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Bunker Gear for Fire Fighters: Does it fit today's fire fighters?

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ABSTRACT

The fit of bunker gear is important to ensure the protection of the firefighter when they are combating structural fire and performing other hazardous duties. Bunker gear is regulated by the National Fire Protection Agency (NFPA) which requires a range of sizes and certain fit regulations due to safety. Firefighters are a specific segment of the population which may be appropriate for a specific sizing scheme. Body scans of career and volunteer male firefighters were compared to SizeUSA data. Differences were found in the height and weight, with male firefighters being heavier and taller than the general population. This research also looks at the procurement and sizing of bunker gear, analyzes body scan data specific to the firefighter population and suggests developing a sizing system specific to this population. A larger study would need to be conducted in order obtain statistically significant results.

Keywords: Bunker gear, Firefighter protection, Turnout gear

Introduction

The image of the heroic fire fighter is iconic. Firefighting is considered a prestigious occupation by 97% of the American public, according to a 2006 Harris Poll. Fire fighters walk into fire engulfed buildings to save lives, put themselves in danger when venting a roof to contain a fire and work diligently to protect the public from harm. On television and in movies, fire fighters are portrayed as healthy, strong individuals who are in top physical condition. Firefighting is a physically demanding and dangerous job. Since they are in a high risk job the general perception is that fire fighters would be in better physical shape than the average person. An understanding of the anthropometrics of the fire fighter population is needed in order to create a sizing scheme for this target market.

According to the U.S. Fire Administration, in 2013 there were 1,140,750 fire fighters in the United States. Of those, 354,600 were professional (or "career") and 786,150 were volunteers (U. S. Fire Administration, 2015). As of 2013, there were only 10,179 female fire fighters in the U.S. (U.S. Census Bureau, 2015). Fire fighters work in a demanding and dangerous occupation. Their bunker gear must be able to protect them through all aspects of their duties, most importantly the hostile environment of a structural fire. Regulations exist that state the level of protection the bunker gear must provide the fire fighter. However, gear that is ill fitting may not

provide complete protection, or may contribute to discomfort and added stress for the fire fighter.

Bunker gear, sometimes also referred to as "turnout gear," consists of a coat and pants. Garments are available in different styles and materials, though all must adhere to safety regulations set forth by the National Fire Protection Association (NFPA). These regulations cover everything including the performance requirements of the materials used in manufacturing the gear, the design elements of the gear, and the testing standards. Previously, the regulations on helmets, gloves, footwear and clothing were in separate standards but the 1997 edition of NFPA standards combined these in to a single document. In the most recent edition (2013), the requirements for two different hazard situations, proximity fire fighting and structural fire fighting, were combined into a single standard.

Structural fires are fires which originate in and burn any part or all of a building, shelter, automobile, aircraft, marine vessel or other structure. Operations may include fire suppression, rescue or property conservation. Proximity fire fighting is a special area within structural fire fighting and it includes the same operations but involves commercial and military aircraft, bulk combustible fires and fires which produce extreme levels of radiant heat. Fires which burn acreage are referred to as wildland fires. The clothing worn to fight wildland fires differs from structural fire fighting bunker gear. This research focused on structural fires and the bunker gear worn by structural fire fighters.

Background

Prior to 1989, fire fighters wore long coats and hip boots for protection (LaBar, 1997). However as building structures and materials changed fires were getting more dangerous and fire fighters felt the need to be more aggressive and active than they could in the longer protective clothing styles (LaBar, 1997). Bunker gear, which included a fingertip length coat and pants combination, was developed for better protection. The transition to the new style of bunker gear was slow, with the last department changing to the new combination bunker gear in 2006 (Dudek, 2006).

The National Fire Protection Association (NFPA), founded in 1896, develops codes and standards related to fire including building codes, processes, design and installation. Their codes are widely accepted and their standards have become law in many cities around the country, usually with minimal or no alterations to the language. NFPA 1971 is the standard on "Protective Ensembles for Structural Fire Fighting and Proximity Fire Fighting" and covers the requirements for bunker gear.

The NFPA first developed a set of standards for bunker gear, NFPA 1971, in 1975 and have renewed or updated this manual about every five years since. The newest version is dated 2013. The NFPA standard requirements that describe the proper fit of bunker gear are found in section 6.1.11. Size ranges are given by body dimensions for both men and women. The sizing increments are also stated in the standard: for chest and waist dimensions the sizes may not have a greater than 2" increment between sizes, for sleeves the standard is 1", and for inseams it is 2". It is also required that "men's and women's sizing shall be accomplished by men's and women's individual patterns" (NFPA, 2007, p. 24). This information is reproduced in Table 1.

Table 1: ***NFPA Table 6.1.11 Available Coat / Trouser Size Ranges***

	Men		Women		Increment	
Dimension	mm	In.	mm	In.	mm.	In.
Chest	865-1525	34-60	710-1270	28-50	50	2
Sleeve	820-965	32-38	710-865	28-34	25	1
Waist	760-1525	30-60	710-1270	28-50	50	2
Inseam	660-915	26-36	610-865	24-34	50	2

Additional requirements which may affect the design include that the collar must be 3" in height, long enough to cover the neck but not so long as to interfere with the helmet (NFPA, 1971, p. 24). These standards are followed by the manufacturers of bunker gear so that they may claim compliance when marketing their gear to fire fighters. Many of the tenders put forth by fire departments to ask for manufacturers bids will require that the gear be NFPA 1971 compliant. Another such regulation is that the coat must overlap the pants by two inches to provide adequate protection. This can be achieved either by a finger length coat paired with pants which sit at the waist, or a shorter coat which is paired with high-waisted pants. Different types of closures are used down the front of the coat and the pants fly and both must be designed to create a moisture proof barrier.

There are numerous companies which provide bunker gear that meets the performance standards as required by the NFPA. Among the largest are Globe Manufacturing, Lion Apparel, and Fire-Dex. The garments are expensive, around $1,000 for a coat and $700 for pants though bulk orders receive discounts. There are only a few materials that meet the required standards for bunker gear and are able to withstand the rigors of the job, therefore the selection of a manufacturer to purchase from is often based on customer service issues (how fast can they turn an order around, how much service do they provide before and after the sale?) and the quality of their manufacturing (LaBar, 1997). Stull, Connor and McCarthy (1996) stated that most fire departments base their clothing decisions on previous experience and cost.

When choosing bunker gear, procurement agents should be familiar with the sizes of their crew as no manufacturers make bunker gear in all sizes. Care should be taken to determine the best manufacturer for the majority of gear and perhaps a secondary manufacturer could be chosen to outfit the extreme sizes, whether large or small. Proper fitting of gear should be the first line defense in the protection of fire fighters. While bunker gear sizing exists with custom options for everyone, an improved sizing system could reduce the number of custom garments and reduce cost.

Career fire fighters have their bunker gear ordered for them through a procurement officer or other person (or committee) in charge of outfitting the workers. Usually the procurement officer chooses manufacturers from which to make the purchases, based on meeting the standards, feedback from the fire fighters and cost. If a bulk order is placed, a manufacturer will usually send salesmen to the fire station to measure the fire fighters and choose the sizes which fit best. It is also not unusual for the manufacturer to send a set of "sizing garments" for the fire fighters to try on to help determine the best size to order.

Volunteer fire fighters must either purchase their own gear or accept what is available from the station. A volunteer department will order gear irregularly, usually when their gear has been through a certain number of fires and has degraded or there has been significant personnel turnover requiring gear to be purchased. In the meantime, new volunteers must wear whatever fits them best among what has been left by the departing volunteers. Therefore it is not unusual for a volunteer to be wearing bunker gear that is too small or too large (Gary A. Woodson, Emergency Services Coordinator, Personal Communication, June 10, 2009).

Fire fighters must wear bunker gear according to fit, not style. Fit, in this instance does not refer to personal preference or style but for safety. Poor fitting bunker gear can be dangerous. Pants should be worn at the true waist level (at or near the navel) and not at the high hip. Care should be taken not to order garments which fit too loosely – which a larger person may prefer. The fit of apparel, especially determining the amount of ease, is individual yet if protective clothing such as fire fighter bunker gear is introduced to the fire fighter with appropriate ease allowances at the beginning of their career, they may become accustomed to the way this type of clothing "fits" much like an athlete does with their sport specific gear.

Poor fit can lead to problems not only with the restricted movement of the wearer but in the bunker gear wearing out quickly. For example, a tight crotch area may lead to crotch blow-out or the ripping apart of the crotch area.

Bunker gear is made of several layers of fabric and numerous components. The coat and pants are required to have three layers: the shell, a moisture barrier and a thermal layer. Each of these layers may be composed of different combinations of 10 to 12 different fabrications. The bunker gear can also be individualized, to a certain extent, through choosing different styles and types of pockets, reflective trim, snaps, rivets, hook & loop closures and zippers. Bunker gear must also be able to work with the other components of the full ensemble; helmets, hoods, boots, and gloves (Schenck, 2003). Rotmann (1992) found in an initial design review of bunker gear that the most important areas included the fit, ease of donning and doffing, and design features that allow the wearer be agile with the dexterity needed to complete the job.

Anthropometric studies on specific populations

Anthropometric studies have been carried out on specific populations in the past, most notably the U.S. Armed Forces. The military has a long history of physical requirements and health standards in order to select soldiers who are suited for the physical challenges of military life. As early as the Civil War, hundreds of thousands of soldiers were measured to determine their overall health and well-being (Gould, 1869; Baxter, 1875). In 1921 Davenport and Love conducted the first anthropometric study on military personnel for the purpose of obtaining better fit in clothing. Similar studies followed and even today, the military uses body scanners to collect anthropometric data and to automatically select correct sizes for their uniforms.

Other anthropometric studies have been carried out on civilians. Giddings and Boles (1990) compared the measurements of black and white males to determine fit issues for trousers. They found that the black males had to make more alterations to obtain good fit and their analysis of comparable measurements found differences between the races. Newcomb, in her unpublished 2005 master's thesis, found differences in Hispanic women's body shapes compared to those of other populations in the SizeUSA study (white, black and other). Newcomb (2005) suggested a sizing system based on body type for the entire population as differences found between the Hispanic and White groups were not statistically significant. However, significant differences were found between the Hispanic and Black groups.

The elderly have also been studied, both men and women. Patterson and Warden (1983) determined that women aged sixty-five and older had significant differences in the bust, waist, hip and abdominal extension when compared to younger adults. Alternative sizing systems for elderly women were developed and recommended. Goldsberry et. al (1996) suggested that apparel manufacturers make the current sizing system more geared towards specific consumers and their particular figure types in their study of women over the age of 55. They also recommended that a new system of sizing be developed for this population to identify the body type the design is meant, and fit, for (Goldsberry, Shim & Reich, 1996).

Elderly men (over age 65) were compared to non-elderly men (between the ages of 30 and 50) to compare any fit problems between the groups (Hogge, Baer & Kang-Park, 1988). This study found no major differences in perceived fit of apparel. As we can see, populations have been studied for size differentiation by occupation, age group, sex and ethnicity.

Fire fighters as a population have been studied in New Zealand. There, researchers obtained anthropometric data of 55 body sites on 691 fire fighters to create a sizing system specific to this population (Laing, Holland, Wilson & Niven, 1999). This study found variations in body measurements of people from different countries and of different ethnic origins. This data was used to create

protective clothing standards in Australia and New Zealand.

The first step in developing a sizing system is to take the measurements of the population you wish to size. These measurements are usually of a static or structural nature to obtain the dimensions of the human body. According to Croney (1981), 100 participants are minimum needed to create worthwhile results in the analysis of a sizing system for a target market. Beazley (1998) used 100 females to create and revise current size charts for women's wear.

Clothing fit

Clothing is fitted by taking the actual body measurement and adding ease allowances. According to MacDonald (2002), ease is the "allowance for body movement and design effect in a garment" (p. 1). Specifically, ease is the extra fabric required in addition to the body measurement to surround the body and allow for movement. There are actually two types of ease, basic or wearing ease is the minimum amount of excess needed between the body and the garment in order to allow for movements such as breathing, walking, eating, or sitting. Design ease is the additional amount of allowance added to create a fashionable or stylish effect. Design ease can be non-existent or it can be large as the ease along the sweep of a circle skirt. Lack of basic ease encumbers the wearer's movements and puts a strain on the garment causing it to wear out faster. Too much ease can also make the garment difficult to move in, catch on objects in the environment, and add to the weight of the garment. Basic ease is determined by numerous factors including the type of garment, texture, thickness and weight of the fabric, the type of activity level required and the size of the person. Design ease is added at the designers' discretion.

Knowles (2006), in her textbook *The Practical Guide to Patternmaking: Menswear* gives the following minimal ease guidelines when checking for the fit of a basic men's sloper: 2 inches at the chest, 1 inch at the abdomen for upper body garments, 1 inch at the waist for lower body garments, 2 inches at the hip and 2 inches at the bicep. These requirements change, however, based on the garment and style. Knowles (2006) states that "menswear styles usually have a loose, comfortable fit. The only areas that often fit closely to the body are shirt necklines, pant and short waistlines, active sportswear and undergarments" (pg. 61). Her chapter on jackets includes additional ease allowance information. The jacket sloper allows for 4 inches of ease at the chest and hips with about 8 inches at the waist. The jacket sleeve allows for 3 to 3 ½ inches of ease in the bicep area. The additional ease is to allow accommodation for the garments worn underneath the jacket, namely a shirt and possibly an undershirt.

Handford (2003) gives different ease allowances for the development of a man's pair of pants. He allows 2 inches of ease in the hips but no ease allowance for the waist. He uses 4 inches of ease at the chest for the casual jacket. No ease allowances are made in his slopers for either neck circumference or waist circumference in the development of a shirt.

Ease allowances for fire fighters bunker gear are varied and not constant. Lion states that their ease allowance at the chest is ten inches but this refers to the outside measurement of the finished product (Karen Lehtonen, Personal Communication, July 19, 2009). This does not take into account the clothes under the body nor the thickness of the bunker coat itself, two variables which would alter the ease allowance by inches. A method of checking for ease in the field calls for the person fitting the garment to place a "flat fist" between the waist of the bunker pants and the person wearing the garment. If the fist fits, then the pants are deemed to fit. This method is widely variable – the size of a person's fist is variable, also the stomach area is flexible allowing for some variation.

Importance of fit for fire fighter bunker gear

The most important element of the bunker gear is that it provides protection to the wearer from the hazards they face while performing their job. In order to provide that protection, bunker gear has three layers. The

outermost layer is usually made of Nomex® or other flame retardant material to protect the wearer from flame and heat. It should also be able to resist water absorption. The middle layer consists of fabrics which provide a moisture barrier and yet are breathable. Since condensation of steam can occur on the middle layer, there must be a protective layer between it and the skin. The innermost layer provides insulation and has thermal properties. Typically a woven fabric is quilted to sheets of insulation fibers; multiple thin sheets are added to increase the trapped air and provide additional insulation. These multiple layers add thickness, weight and bulkiness to the garment further complicating the sizing and fit issues.

Bunker gear must be able to be donned quickly. There is no time for changing in or out of the station uniform or civilian clothing before donning the gear, therefore whatever the fire fighter is wearing when the emergency call comes is the first layer of protection. Fire fighters are trained to be able to don their bunker gear in less than two minutes. This varies only slightly from station to station with some having less time to don their gear and other stations allowing more time but including the donning of the breathing apparatus.

Fire fighter gear must fit properly to perform at its highest level. Ease of movement is important in evaluating the fit. Tight fit restricts movement; loose fit can not only restrict movement but also has the tendency to catch on obstructions and hamper movements. Clothing in a size too large can impede motion and performance (Manley, 1997). NFPA 1500, which is the Standard on Fire Department Occupational Safety and Health Program looks at the interface between protective components and specifies at least a two inch overlap of all layers. This minimum overlap is evaluated in only two positions; first is standing with hands together and reaching over the head as high as possible and secondly, also standing with hands reaching overhead but with the body bent forward as a 90-degree angle, to the side (right or left) and backwards. Poor fit (garments that are too short) can leave wrists and ankles uncovered and susceptible to burning. Poor fit can also lead to the clothing wearing out in certain places or not functioning properly when needed. It is also suggested that fit be reviewed in active positions on a training field before being used in an actual fire situation (Stull & Stull, 2008).

Care must be taken in fitting the garment to the activity performed. Most fire fighters move within the burning buildings on their knees or in a "duck walk" stance so as not to inhale the smoke at the higher levels. These positions elongate the vertical areas of the body needing coverage and are one of the reasons why fire coats are long. Some coats are styled even longer in the back. As per NFPA standards, 2" of coat must cover the waist of the pants at all times in all positions.

The sizing for bunker gear is based on a set of measurements including the chest, waist, sleeve length and inseam. These measurements are taken of the fire fighters while they wear their station uniform as these garments are generally worn under the bunker gear. Nighttime calls are but one situation when a professional fire fighter would not be wearing their station uniform. Also, volunteers would not normally have station uniforms issued to them as they would be interrupting their normal daily routine to attend any emergency situation and therefore would be wearing civilian clothing under the bunker gear. The changing of the seasons can also alter the garments worn under the bunker gear, as summer clothing will be different from that worn in the winter.

Whatever the fire fighter is wearing at the time of the call is what remains under the gear. This could be jeans and a polo shirt, a sweat suit, pajama pants and a t-shirt or perhaps merely underwear if they are sleeping. This range of weights and thicknesses of garments could alter the fit of the bunker suit. However, it is important that garments be worn under the bunker suit as this gives another layer of protection from the heat of the fire. The extra layer of trapped air incorporated in the station gear or civilian clothing provides a layer of insulation from the heat. Standardizing the station gear

would make sizing parameters easier to control but only for the professional fire fighters who would be able to wear specialized clothing while on duty.

Bunker gear sizing

The NFPA has set requirements for available coat and trousers sizes as well as the increments between sizes as stated in 6.1.11.1 (NFPA, 2007, p. 24). See Table 1. For men, the size range for chests is 34 inches through 60 inches with sizes set at 2 inch increments, sleeve lengths of 21 to 38 inches in one inch increments, waists between 30 and 60 inches with 2 inches or less between sizes and inseam lengths between 26 and 36 inches with increments no greater than 2 inches. Women sizes have the same increment requirements for each dimension with smaller dimensions given for the ranges: chest is between 28 and 50 inches, sleeve length is between 28 and 34 inches, waist circumference is 28 – 50 inches and the inseams are between 24 and 34 inches. It is not required that all sizes be offered by the manufacturers to be compliant, just that the size increments be within the tolerance level set forth by the NFPA committee. Neither required proportions nor linkages between the measurements are specified, so these standards leave room for much variation among sizing systems of the various manufacturers.

Several companies' promotional materials (catalog and websites) were investigated for information on how bunker gear is actually sized. Instructions for measuring and ordering bunker gear can be found on most manufacturers or retailer's websites and catalogs. Each set of directions is unique but many manufacturers will send a person to the station to measure the fire fighters if a large order is being placed. This helps to ensure that the measurements are taken reliably for that particular manufacturer. There is no standard method of measuring a fire fighter for bunker gear as the directions vary greatly from manufacturer to manufacturer.

Coat. For purchasing a coat, typically the chest and sleeve length are the required measurements, though some manufacturers also use additional measurements. Directions for measuring the chest included such statements as: "Take a deep breath and hold it. Measure around the largest part of the chest" and "Have the wearer take a deep breath and fill the lungs before measuring. Measure over clothing around the fullest part of the chest with the arms at rest." Some are vague as in "Measure loosely over clothing." One company asks that both the chest and the belly be measured and to use the largest of these measurements as the coat size. Some measuring guides show a fully clothed sketch of a man being measured as a visual guide; measuring a clothed person may be assumed for those directions that do not mention it specifically.

Some manufacturers have different arm positions for taking the chest measurement as is seen by these quotes: "Arms should rest by their sides. Both an under-the-arm measurements and over-the-arm measurement should be taken at the widest part of the chest/bust" or "Lift both arms at 90° angle in relation to torso. Position the measuring tape around the torso at the largest area below the arms. Lower arms to the side of the body in a relaxed position. You will notice a slight extension of the measuring tape. This is normal. Readjust the measuring tape, leaving enough room to insert a flat fist between the tape and the body." More complicated directions were also found such as: "Raise both arms to 90° to the body. Position the measuring tape around the fullest part of the chest, over the shoulder blades, and under the arms. Take a deep breath; hold it, and lower arms. Record the largest measurement".

The sleeve measurement is taken in a variety of ways as well. One manufacturer instructs "Bend elbow and hook thumb under belt buckle, and beginning at center back of neck, measure across top of shoulders, around point of elbow to midpoint from wrist bone to knuckles." Another says to "Measure sleeve length from the middle of the back from the vertebrae at the base of the neck, over the shoulder to the point on the hand that is required. Generally done to the thumb

crotch. Do not bend arm." Yet another manufacturer states "Have the wearer hold arm straight down at side. Measure from the base of the back of the neck, over the shoulder, and down the arm to the top knuckle of the little finger where it joins the hand. Round up to the nearest standard length." Each of these methods would give a slightly different measure and since most sleeves are sold in one inch increments, the sleeves could vary by that amount.

Women are sized similarly to the men with the exception being that some manufacturers require women's hip measurements in addition to the standard measurements for men. Most of the bunker gear manufacturers do not produce standard sizes in pants below a 30" waist. Indeed, no manufacturer was found that offered the smaller range of sizes as stated by the NFPA 1971 standards which give inseams as short as 24" for women. As for coats, the smallest chest circumference offered was 31" and yet the NFPA standards go as low as a 28" chest for women. With so few women fire fighters, the issue of too small bunker gear is not typically addressed by manufacturers and was not fully explored in this study.

Research questions

The following questions were addressed in this study:

1. Does the fire fighter population correlate in body size to the general population?
2. Are fire fighters unique in their body composition so that they would benefit from an extensive anthropometric study and the development of sizing schemes specifically for this population?
3. Do the current sizes available meet the needs of the fire fighter population?

Methods

Subjects

The subjects were 103 volunteer or professional fire fighters from the Midwest. They included 100 Caucasians, one black and two Hispanics. The population included twelve women (11.6%). All were between the ages of 20 and 55 with years of experience ranging from 3 months to 32 years with an average of 11 years. Comparatively, 90.9% of all fire fighters in the U.S. are between the ages of 20 and 60 (U.S. Fire Administration, 2009). This research analysis will focus only on the male participants of this study.

Subjects were recruited through email contact, passing out flyers at a fire exposition, and word of mouth. More than half of the subjects were from attendees from a local biannual fire fighter training institute. The institute brings in thousands of fire fighters for training at each session. A fire equipment exposition held in a public venue during the training school was attended by a wide range of interested parties, not only training institute attendees.

Method

Body scanning can be used to collect the data necessary to create an effective sizing system for any target market, in this case fire fighters. The NX-16 body scanner, developed by the Textile/Clothing Technology Corporation (TC2), was used to obtain body dimensions. The body scanner automatically generates over 200 measurements from the scanned body in a matter of seconds. Linear measuring systems do not give the rich information available when analyzing a three-dimensional body. Body fat location, posture, shoulder slope and more accurate girth and vertical measurement are a few of the kinds of data a body scanner can collect that are difficult or impossible using traditional methods.

Each fire fighter was weighed before they undressed and height was measured. The weight recorded was five pounds less than what registered on the scale to account for their clothing. Their BMI was calculated and recorded using their height in inches and weight in pounds, using the formula: BMI = 703.1 X (weight in pounds)/(height in inches)^2 (National Institutes of Health, 2013). They were then body scanned while wearing their commonly worn undergarments. If their undergarments were not suitable, a scan garment was given to them. Typically, this was necessary when the men were wearing woven boxer shorts as this type of garment

stands away from the body and would result in inaccurate body measurements. Knit shorts with an elastic waist were given to these subjects.

Results

Comparison between fire fighters and the general population

SizeUSA (2004) was used as a basis for comparing the two populations. This study derived body scan measurements for over 3,500 men from across the United States and is used by some apparel companies to help improve sizing for their apparel. According to the owners of the data, the Textile/Clothing Technology Corporation, the SizeUSA study is a representative sample of the U.S. population. Subjects were scanned at different locations across the country, and efforts were made to recruit representative numbers of different ethnicities and sizes of subjects (SizeUSA 2004).

Height. The height of males from SizeUSA was compared to the height of male fire fighters scanned for this study. The range of height for the fire fighters was almost as wide as for the general population with fire fighter's height starting at 58" and topping out at 78" (Figure 1). While the general population's height range is bell-shaped with just over 13% of the men at 69" being the largest group, the fire fighter's heights showed more variation and were skewed towards being taller. The largest percentages of fire fighters (15.5%) were at 70", while the next largest percentage (14.5%) measured at 72" and the third largest (13.5%) at 71". Overall, 67% of the fire fighters were above 69" and 33% were at or below 69".

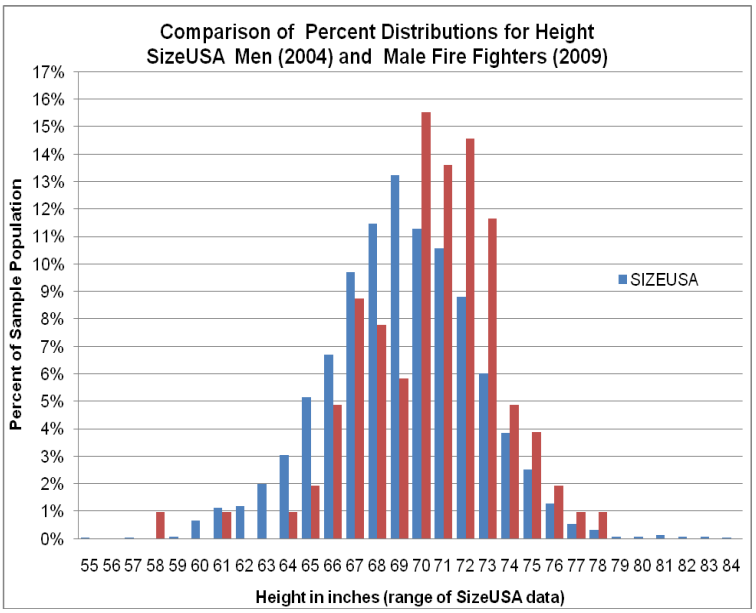

Figure 1: ***Comparison of percent distribution for height***

Weight. The weight of the males from SizeUSA was compared to the weight of the male fire fighters. The range of weights for the fire fighters was only slightly smaller with weight starting at 140 pounds; for the general population, weight started at 120 pounds (just over 1%). For the general population, 180 pounds was the largest category at 23 % with the second largest at 200 pounds (20%). The results of the comparison to the general population are slightly skewed in the heavier ranges but drop dramatically as the weight goes higher (Figure 2). The fire fighter's weight ranges varied from 140 to 360 pounds with the weights of 200, 220 and 240 each having

16.5% of the population. The second largest category was 180 pounds at 15.5%. Almost 10% had a weight of 260 while 12% had either a weight of 140 or 160 pounds.

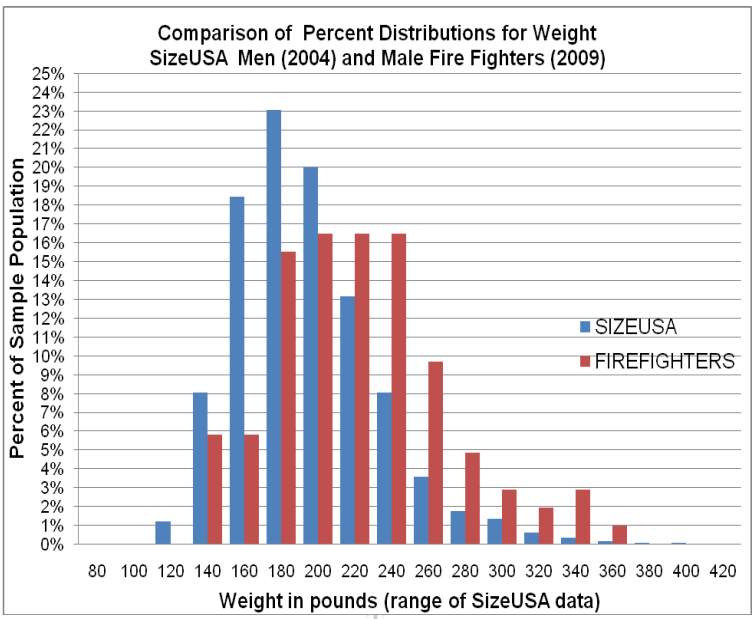

Figure 2: ***Comparison of percent distribution for weight***

Chest girth. The range of chest girths for the fire fighters was between 34.12" and 63.29" with an average of 46". SizeUSA males range from a chest girth of 31.08" to a maximum of 63.1" and average 42.96" or more than 4" smaller than the fire fighters.

Waist girth. The fire fighters waists ranged from 29.54" to 65.12" with an average of 40.47". The males in the SizeUSA data show a range of waist girths from 25.58" to 63.78" with an average waist girth of 37.75".

Chest minus Waist Drop. The difference between the circumference of the chest and waist is referred to as the drop. Most apparel manufacturers assume a larger chest than waist circumference and draft their patterns accordingly. In the SizeUSA data, males range from a -5.5" drop (meaning that their waist is larger than their chest) to a 14.09" drop with an average of 5.78". The firefighters had a drop range of -1.83" to 11.54" with an average of 5.73".

Bunker Gear sizing

Catalogs and websites of the major manufacturers of fire fighting bunker gear were examined to determine the sizing used to order bunker gear. Two of the companies stated that they only manufacture gear as "custom" and therefore no measurement charts were provided. All the manufacturers offer the mid-ranges of sizes in standard lengths with 33 inch to 36 inch sleeve lengths being offered by every manufacturer for coats as well as standard 29 inch inseams for pants.

Coat. Bunker coats are sized by chest circumference and sleeve length. One company has the smallest chest measurement at 31", with two additional manufacturers starting at 32". The most common sizes offered are chest measurements ranging from 36" up to 52", though some manufacturers' standardized sizing goes up to 58" and one manufacturer lists a 71" circumference chest (7XL). See Table 2. This wide range of sizes fits the chest measurements of all of the participants in this study. Only eight

participants had a chest measure above 52" and only one of these measured above 60". Comparing the firefighting data to the catalog charts indicates that the average chest size (46") falls within the XL size category.

Table 2: ***Sizes of coats by chest measurements (in inches) from seven different bunker gear manufacturers.***

	XS	S	M	L	XL	2XL	3XL	4XL	5XL	6XL	7XL
A	31-34	35-38	39-42	43-46	47-50	51-54	55-58	59-62	63-66	67-70	71
B	36	38	40	42	44	48	48	50	--	--	--
C	--	34-36	38-40	42-44	46-48	50-52	--	--	--	--	--
D	38	40	42	44	46	48	50	52	54	56	58
E	--	--	38-40	42-44	46-48	50-52	--	--	--	--	--
F	32-34	36-38	40-42	44-46	48-50	52-54	56-58	--	--	--	--
G	32-34	36-38	40-42	44-46	48-50	52-54	56-58	--	--	--	--

Sleeve lengths available vary with the shortest available at 29" and the longest offered in standard sizing at 37". The shorter sleeves are typically standard in the smaller sizes with the longer sleeves only available on the larger sizes without custom ordering. See Table 3 for the breakdown of sleeve lengths by chest circumference measurement. The data set had a range of 29.6" to 36.4" in sleeve length as measured from the center back neck to wrist.

Table 3: ***Standard sleeve lengths available by chest size from seven different bunker gear manufacturers.***

	XS	S	M	L	XL	2XL	3XL	4XL	5XL	6XL	7XL
A	32	33	34	35	36	36	36	36	37	37	37
B	33	34	34	34	34	36	36	37	--	--	--
C	--	33	34	35	36	37			--	--	--
D	--	34.5	35.5	36.5	36.5	36.5	36.5	36.5	--	--	--
E	--	--	--	--	--	--	--	--	--	--	--
F	29	32	34	35	35	36	36	--	--	--	--
G	32	32	34	35	35	36	36	--	--	--	--

Note: No sleeve information given from manufacturer E.

In fitting the coat, you must combine the chest circumference measurement with the arm length measurement. In this example, the firefighter data was compared with catalog A which has the widest range of chest circumferences. The largest size group in this sample is "Large" with a chest circumference range of 42.6" – 46.5" (catalog states 43"-46"). In this size range, the sleeve lengths needed would vary from 29.4" – 34.77" or a difference of 5.37". The catalog only gives one length option in this chest size, 35", which is .25" longer than the longest arm in this range. Therefore the 28 participants in this size range would need to have their coats custom ordered or altered to fit their shorter arms. For each given chest circumference, the arm lengths within each circumference range vary from 2.87" to 5.37" differences.

Pants. Bunker gear pants are sized by waist circumference and inseam measurements. Only one company was found to have a size to fit waists smaller than 30" as their extra-small was sized for a waist of 26"-28". All the other manufacturers started at a 30" waist and all manufacturers went up to a 46" waist with two going up to a waist measure of 56". Most manufacturers size their waist in 2" increments and offer their pants in sizes of 30" to 32", 34 to 36", and 38" to 40" and so on. Only one manufacturer was found that provides 1" increments for sizing at the waist. See Table 4.

Table 4: ***Sizes of pants by waist circumference measurement from seven different bunker gear manufacturers.***

A	--	--	--	--	--	--	--	--	--	--	--
B	36	38	40	42	44	46	48	50	--	--	--
C	--	30-32	34-36	38-40	42-44	46-48	--	--	--	--	--
D	34	36	38	40	42	44	46	48	50	52	54-56
E	--	--	32-34	36-38	40-42	44-46	--	--	--	--	--
F	26-28	30-32	34-36	38-40	42-44	46-48	50-52	--	--	--	--
G	26-28	30-32	34-36	38-40	42-44	46-48	50-52	54-56	--	--	--

Note: No waist circumference information given from manufacturer A.

The waist measurements for the data set start at 29.55" and would most likely fit the 30" to 32" size offered by all the manufacturers. The waist sizes listed in Table 4 would also fit all but one study participant (the largest waist measure of 65.12"). Only one manufacturer offers sizes at both the extra small (26"-28") and up to 4XL (54" – 56"). Therefore all but two participants in this study would be able to find bunker pants which fit at the waist through a single manufacturer.

Four of the seven manufacturers of bunker gear studied had 29" as the standard inseam length. One catalog states that this length inseam is suitable for all people between 69" and 74" tall. Inseam options are available, with 32" being the next most common inseam length offered. Among the six manufacturers, inseams are available in 27", 29", 30", 31", and 32". One company offered inseams at 33" and up for an abbreviated waist size range at an extra cost. Another company's sizes show the inseam decreasing 2" at their largest size of 4XL for an inseam length of 27". One company offered a standard "short" length with a 27" inseam. See Table 5 of inseam lengths by waist size.

Table 5: ***Inseam lengths available by waist size for seven different bunker gear manufacturers.***

A	No inseam information given							
B	30	32	32	32	32	32	32	32
C	--	29	29	29	29	29	--	--
D	29	29	29	29	29	29	29	27
E	No inseam information given							
F	All waist sizes are offered either 29" or 32" lengths							
G	29	29	29	29	29	29	29	29

In examining the standard inseam length of 29", the male only data set showed 64 fire fighters with heights between 69" and 74". Inseam measurements were derived from the data by taking the crotch height and subtracting the ankle height. Of those, only nine out of the 64 have inseams of between 28.5" and 29.5" which would fit the inseam standard of 29". Widening the accepted inseam length to between 28" and 30" would still only yield 16 participants. Within this height group of 64 participants, the shortest inseam was 24.79" and the longest inseam was 32.58, both are well outside the suggested 29" inseam. Fire fighters shorter than 69" (N=19), with the shortest being 65" in height, had inseams ranging from 24.62" to 29.33". Fire fighters taller than 74" (N=8) with the tallest being 78" had inseams ranging from 28.28" to 30.22. Pairing the waist and inseam measurements, all but one of the fire fighters would be able to find bunker pants which fit in the waist at the various inseams offered although the majority would incur higher costs due to lengthening or shortening of the inseam.

Conclusion

The fire fighter sample in this study, when compared to the SizeUSA data, were taller and heavier than the general population. The comparison between chest and waist girths also showed that firefighters were larger than the general population. However, the chest minus waist drop average was almost identical in both samples even though there was a wider variation in the general population.

Fire fighters in this study were larger than the general population and may benefit from an extensive anthropometric study and the development of sizing schemes specifically for this population based on this research. The current sizes of bunker gear offer a wide choice of sizes by chest and waist circumferences but are too narrow in their offering of sleeve and inseam lengths without custom ordering. A more useful and cost saving measure, for both the fire departments and manufacturers of bunker gear, would be to generate a sizing system which fit the proportion variations of the population and reduce the number of custom sizes required. The development of a standard for the purpose of measuring fire fighters to purchase bunker gear would also be helpful.

Limitations

This study was conducted on 103 fire fighters from the Midwest and concentrated the 91 male participants and therefore can only be used to draw conclusions on this group of participants. However, additional studies have been conducted on larger groups of fire fighters in the New England area and some of the results are parallel, as in the case of higher BMI's (Tsismenakis et, al, 2009).

Body scanners only capture data on the size of the body, not the fit of the garments. Fit is determined by personal preference, safety requirements, wearing ease and manufacturing tolerance levels. Garment measurements, when compared to body measurements, can help in determining fit but this is also not conclusive.

To be able to develop a truly useful sizing system for fire fighter bunker gear, a much larger scale study needs to be conducted. Ideally, this would include a statistically significant number of women as the smaller sizes are lacking when the

manufactured bunker gear were researched. Beazley (1998) recommends a study of no less than 500 participants in order to obtain statistically significant results for a sizing system.

The proper sizing and fit of bunker gear is important not only to help the fire fighter perform their duties but also to protect their life. Improperly fitted gear could bind or catch on objects, restrict movement or not properly overlap, leaving skin susceptible to burning. Every effort must be made to ensure that the people to protect the lives of others have the protection they need to do their jobs safely. Anthropometric data collection and assessment of the sizing and fit of fire fighter's uniforms are important in achieving this goal. Future research should also look into dynamic anthropometry or the measuring of the stretch and movement of a human (Pheasant, 1986). This would be particularly helpful in the case of fire fighters who must be protected in all working positions for their safety.

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