ( $\bar{x}_{station} = 3.22$ ,  $\bar{x}_{turnout} = 2.11$ ) and performance ( $\bar{x}_{station} = 3.56$ ,  $\bar{x}_{turnout} = 2.33$ ) for both their station pants as well as their turnout pants, in comparison with male firefighters (mobility:  $\bar{x}_{station} = 4.16$ ,  $\bar{x}_{turnout} = 3.33$ ; performance:  $\bar{x}_{station} = 4.33$ ,  $\bar{x}_{turnout} = 3.83$ ). All survey questions were scored lower by female firefighters. In particular, the results were statistically significant on the overall satisfaction of their turnout pants (P=.026) as well as comfort (P=.006), mobility (P=.045) and performance (P=.004) of their turnout pants.

Uniform	Survey topic	Sex	Ν	Mean	Std.	t	df	Sig. (2-tailed)
					Deviation			
	Overall	Female	9	2.56	1.01	-2.10	13	.056
	Satisfaction	Male	6	4.00	1.67			
	Protection from	Female	9	3.00	1.22	-1.71	13	.11
	occupational risks	Male	6	4.00	.894			
Station	Comfort	Female	9	2.67	1.22	-1.29	13	.21
Pants		Male	6	3.50	1.22			
	Mobility	Female	9	3.22	1.30	-1.43	13	.18
		Male	6	4.16	1.17			
	Performance	Female	9	3.56	1.24	-1.46	13	.20
		Male	6	4.33	.82			
	Overall	Female	9	2.11	.78	-2.51	13	.026*
	Satisfaction	Male	6	3.5	1.38			
	Protection from	Female	9	4.0	1.00	-1.49	13	.159
	occupational risks	Male	6	4.67	.52			
Turnout	Comfort	Female	9	2.56	.88	-3.30	13	.006**
pants		Male	6	4.33	1.21			
	Mobility	Female	9	2.11	.93	-2.22	13	.045*
		Male	6	3.33	1.21			
	Performance	Female	9	2.33	.50	-3.45	13	.004**

**Table 2**. Firefighters' perception of station and turnout pants

Male 6 3.83 1.17

Significant differences between female and male firefighters ( \* p < .05, \*\* p < .01)

Using a 5-point Likert scale (1=very tight, 3=neutral, and 5=very loose), the participants rated the uniform pants on the following eight landmark points: waist, hips, thigh girth, knee girth, calf girth, ankle girth inseam length and pant rise. Figure 1 illustrates female firefighters' evaluation on the fit of the waist, hips, and thighs of station pants being too tight and the fit of the knee, calf, ankle and pant rise too loose. On the other hand, male firefighters' scores fluctuate less than female firefighters, but also vary less within the range of tight to loose. As for the fit of turnout pants, female firefighters showed that overall, they perceived their turnout pants to be too loose in each of the 8 measurement points. Male firefighters' scores were closer to 3 on a 5-point scale, which represented almost no complaints on fit. However male participants did express dissatisfaction with the inseam fit of turnout pants (mean score = 2.5) scoring it as "too tight."



Figure 2. Fit evaluation rated by firefighters: station pants



Figure 3. Fit evaluation rated by firefighters: turnout pants

## 4.3.3 3D Body Scan

Each participant was scanned at three different levels: 1) undergarment, 2) station pants, 3) station pants + turnout pants. Of more than 400 measurement points, 3D scan data at the selected 8 lower-body landmarks were generated and compared between males and females. Baseline measurements of the participants showed gender differences in the landmark points. Overall, female firefighters had a smaller waist measurement ( $\bar{x}_{female}$ = 33.09 in,  $\bar{x}_{male}$ =36.17 in.), thigh circumference ( $\bar{x}_{female}$ =24.38 in.;  $\bar{x}_{male}$  =26.79 in.), and calf circumference ( $\bar{x}_{female}$ =14.69 in.;  $\bar{x}_{male}$  =15.81 in.) than male firefighters, while hip measurements were almost identical between the genders ( $\bar{x}_{female}$ =42.40in;  $\bar{x}_{male}$ =42.54in). This may indicate that female firefighters have proportionally a larger hip circumference than male firefighters, considering the difference in waist measurement. Female firefighters that were measured, on average, had a longer crotch length ( $\bar{x}_{female}$ =27.19 in.;  $\bar{x}_{male}$ =26.93) and shorter leg length ( $\bar{x}_{female}$ =29.35 in.;  $\bar{x}_{male}$ =31.67 in.). The male body shape naturally differs from the female body shape. The male torso is typically longer than a female's, where the waist line is lower, not as tapered; the hips are not prominent and the pelvis is narrower. Females, on the other hand, often have hips that a prominent, with a waist circumference that is tapered in relation to their hip circumference. Therefore, if female firefighters are wearing uniform pants designed for males, they tend to wear uniform pants that have the wider waist and thigh to accommodate their proportionally wider hips. This ultimately causes overall poor fit, not just localized to one area.

To calculate the functional ease of the pants, baseline measurements, measured while wearing undergarments only were subtracted from the measurements collected while the participant was wearing their station pants and from their turnout pants (Table 3). Functional ease refers to the need of a garment to accommodate and adapt to the user's movement (Boorady, 2011). This aspect is especially important in physically demanding professions, such as firefighting, and has been of interest to a variety of researchers (Ashdown, Loker, Schoenfelder, & Lyman-Clarke, 2004; Boorady, 2011; Hsiao, 2013; Mordecai & Freeman, 2012).

Regardless of the sex, turnout pants expressed the higher amount of functional ease in all measurement points except the pants rise than station pants, meaning that the firefighter's turnout pants were generally baggier than the station pants. Poor fit was demonstrated in scenarios where the garment was very close to the baseline measurement or drastically different. Results were compared against the opposing sex. The 3D scan data showed that female firefighters had a looser fit at the wait and crotch, while they had a tighter fit at the hips of both station and turnout pants, as compared to male firefighters. This result signifies that female firefighters wear uniform pants with waist and pant rise (i.e., the crotch length) that are too baggy and hips that are too tight, which corresponds with the survey data. The pants rise for male firefighters may be

explained by the fact that the participating firefighters in this study were taller than the average U.S. males (average male height = 67 inches, participant sample = 71 inches), so proportionally they experienced a tight fit at the pants rise. Data also showed a statistical significance in gender comparison of the functional ease of station pants at the thigh (t=3,129, df=13, p=.008) and ankle (t=2.207, df=13, p=.46), signifying that female firefighters experience a loose fit (i.e. baggy) at the thigh and ankle of the station pants. This could be explained that female firefighters tended to choose to wear loosely fitting station pants to accommodate their hips.

Measurement	Garment	Sex	Ν	Mean	Std. Deviation	Sig. (2- tailed)
	Station pants	Female	9	2.78	2.06	0.21
Waist		Male	6	1.57	1.09	
	Turnout pants	Female	9	5.31	1.75	0.293
		Male	6	4.33	1.63	
	Station pants	Female	9	1.78	1.65	0.55
Hips		Male	6	2.28	1.27	
	Turnout pants	Female	9	9.69	3.12	0.25
		Male	6	11.34	1.54	
	Station pants	Female	9	2.96	0.95	0.008**
Thigh		Male	6	1.32	1.07	
	Turnout pants	Female	9	8.56	1.48	0.59
		Male	6	9.12	2.44	
	Station pants	Female	9	5.5	1.23	0.76
Knee		Male	6	5.31	1.03	
	Turnout pants	Female	9	11.27	1.7	0.36
		Male	6	12.02	1.13	
	Station pants	Female	9	5.39	1.06	0.17
Calf		Male	6	4.67	0.69	
	Turnout pants	Female	9	11.43	1.43	0.49
		Male	6	12.02	1.82	
	Station pants	Female	9	7.97	1.34	0.046*
Ankle		Male	6	6.68	0.54	
	Turnout pants	Female	9	14.3	2.35	0.359
		Male	6	15.44	2.12	
	Station pants	Female	9	0.78	4.52	0.857
Inseam		Male	6	0.4	2.6	

**Table 3**. Difference between baseline measurements and uniform pants, based on mean data (inches)

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	Turnout pants	Female	9	2.56	3.29	0.135
		Male	6	5.26	3.08	
	Station pants	Female	9	0.68	1.49	0.184
Pant Rise		Male	6	-0.27	0.88	
	Turnout pants	Female	9	0.82	1.43	0.101
		Male	6	-0.47	1.3	

Significant differences between female and male firefighters (\* p<.05, \*\* p<.01)

## 4.3.4 Joint Angle Assessment

Joint angles were measured in two active positions: bending/lifting and stepping. The bending/lifting action required participants to bend down, pick up a large object and lift it 12 inches off the ground. The stepping motion required participants to step up on an 8" step (step 1) as well as a 17" step (step 2). Of the 8 measurement points, three particular joint angles, (hip flexion, knee flexion and dorsiflexion) were measured in this task using a goniometer (Lafayette Instrument, Model No. 01135). These lower-body positions were guided by Keyserling and Budnick's (1987) study that evaluated joint angles of working postures. These three joint areas were chosen because of their primary role in the lower-body movement. To compare the percentage loss in ROM between the sexes, the differences between the joint angles at the three flexion points wearing the station and turnout pants were measured. The results showed that while wearing station pants, female firefighters experienced a 2.34% of motion difference (loss) in hip flexion as compared to their male colleagues. Knee ROM was also reduced for female firefighters at the bending and stepping levels for both the station and turnout pants in the range of .42% to 5.72%. Female firefighters also lost ROM at the stepping levels, and a greater loss was evident as the stepping height increased. While wearing turnout pants, female firefighters experienced .84% of motion difference (loss) in hip flexion as compared to their male colleagues. Dorsiflexion ROM was also reduced for female firefighters at the bending and stepping levels for the turnout pants in the range of 2.3% to 12.2%. Overall, female firefighters

showed a narrower ROM in the occupational positions than their male counterparts, potentially

due to poor fitting uniform pants that impede a full range of movement.

**Table 4**. Joint angles for firefighters in occupation-related positions & ROM % difference

 between genders

			Station			Turnout	
Joint Angle	Position	Female	Male	ROM	Female	Male	ROM
		(N=9)	(N=0)		(N=9)	(N=6)	
				70			70
Hip Flexion	Bending	92.78	95	2.34%	92.22	93	.84%
	Step 1	122.78	124.17	1.12%	119.22	121.83	2.14%
	Step 2	90.89	90.67	.24%*	91.33	91	.36%*
Knee Flexion	Bending	123.56	127.5	3.09%	116.44	123.5	5.72%
	Step 1	111.11	114	2.54%	111.33	115	3.19%
	Step 2	88.11	91.5	3.70%	92.44	92.83	.42%
Dorsiflexion	Bending	90.63	89	1.83%*	83.33	95	12.28%
	Step 1	89.22	90.17	1.05%	84.11	89.67	6.20%
	Step 2	84	87	3.45%	86.11	88.17	2.34%

\*ROM at the positions did not decrease.

Data were also collected in the form of still images that illustrate visual representation of poor fit. Photographs were evaluated for areas that show stress folds, compression of the body, and distorted areas of the silhouette that visually identify areas of misfit (Ashdown et al., 2004). Images were also used to support and further understand the participant's claims (via survey, active position evaluation or exit interview) of poor fit or discomfort. Congruent with survey results, female firefighters show more garment tension at their hips, across their abdomen, throughout their seat, and waist than their male counterparts. Figure 3 shows a visual comparison between the two sexes.

Bending & Lifting (Station pants)

Step 1 (Station pants)

Step 2 (Station pants)

Step 1 (Turnout pants)

Figure 4. Visual fit analysis in active positions





Female

Male

## 4.3.5 Exit Interview

The exit interview data revealed that seven out of nine female firefighters would like to change and improve the fit of their station pants, while only one of the six male participants mentioned the fit as an aspect he would like to change about his station pants. Main areas identified as needing improvement included lower waist position, less tight in the hips, and shorter pant rise. The two female firefighters who did not specifically comment on the fit of their station pants mentioned wanting to reduce the amount of fabric or "bulk" of fabric at the front of the abdomen. The excess fabric on the front placket of the pants seemed especially noticeable to the participants when they were bending or moving. The male participant who indicated the fit of station pants as a concern identified poor fit in the crotch that radiated down to his knee during movements that required a stepping action.

When asked which aspect firefighters would most like to change about their turnout pants, four female firefighters commented that they found their turnout pants to be too bulky and that due to the bulkiness, they felt restricted. Comments included:

I think I would change the bulkiness if at all possible. While I was bending over, picking things up, I hadn't ever realized that it changes my body mechanics - completely. So probably just the bulkiness if that's even possible (Female FF #05).

The proportions of them to be less bulky. As they are currently, they are so wide that when I walk, there is some abrasion between my legs and ankle area. This causes holes and comprises the safety and efficacy of my pants. So, I would make them more fitted, to me (Female FF #06).

One female firefighter desired increased flexibility in her turnout pants. She commented that in order to achieve her desired ease in range of motion, she purposely wears turnout pants that are too big despite the fact that she notices an increase in bulkiness.

When asked to identify one thing they liked about their turnout pants, two female firefighters could not identify one aspect they enjoyed. Two female firefighters stated that they best enjoyed their pants pockets; two stated that the length of their current turnout pants satisfies them. The remaining female firefighters referred to previous turnout pants they have worked in and said in comparison, what they are wearing now are improved in fit and size.

In contrast, two male participants commented on enjoying the overall fit and ease of mobility in their turnout pants. One commented, "I like the fact that when I have them on, I don't feel restricted at all. I feel like I have clear movement (Male FF #10)."

Two female firefighters suggested that the station uniform needs further development and improved sizes for female bodies. One participant commented that she feels as though poor fit affects her ability to look professional in her station uniform:

If we are going out in the public, the men always look nice and we kind of always look frumpy - it seems. Or, our station pants are super tight or super loose, or they just never fit us the same way they fit the men. So it doesn't have to be a tight-cut women's t-shirt, but a men's medium t-shirt just always looks like you're wearing your dad's clothes (Female FF #04).

## 4.4 Discussion

Female participants in this study were, on average, older in age and had served more years within the occupation of firefighting than the male participants. Overall, female firefighters were eager to participate and easily expressed their concerns about their current

turnout uniform. However, male participants were, in general, younger and served fewer years as firefighters, overall. Firefighters typically are not fitted for their personalized station uniform until after passing a training academy and being hired with a department. Firefighters with only one year of experience may still be wearing a "hand me down" garment; for this study there were two male firefighters who had only 1 year of firefighting experience. A lack of a personalized uniform could result in poor fit as a result of wrong sizing. This speculation needs to further be investigated.

Female firefighters identified that their overall satisfaction with the fit of their station pants and turnout pants is lacking. This is consistent with the previous studies that have been conducted (Boorady et al., 2013b; Hulett et al., 2008; Park & Hahn, 2014; Sinden et al., 2011). Female firefighters continued to express an increased perception of hindered mobility and reduced job performance due to wearing both their station pants and turnout pants. In other words, female firefighters consider their current uniform to be a potential risk factor for reduced job performance and mobility. Female firefighters' survey responses were supported by their exit interviews which continued to elaborate on their desire to improve uniform fit in an attempt to increase mobility. Female firefighters (and one male firefighter) discussed having to make adjustments to their station pants when stepping up to accommodate for a lack of ease or stretch within the garment. By pulling their station pant leg up, firefighters were able to shorten the pant rise and allow a greater range of motion with their hip. The necessity to make this accommodation was present when firefighters wore their station pants under their turnout pants and prompted many of the participants (of both sexes) to prefer wearing shorts instead. While shorts allowed for less tension at the knee, and were viewed as less distracting during an

emergency situation, the accommodation likely increases the firefighter's occupational hazards by exposing their bare skin to the fire.

Through the subjective evaluation, female firefighters reported the waist, hips and thigh circumference of their station pants to be too tight. Congruent with the survey data, the 3D body scan data expressed the smallest margin of measurement difference for waist, hips, thigh, inseam and pant rise between the female firefighters' baseline measurements and their station pants, signifying a narrow ease around the body parts. While the survey evaluates the wearer's perceived experience with fit and comfort, the 3D body scanner uses objective measurements only. All defined measurement points on turnout pants were perceived as too big for female firefighters, except for their inseam. Again, congruent with the survey responses, the 3D body scanning measurements noted at least a 5" margin of ease, with the exception of the inseam and pant rise.

Female firefighters reported feeling tension at the hip during the bending and stepping activities. Specifically they reported that there was an excess of material located at the abdomen, which continually bunched up with any movement outside of standing still. Participants repeatedly stated that they specifically order station pants 1-2 sizes larger than their recommended size for them to feel increased ease in the hips and extended movement. A consequence of ordering a larger size, however, is that the crotch would then hang lower; thus, making it more difficult to step up or have full range of lower body motion. With the stepping action, both male and female participants reported feeling strong tension at their knee, from a lack of stretch or flexibility in their station pants.

Both female and male participants reported feeling the same tension at the knee when they were wearing their turnout pants. Many assumed that was due to the station pants more

than the turnout pants. Although the firefighters did feel a sensation of pinching or tightness at their knee, overall, participants still found their turnout pants to be bulky and restrictive in their movement.

## 4.5 Conclusion

This study focused on evaluating gender-specific fit discrepancies in relation to firefighters' body shape and movements. The findings of this study suggest that female firefighters' lower satisfaction with their station pants and turnout pants, compared to that of their male colleagues, may be attributed to the use of turnout ensembles better designed for the male body shape. Current uniform pants are ill-fitting for female firefighters, specifically in the waist, hips and thigh. Although research and standards have been dedicated to improving PPE, the low satisfaction ratings from this study suggest the need to further develop uniform designs and fit for female firefighters. The turnout ensemble is especially critical to the firefighter as it is their main protection against high heat stress, hazardous chemicals, gas and physical collision (Park & Hahn, 2014). In addition, they are required to perform physically demanding tasks and wearing an ill-fitting uniform can increase discomfort, physical strain, and risk of injury or stress. In particular, wearing poor fitting uniforms may impede or compromise proper body movement (Park & Hahn, 2014) that may cause increased strain, discomfort or increased injury risk. In addition, restricted lower body movement due to a low crotch and poor fit in the hips can have a negative impact on female firefighters' physical movement when having to bend, step up, or move quickly.

The sources of data collected for this study are representative of only those community members involved. Nine female and six male structural firefighters located in the Midwestern region of the United States participated in this study. As such, due to a small sample size, results

from this study may not be generalizable to the larger firefighting community. Further investigations are desired with a larger sample size of both male and female firefighters. In addition, this study evaluated firefighters' perceptions of their current station and turnout pants, which may vary in design, longevity and manufacturer. Researchers should continue to evaluate specific designs and fit to in relation to female firefighters' mobility and comfort. The goniometer remains as one of the most versatile and commonly used instruments within the clinical industry (Gajdosik & Bohannon, 1987), however, it should be acknowledged that the reliability of goniometry may be affected by many factors, including human error. Some previous research has noted that there may be up to a 15-degree margin of error (Gajdosik & Bohannon, 1987; Harris, Smith, & Krukowski, 1985; Enwemeka, 1986); thus to improve data reliability and validity, other measurement protocols such as the wireless motion capture (MoCap) system should be considered for future research. Designers should explore design solutions for innovative uniforms that satisfy a need for high protection and high mobility that are required for firefighters. In an attempt to increase mobility, particular attention should be given to the station pants, which currently offer no stretch or ease with body movements. Moreover, it is important to evaluate and improve the firefighting uniform as a full ensemble to ensure that each element works efficiently and compatibly with one another.

The outcome of this study is expected to provide the apparel industry and researchers with practical guidance in advancing the development of improved fit and sizing systems for female structural firefighters; as well as provide scientific evidence of poor fit to policy makers within the firefighting industry. Three-dimensional body scanning technology offers a vital tool to generate and store accurate anthropometric data of diverse populations with various body shapes. Collecting this information is a crucial step in the development of customized garments

and improved uniform size-ranges for female firefighters that specifically address differences in physical profiles, not just smaller versions of one pattern. Anthropometric and ROM data, along with descriptive accounts from the study participants, can be used to facilitate effective communication with the manufactures of firefighter protective clothing by providing a visual, numerical and descriptive account of female firefighter's fit concerns. A multi-dimensional fit evaluation provides a comprehensive representation of the relationship between the wearer and the garment, which helps in understanding how to adjust patterns and sizing systems to better fit the female firefighter population and ultimately improve their occupational safety in the fire field.

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APPENDICES

## APPENDIX A

## **IRB** Approval Letter

Research Integrity & Compliance Review Office Office of the Vice President for Research 321 General Services Building - Campus Delivery 2011 Fort Collins, CO TEL: (970) 491-1553

TEL: (970) 491-1553 FAX: (970) 491-2293

### NOTICE OF APPROVAL FOR HUMAN RESEARCH

DATE:	April 20, 2014					
то:	Park, Juyeon, 1574 Design and Merchandising	Park, Juyeon, 1574 Design and Merchandising				
	Langseth-Schmidt, Kiri, 1574 Design and Mer	Langseth-Schmidt, Kiri, 1574 Design and Merchandising, Miller, Nancy, 1574 Design and Merchandising				
FROM:	Barker, Janell, Coordinator, CSU IRB 2	Barker, Janell, Coordinator, CSU IRB 2				
PROTOCOL TITLE:	Fit evaluation of structural firefighters' protective pants using a 3D body scanner: A gender comparison study					
FUNDING SOURCE:	NONE					
PROTOCOL NUMBER:	14-4833H					
APPROVAL PERIOD:	Approval Date: April 16, 2014	Expiration Date: March 26, 2015				

The CSU Institutional Review Board (IRB) for the protection of human subjects has reviewed the protocol entitled: Fit evaluation of structural firefighters' protective pants using a 3D body scanner: A gender comparison study. The project has been approved for the procedures and subjects described in the protocol. This protocol must be reviewed for renewal on a yearly basis for as long as the research remains active. Should the protocol not be renewed before expiration, all activities must cease until the protocol has been re-reviewed.

If approval did not accompany a proposal when it was submitted to a sponsor, it is the PI's responsibility to provide the sponsor with the approval notice.

This approval is issued under Colorado State University's Federal Wide Assurance 00000647 with the Office for Human Research Protections (OHRP). If you have any questions regarding your obligations under CSU's Assurance, please do not hesitate to contact us.

Please direct any questions about the IRB's actions on this project to:

Janell Barker, Senior IRB Coordinator - (970) 491-1655 <u>Janell.Barker@Colostate.edu</u> Evelyn Swiss, IRB Coordinator - (970) 491-1381 <u>Evelyn.Swiss@Colostate.edu</u>

Barker, Janell

Barker, Janell

Approval is to recruit up to 20 participants with the approved recruitment and consent. The above-referenced project was approved by the Institutional Review Board with the condition that the approved consent form is signed by the subjects and each subject is given a copy of the form. NO changes may be made to this document without first obtaining the approval of the IRB. NOTE: When available, please submit the email/letter of support from the PFA chef as an amendment via eProtocol to document his/her willingness to assist with this research.

Approval Period: Review Type: IRB Number: April 16, 2014 through March 26, 2015 EXPEDITED 00000202



DATE

## APPENDIX B

## Email Script to PFA & to FireWomen.org:

Dear \_\_\_\_\_,

I am a graduate student who is working with Dr. Juyeon Park in the Department of Design and Merchandising at Colorado State University, in Fort Collins. For my thesis, I am conducting a research study on measuring lower-body dimensions of structural firefighter participants using 3D body scanning technology, in an effort to identify a fit evaluation protocol for the development of improved firefighting protective pants.

In recruiting participants for the study, I would like to reach <u>female</u> firefighters who may be interested in assisting with this study. For this project, a visit to the CSU campus would be required and appointments are expected to start in early June. Could you please forward the recruitment message that is attached to this e-mail, to your firefighters?

Please feel free to contact me if you have any questions or need clarification. Thank you for your time and consideration.

Sincerely,

Kiri Langseth-Schmidt Graduate Student & Research Assistant Department of Design & Merchandising Colorado State University Kiri424@gmail.com 218-349-7280

Dr. Juyeon Park, Ph.D. Director, Human Body Dimensioning Facility Department of Design & Merchandising Colorado State University Juyeon.park@colostate.edu 970-491-4104

## APPENDIX C

## Firefighter Recruitment Letter

Dear Firefighters,

I am Kiri Langseth-Schmidt, a graduate student in the Department of Design and Merchandising at Colorado State University. Currently I am doing a study on measuring lower-body dimensions of structural firefighter participants using 3D body scanning technology, in an effort to identify a fit evaluation protocol for the development of improved firefighting protective pants.

## I am looking for:

- FEMALE participants;
- Who have at least one season of experience in structural firefighting;
- Who are 18+ years old.

Once you agree to participate, you will be asked to visit our research lab, (Human Body Dimensioning Lab) in room 141, Gifford Building on the CSU campus. Prior to 3D scanning, you will be asked to complete a survey that consists of questions about your work experience and perception of the current personal protective clothing. Following the survey, you will be invited to participate in the 3D body scanning. You will be scanned in three different layers of clothing (undergarments for baseline measurements, station pants only, and station pants + turnout pants). You will be scanned in a standing position as well as a ladder climbing position to better understand garment performance. The total time asked is approximately 1 1/2 hours, and you will be compensated in cash (\$20/hr) for your participation.

The 3D body scanner uses non-invasive laser beams to measure the dimensions of the human body, so there will be no known risks associated with the data collection procedure. The collected data from this study will contribute to the development of protective clothing with enhanced mobility, performance, and safety.

If you are interested in participating in this study, or you have questions, please contact me by phone or email. I will then contact you for scheduling of your appointment. Thank you very much for your willingness to participate in advance.

Sincerely,

Kiri Langseth-Schmidt Graduate Student & Research Assistant Dept of Design & Merchandising Colorado State University Kiri424@gmail.com 218-349-7280 Dr. Juyeon Park, Ph.D. Director, Human Body Dimensioning Facility Dept of Design & Merchandising Colorado State University Juyeon.park@colostate.edu 970-491-4104

## APPENDIX D

### Participant E-mail

Dear (Participant),

Thank you for your interest in participating in my upcoming study that evaluates the fit of structural firefighter turnout pants. Your survey and scan appointment is scheduled for (date) at (time) in the Human Body Dimensioning Lab located on the Colorado State University Campus in the Gifford Building, room 141.

When you come to your appointment, please bring the following:

- 1) Station pants
- 2) Turnout pants
- 3) Boots
- 4) Any tools or equipment that are associated with your pants

This study focuses on measuring lower-body dimensions, you do not need to bring your turnout jacket, helmet, and SBCA. A basic T-shirt (or long sleeve shirt) may be worn on top. Please be aware that your body will be measured in undergarments (sports bra & bottoms), using a 3D body scanner to acquire baseline body measurements; this image & data will only be seen by the researchers.

The 3D body scanner uses non-invasive depth sensors, so there will be no known risks associated with the procedure. Your identity will not be linked with any of your scan or survey information. The total duration of time commitment expected is approximately  $1\frac{1}{2}$  hours, and you will receive a monetary stipend (\$20/hr) for your time and assistance with this project.

Please view the following video on the 3D body scanning process: http://youtu.be/PxKH9C7bs7Y

We are located here (the lab is located on the floor that you will enter on, in the South West corner):

http://maps.colostate.edu/default.aspx?tag=4&location=63

Parking is free on Lake Street, however, finding parking can be tricky. The Lake Street parking garage has the best prices (\$1.25/hour) & is only a short walk to our building: http://maps.colostate.edu/default.aspx?tag=15&location=102

If you have any questions or concerns regarding this study, please feel free to contact me at <u>Kiri424@gmail.com</u> or 218-349-7280 (call or text).

Sincerely,

Kiri Langseth-Schmidt Graduate Student & Research Assistant Dept of Design & Merchandising Colorado State University <u>Kiri424@gmail.com</u> 218-349-7280

Dr. Juyeon Park, Ph.D. Director, Human Body Dimensioning Facility Department of Design & Merchandising Colorado State University Juyeon.park@colostate.edu 970-491-4104

## APPENDIX E

## Data Protocol



Establishment of a fit evaluation protocol for structural firefighters' protective pants using a 3D body scanner: A gender comparison study

### Order of events:

- 1. Appointment overview
- 2. Paperwork
  - a. Participant consent
  - b. Survey
- 3. Baseline Measurements
  - a. 3D body scanning Introduction
    - i. Baseline measurements (undergarments)
- 4. Station pants\*
  - i. 3D Scan
  - ii. Active Positions
    - 1. Bend & picking up object
    - 2. Ladder climbing
- 5. Station pants + turnout pants\*
  - i. 3D Scan
  - ii. Active Positions
    - 1. Bend & picking up object
    - 2. Ladder climbing
- 6. Station pants + turnout pants + tools\*
  - i. 3D Scan
  - ii. Active Positions
    - 1. Bend & picking up object
    - 2. Ladder climbing
- 7. Exit interview
  - a. Recorded participant questions (4-5 short)
- 8. Participant compensation
  - a. Receipt
- \* = Still & video imaging may be used

## APPENDIX F

### Participant consent

#### Consent to Participate in a Research Study Colorado State University

# TITLE OF STUDY: Establishment of a fit evaluation protocol for structural firefighters' protective pants using a 3D body scanner: A gender comparison study

### WHY AM I BEING INVITED TO TAKE PART IN THIS RESEARCH?

You were recruited as a study participant, because you are female, you have at least one season's experience in structural firefighting, and are 18 years or older.

### WHO IS DOING THE STUDY?

Kirian (Kiri) Langseth-Schmidt, Graduate Student, Co-PI, Department of Design and Merchandising, Colorado State University, <u>Kiri.Langseth-Schmidt@colostate.edu</u> Juyeon Park, Ph.D., PI, Department of Design & Merchandising, Colorado State University, Juyeon.Park@colostate.edu

### WHAT IS THE PURPOSE OF THIS STUDY?

The purpose of this study is to evaluate lower-body measurements of structural firefighters using 3D body scanning technology. The focus of this study is to identify areas of poor fit in firefighting pants (comparing male and female structural firefighters) & to establish an effective method for evaluating proper fit of these garments.

#### WHERE IS THE STUDY GOING TO TAKE PLACE AND HOW LONG WILL IT LAST?

The data collection will take place at the Human Body Dimensioning (HBD) Laboratory, located in the Gifford building at Colorado State University. The total duration of time commitment expected is approximately 1 ½ hours, and you will be compensated in cash (\$20/hour) for your participation. Thus, you will receive \$30 upon the completion of your participation.

#### WHAT WILL I BE ASKED TO DO?

If you decide to join this study, you will be contacted by phone or e-mail to establish a convenient time for your appointment. All research will take place on the Colorado State University campus. You will receive an appointment confirmation via e-mail that includes a reminder to bring your station pants, turnout pants, boots and any tools or equipment associated with your pants. This study focuses on measuring lower-body dimensions and therefore, you do not need to bring your turnout jacket, helmet or SBCA. Please be aware that your body will be measured in undergarments (those typically worn under your uniform) using a 3D body scanner.

Upon your arrival to the Human Body Dimensioning Lab, the study investigator will greet you and outline the details of your appointment. You will then be asked to complete a survey that consists of questions about your background information, and perception of personal protective clothing; specifically the fit and comfort of your station and turnout pants.

Following the survey, you will be invited to participate in the 3D body scanning. You will be asked to put on the three different layers of clothing (1. Undergarments, 2. Station pants, 3. Station pants + turnout pants) and stand in the center of the 3D body scanner, while non-invasive (depthsensor) laser beams measure the dimensions of your body. In addition to a standing position, the study investigator will also ask you to stand in an occupation related position (i.e., ladder climbing position). For the occupation related position, you will be asked to pose with your right foot on two different platform heights, to mimic a ladder climbing position. Your joint angles will be measured using a goniometer & your pose may be photographed or video documented.

Following the completion of the body scanning, you will be invited to revisit your survey, if you would like to contribute any new information. Still photos may be taken, in addition to the 3D

Page 1 of 3 Participant's initials \_\_\_\_\_ Date \_\_\_\_\_

CSU#: 14-4833H APPROVED: 4/16/14 EXPIRES: 3/26/15 body scans, as a visual tool for the study investigators to evaluate stress folds, garment tension and/or visual representation of poor fit.

### ARE THERE REASONS WHY I SHOULD NOT TAKE PART IN THIS STUDY?

You should not participate in this study if you do not meet the inclusion criteria: female structural firefighter; has a minimum of one year of work experience; is 18 years or older.

### WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

You may experience minor psychological discomfort when your body is scanned with the scanning devices. However, the 3D body scanner and Kinect motion system use non-invasive depth sensors to measure the dimension of the human body, there are no known risks associated with the procedures. If you feel uncomfortable with the experiment procedure, please feel free to let one of the study investigators know. Additionally, you may withdraw from the study at any time.

#### ARE THERE ANY BENEFITS FROM TAKING PART IN THIS STUDY?

There will be no direct benefit to participants. However, your study participation may contribute to the development of improved protective clothing for structural firefighters with enhanced comfort, fit, performance, and safety. Upon request, you may receive a copy of your scan data that includes multiple measurement data points.

#### DO I HAVE TO TAKE PART IN THE STUDY?

Your participation in this research is voluntary. If you decide to participate in the study, you may withdraw your consent and stop participating at any time without penalty or loss of benefits to which you are otherwise entitled.

### WHO WILL SEE THE INFORMATION THAT I GIVE?

We will keep private all research records that identify you, to the extent allowed by law. For this study, we will assign a code to your data (e.g. "Participant 1") so that the only place your name will appear in our records is on the consent form and in our data spreadsheet, which links you to your code. If necessary, the Colorado State University Institutional Review Board (CSU IRB), and the study investigators may inspect these records. All original data will be stored in the principal investigator's research file storage and destroyed after three years of the study completion. Only the researchers will view the photos taken of you. In the event that a fire department wants to examine data, or for publication purposes, the photos will be cropped to remove the face and torso, and focus on the lower body (waist and legs) to protect your identity. No photos will be taken for the baseline (undergarment) position. Photos will also be destroyed after three years of the study completion.

### CAN MY TAKING PART IN THE STUDY END EARLY?

If, for any reason, you wish to end your participation early, feel free to request the study investigators to make arrangements.

### WILL I RECEIVE ANY COMPENSATION FOR TAKING PART IN THIS STUDY?

\$20/hour cash incentive will be compensated upon completion of your participation. The estimated time commitment is 1 hour and 30 minutes, and the total compensation for your participation will be \$30. Your identity/record of receiving compensation (NOT your data) may be made available to CSU officials for financial audits.

#### WHAT IF I HAVE QUESTIONS?

Before you decide whether to accept this invitation to take part in the study, please ask any questions that might come to mind now. Later, if you have questions about the study, you may contact Kiri Langseth-Schmidt at <u>Kiri.Langseth-Schmidt@colostate.edu</u> or Juyeon Park, PhD at <u>Juyeon.Park@colostate.edu</u>. If you have any questions about your rights as a volunteer in this study, contact Janell Barker, Human Research Administrator at (970) 491-1655. Please take a copy of this consent form with you for your record.

Page 2 of 3 Participant's initials \_\_\_\_\_ Date \_\_\_\_

CSU#: 14-4833H APPROVED: 4/16/14 EXPIRES: 3/26/15
If you are interested in participating in this project, please sign below. Your signature acknowledges that you have read the information stated and willingly sign this consent form. Your signature also acknowledges that you have received, on the date signed, a copy of this document containing 3 pages.

Signature of person agreeing to take part in the study

Date

Printed name of person agreeing to take part in the study

Name of person providing information to participant

Date

Signature of Research Staff

Page 3 of 3 Participant's initials \_\_\_\_\_ Date \_\_\_\_\_

# APPENDIX G

## Participant Consent (Male)

#### Consent to Participate in a Research Study Colorado State University

# TITLE OF STUDY: Establishment of a fit evaluation protocol for structural firefighters' protective pants using a 3D body scanner: A gender comparison study

#### WHY AM I BEING INVITED TO TAKE PART IN THIS RESEARCH?

You were recruited as a study participant, because you are male, you have at least one season's experience in structural firefighting, and are 18 years or older.

## WHO IS DOING THE STUDY?

Kirian (Kiri) Langseth-Schmidt, Graduate Student, Co-PI, Department of Design and Merchandising, Colorado State University, <u>Kiri.Langseth-Schmidt@colostate.edu</u> Juyeon Park, Ph.D., PI, Department of Design & Merchandising, Colorado State University, <u>Juyeon.Park@colostate.edu</u>

## WHAT IS THE PURPOSE OF THIS STUDY?

The purpose of this study is to evaluate lower-body measurements of structural firefighters using 3D body scanning technology. The focus of this study is to identify areas of poor fit in firefighting pants (comparing male and female structural firefighters) & to establish an effective method for evaluating proper fit of these garments.

### WHERE IS THE STUDY GOING TO TAKE PLACE AND HOW LONG WILL IT LAST?

The data collection will take place at the Human Body Dimensioning (HBD) Laboratory, located in the Gifford building at Colorado State University. The total duration of time commitment expected is approximately 1 ½ hours, and you will be compensated in cash (\$20/hour) for your participation. Thus, you will receive \$30 upon the completion of your participation.

#### WHAT WILL I BE ASKED TO DO?

If you decide to join this study, you will be contacted by phone or e-mail to establish a convenient time for your appointment. All research will take place on the Colorado State University campus. You will receive an appointment confirmation via e-mail that includes a reminder to bring your station pants, turnout pants, boots and any tools or equipment associated with your pants. This study focuses on measuring lower-body dimensions and therefore, you do not need to bring your turnout jacket, helmet or SBCA. Please be aware that your body will be measured in undergarments (those typically worn under your uniform) using a 3D body scanner.

Upon your arrival to the Human Body Dimensioning Lab, the study investigator will greet you and outline the details of your appointment. You will then be asked to complete a survey that consists of questions about your background information, and perception of personal protective clothing; specifically the fit and comfort of your station and turnout pants.

Following the survey, you will be invited to participate in the 3D body scanning. You will be asked to put on the three different layers of clothing (1. Undergarments, 2. Station pants, 3. Station pants + turnout pants) and stand in the center of the 3D body scanner, while non-invasive (depthsensor) laser beams measure the dimensions of your body. In addition to a standing position, the study investigator will also ask you to stand in an occupation related position (i.e., ladder climbing position). For the occupation related position, you will be asked to pose with your right foot on two different platform heights, to mimic a ladder climbing position. Your joint angles will be measured using a goniometer & your pose may be photographed or video documented.

Following the completion of the body scanning, you will be invited to revisit your survey, if you would like to contribute any new information. Still photos may be taken, in addition to the 3D

Page 1 of 3 Participant's initials \_\_\_\_\_ Date \_\_\_\_

body scans, as a visual tool for the study investigators to evaluate stress folds, garment tension and/or visual representation of poor fit.

### ARE THERE REASONS WHY I SHOULD NOT TAKE PART IN THIS STUDY?

You should not participate in this study if you do not meet the inclusion criteria: male structural firefighter; has a minimum of one year of work experience; is 18 years or older.

#### WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS?

You may experience minor psychological discomfort when your body is scanned with the scanning devices. However, the 3D body scanner and Kinect motion system use non-invasive depth sensors to measure the dimension of the human body, there are no known risks associated with the procedures. If you feel uncomfortable with the experiment procedure, please feel free to let one of the study investigators know. Additionally, you may withdraw from the study at any time.

## ARE THERE ANY BENEFITS FROM TAKING PART IN THIS STUDY?

There will be no direct benefit to participants. However, your study participation may contribute to the development of improved protective clothing for structural firefighters with enhanced comfort, fit, performance, and safety. Upon request, you may receive a copy of your scan data that includes multiple measurement data points.

### DO I HAVE TO TAKE PART IN THE STUDY?

Your participation in this research is voluntary. If you decide to participate in the study, you may withdraw your consent and stop participating at any time without penalty or loss of benefits to which you are otherwise entitled.

#### WHO WILL SEE THE INFORMATION THAT I GIVE?

We will keep private all research records that identify you, to the extent allowed by law. For this study, we will assign a code to your data (e.g. "Participant 1") so that the only place your name will appear in our records is on the consent form and in our data spreadsheet, which links you to your code. If necessary, the Colorado State University Institutional Review Board (CSU IRB), and the study investigators may inspect these records. All original data will be stored in the principal investigator's research file storage and destroyed after three years of the study completion. Only the researchers will view the photos taken of you. In the event that a fire department wants to examine data, or for publication purposes, the photos will be cropped to remove the face and torso, and focus on the lower body (waist and legs) to protect your identity. No photos will be taken for the baseline (undergarment) position. Photos will also be destroyed after three years of the study completion.

#### CAN MY TAKING PART IN THE STUDY END EARLY?

If, for any reason, you wish to end your participation early, feel free to request the study investigators to make arrangements.

## WILL I RECEIVE ANY COMPENSATION FOR TAKING PART IN THIS STUDY?

\$20/hour cash incentive will be compensated upon completion of your participation. The estimated time commitment is 1 hour and 30 minutes, and the total compensation for your participation will be \$30. Your identity/record of receiving compensation (NOT your data) may be made available to CSU officials for financial audits.

## WHAT IF I HAVE QUESTIONS?

Before you decide whether to accept this invitation to take part in the study, please ask any questions that might come to mind now. Later, if you have questions about the study, you may contact Kiri Langseth-Schmidt at <u>Kiri.Langseth-Schmidt@colostate.edu</u> or Juyeon Park, PhD at <u>Juyeon.Park@colostate.edu</u>. If you have any questions about your rights as a volunteer in this study, contact Janell Barker, Human Research Administrator at (970) 491-1655. Please take a copy of this consent form with you for your record.

Page 2 of 3 Participant's initials \_\_\_\_\_ Date \_\_\_\_\_

If you are interested in participating in this project, please sign below. Your signature acknowledges that you have read the information stated and willingly sign this consent form. Your signature also acknowledges that you have received, on the date signed, a copy of this document containing 3 pages.

Signature of person agreeing to take part in the study

Date

Printed name of person agreeing to take part in the study

Name of person providing information to participant

Date

Signature of Research Staff

Page 3 of 3 Participant's initials \_\_\_\_\_ Date \_\_\_\_\_

# APPENDIX H

# Participant Survey

Health&Human Sciences Design & Merchandising



Establishment of a fit evaluation protocol for structural firefighters' protective pants using a 3D body scanner: A gender comparison study Please take a few minutes to fill out this survey, prior to 3D body scanning.

Background Information						
Sex: 🗆 Male 🗆 Female	Age:	years old				
Physical Profile:						
Height ft in	Weight Ibs					
Regular clothing size (circle): XS	S M L XL 2XL	3XL 4XL				
Regular shoe size (circle): 5 5 $\frac{1}{2}$ 6	61/2 7 71/2 8 81/2 9 91/2 10 101/2	2 11 11 ½ 12 12 ½ 13 13 ½ 14				
Occupation Type and Duration:						
Type of firefighter (circle): 🛛 Structural 🖓 Wildland 🖓 Both						
Prof	essional 🗆 Volunteer					
What is your job responsibility (title)?						
What is your department?						
How long have you been in the firefig	ghting occupation? yea	ır(s) month(s)				
Marital Status: Single Widowed	□ Married □ In relationship	Divorced				
Ethnicity: D Native American Asian Multiracial	Ethnicity:       Image: African American       Image: Caucasian         Image: Asian       Image: Hispanic/Latino       Image: Caucasian         Image: Multiracial       Image: Other Image: Caucasian       Image: Caucasian					
Station Pants Ple	ease answer the following questions in	n regards to your station pants.				
Current Size: Waist Inseam (length)						
Longevity: How old are your current station pan Less than 1 year old 5-6 years old	ts? □ 1-2 years old □ 7-8 years old	□ 3-4 years old □ 9+ years old				
Replacement: How often do you receive new static Less than 1 year Every 5-6 years old	on pants? □ Every 1-2 years □ Every 7-8 years old	<ul> <li>Every 3-4 years old</li> <li>Never</li> </ul>				
Frequency: Do you wear station pants under you Yes, always.	ur turnout pants? Sometimes.	□ Never.				
hank you for your participation. For office use only: ID#						





If you checked "sometimes" or "never," please list what you typically wear under your turnout pants:

## Evaluation of Current Station Pants

# Please rate your current station pants & provide comments, if necessary:

Station pants evaluation (1 = strongly disagree, 3 =	neutral,5	5 = S	stron	gly a	igree	e)
Overall, I am satisfied with the fit of my current station pants. Comments:		1	2	3	4	5
My current station pants help to protect me from occupational injuries or risks. Comments:		1	2	3	4	5
My current station pants are comfortable. Comments:		1	2	3	4	5
My current station pants hinder (or reduce) my mobility. Comments:		1	2	3	4	5
My current station pants hinder (or reduce) my job performance or duties. Comments:		1	2	3	4	5
I have experienced occupational injury or risks due to the poor fit of my station p Comments:	ants.	1	2	3	4	5
I have experienced occupational injury or risks due to the stiffness (inflexibility) of station pants. Comments:	my	1	2	3	4	5
I have experienced occupational injury or risks due to the bulkiness of my station Comments:	pants.	1	2	3	4	5

## Please rate the <u>fit</u> of your station pants:

Current Station Pants Fit Evaluation	(1 = very tight, 3 = perfect	fit, 5	= Ve	ery Ic	oose)	
Waist		1	2	3	4	5

Thank you for your participation.





Comments:					
Hips	1	2	3	4	5
Comments:					
Upper thigh girth (circumference around upper thigh)	1	2	3	4	5
Comments:					
Knee girth (circumference around knee)	1	2	3	4	5
Comments:					
Calf girth (circumference around calf)	1	2	3	4	5
Comments:					
Ankle girth (circumference around ankle)	1	2	3	4	5
Comments:					
Inseam length (distance from crotch to floor)	1	2	3	4	5
Comments:					
Distance from waist to crotch (pant rise)	1	2	3	4	5
Comments:					

#### Alterations:

Have you made any alterations to your station pants to improve the fit or comfort?

If you checked "yes" above, please describe:

# Turnout Pants Please answer the following questions in regards to your turnout pants

Current Size:

Waist \_\_\_\_\_ Inseam (length) \_\_\_\_\_

Thank you for your participation.

		Health*Human Sciences Design & Merchandising	Colorado State University
Longevity:	out pants?		
$\square$ Less than 1 year old	$\square$ 1-2 years old	$\Box$ 3-4 years old	
$\Box$ 5-6 years old	$\square$ 7-8 years old	$\square$ 9+ years old	
Replacement:			
How often do you receive ne	w turnout pants?		
🗆 Less than 1 year	Every 1-2 years	Every 3-4 years	old
Every 5-6 years old	Every 7-8 years old	□ Never	
Pockets: What items do you <u>carry</u> in yc	pur turnout pants pockets?		
Estimated weight of it	ems carried:	lbs.	
Attachments: What items do you <u>attach</u> to	your turnout pants?		
Estimated weight of it	ems attached:	lbs.	
Alterations: Have you made any alteration	ns to your turnout pants to imp	prove the fit?	
If you checked "yes" above.	please describe:		
Suspenders:			
Do you wear suspenders with	your turnout pants?		
🗆 Yes 🛛 No	□ Sometimes		

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For office use only: ID# \_\_\_\_\_

Thank you for your participation.





# Evaluation of Current Turnout Pants

# Please rate your current turnout pants & provide comments, if necessary:

Turnout Pants evaluation (1 = strongly	disagree, 3 = neutral,5	5 = S	trong	gly a	gree	)
Overall, I am satisfied with the fit of my current turnout pants. Comments:		1	2	3	4	5
My current turnout pants help to protect from occupational injuries Comments:	or risks.	1	2	3	4	5
My current turnout pants are comfortable. Comments:		1	2	3	4	5
My current turnout pants hinder (or reduce) my mobility. Comments:		1	2	3	4	5
My current turnout pants hinder (or reduce) my job performance or Comments:	duties.	1	2	3	4	5
I have experienced occupational injury or risks due to the poor fit o Comments:	f my turnout pants.	1	2	3	4	5
I have experienced occupational injury or risks due to the stiffness (i turnout pants. Comments:	nflexibility) of my	1	2	3	4	5
I have experienced occupational injury or risks due to the bulkiness pants. Comments:	of my turnout	1	2	3	4	5

# Please rate the <u>fit</u> of your turnout pants:

Current Fit Evaluation	(1 = very tight, 3 = perfec	t fit,	5 = v	ery l	oose	)
Waist		1	2	3	4	5
Comments:						

Thank you for your participation.

# Design & Merchandising



Hips Comments:	1	2	3	4	5
Upper thigh girth (circumference around upper thigh)	1	2	3	4	5
Comments:					
Knee girth (circumference around knee)	1	2	3	4	5
Comments:					
Calf girth (circumference around calf)	1	2	3	4	5
Comments:					
Ankle girth (circumference around ankle)	1	2	3	4	5
Comments:					
Inseam length (distance from crotch to floor)	1	2	3	4	5
Comments:					
Distance from waist to crotch (pant rise)	1	2	3	4	5
Comments:					
	1				

## Notes:

Are there any additional notes you would like to add?

Thank you for your participation.

# APPENDIX I

# Joint Angle Worksheet

Design & Merchandising



For office use only: ID# \_\_\_\_\_

# Ladder climbing – active body position Station Pants:

Position	Bending & Lifting	1 <sup>st</sup> Step: 8.25"	2 <sup>nd</sup> Step: 17.5"
Hip angle			
Comments:			
Knee angle			
Comments:			
Ankle angle			
Comments:			
Photo(s)	Distance from toe to		
	step:		

# Station pants + Turnout Pants:

Position	Bending & Lifting	1 <sup>st</sup> Step: 8.25"	2 <sup>nd</sup> Step: 17.5"
Hip angle			
Comments:			
Knee angle			
Comments:			
Ankle angle			
Comments:			
Photo(s)	Distance from toe to		
	step:		
	-		





# Station pants + Turnout Pants + GEAR:

Position	Bending & Lifting	1 <sup>st</sup> Step: 8.25"	2 <sup>nd</sup> Step: 17.5"
Hip angle			
Comments:			
Knee angle			
Comments:			
Ankle angle			
Comments:			
Photo(s)	Distance from toe to		
	step:		

# APPENDIX J

# Exit Interview Script



Establishment of a fit evaluation protocol for structural firefighters' protective pants using a 3D body scanner: A gender comparison study

Exit Interview

- 1. If you could <u>change</u> one (1) thing about your station pants, what would it be?
- 2. If you had to identify one (1) aspect that <u>you like</u> about your station pants, what would it be?
- 3. If you could <u>change</u> one (1) thing about your turnout pants, what would it be?
- 4. If you had to identify one (1) aspect that <u>you like</u> about your turnout pants, what would it be?
- Is there anything else that you would like to add related to your firefighting uniform, fit or comfort? (may be other items besides pants)