Published in final edited form as:

Hum Factors. 2014 August ; 56(5): 873–910.

Sizing Firefighters: Method and Implications

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Abstract

Objective—This article reports new anthropometric information of U.S. firefighters for fire apparatus design applications (Study 1) and presents a data method to assist in firefighter anthropometric data usage for research-to-practice propositions (Study 2).

Background—Up-to-date anthropometric information of the U.S. firefighter population is needed for updating ergonomic and safety specifications for fire apparatus.

Method—A stratified sampling plan of three-age by three-race/ethnicity combinations was used to collect anthropometric data of 863 male and 88 female firefighters across the U.S. regions; 71 anthropometric dimensions were measured (Study 1). Differences among original, weighted, and normality transformed data from Study 1 were compared to allowable observer errors (Study 2).

Results—On average, male firefighters were 9.8 kg heavier and female firefighters were 29 mm taller than their counterparts in the general U.S. population. They also have larger upper-body builds than those of the general U.S. population. The data in weighted, unweighted, and normality transformed modes were compatible among each other with a few exceptions.

Conclusion—The data obtained in this study provide the first available U.S. national firefighter anthropometric information for fire apparatus designs. The data represent the demographic characteristics of the current firefighter population and, except for a few dimensions, can be

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directly employed into fire apparatus design applications without major weighting or nonnormality concerns.

Application—The up-to-date firefighter anthropometric data and data method will benefit the design of future fire apparatus and protective equipment, such as seats, body restraints, cabs, gloves, and bunker gear.

Keywords

firefighter; anthropometry; cab; protective equipment; body build; apparatus

Introduction

The National Fire Protection Association (NFPA) estimated that there were approximately 1,103,300 firefighters in the United States in 2010 (Karter & Stein, 2011). The average rate of fatal workplace injuries to firefighters was 16.6 per 100,000 employed, which was 4.15 times higher than the 4 per 100,000 rate for all workers in 2006 (U.S. Department of Labor [DOL], 2006). In addition, firefighters sustained approximately 71,875 injuries in 2010 as reported by the NFPA (Karter & Molis, 2011). A National Fallen Firefighters Foundation white paper reported that firefighter anthropometry for fire apparatus and protective equipment design (e.g., cabs, seats, body restraints, egresses, bunker gear) is a pressing issue to protect firefighters from being killed in crashes and rollover incidents, falls from vehicles, and excessive thermal and chemical exposures (Routley, 2006). Various concerned parties, including professional associations, fire apparatus standards committees, and apparatus manufacturers, jointly advocated for an anthropometric survey of U.S. firefighters to advance fire apparatus designs.

Anthropometry databases on U.S. firefighters are very limited. Veghte (1991) reported 30 measurements of 20 firefighters with a focus on protective clothing application. Hsiao, Long, and Snyder (2002) reported 14 measurements of 189 protective services persons (including firefighters) based on the National Health and Nutrition Examination Survey database of 1988 to 1994. A recent British anthropometry survey of 316 female firefighters reported data of 61 measurements for personal protective equipment design use (Stirling, n.d.). An anthropometry study of 122 firefighters was also reported for seat belt evaluation (U.S. Department of Commerce, 2008). Most of these data were collected without fire gear, rendering them applicable for some applications such as seat height determination and mask design but insufficient for some applications such as seat belt design and cab space arrangement in that firefighters typically ride fire trucks while in gear. In addition, these studies were limited to a few specific applications and their sample size. The recent large-scale Civilian American and European Surface Anthropometry Resource (CAESAR) survey offered a good potential for some product design applications (Harrison & Robinette, 2002). However, CAESAR has major limitations in its applications to fire apparatus designs in that it is a generic anthropometric study of subjects drawn from 15 sectors of industry; not one firefighter was included in the total sample of 2,353 subjects. It has been shown that the U.S. firefighter population has a larger build than the general U.S. population (Hsiao et al., 2002); applying data from the CAESAR survey to the firefighter population for apparatus design would be inappropriate. Another recent national anthropometry survey of 20,015 children

and adults offered a good prospective on diversity of anthropometry among current populations (Fryar, Gu, & Ogden, 2012). Due to the nature of the study on health and nutrition, only very limited dimensions were measured. The information on body height, body weight, waist circumference, upper arm length, and upper leg length can be used for certain product design applications. However, the report did not provide information on the number of firefighters in the survey nor offer specific anthropometry information on firefighters.

This research represents the first large-scale anthropometry survey of American firefighters to facilitate design of the next-generation fire apparatus and firefighter personal protective equipment (PPE), and the paper reports the data method and implications of the research, which is organized in two studies. Study 1 presents body measurements both in gear and without gear, the first available in the literature for various fire apparatus and firefighter PPE design applications. The study also provides detailed information on differences in body builds between firefighter and civilian groups and delivers a key message that caution must be made by designers and human factors engineers in selecting anthropometry databases that are adequate for their occupational applications. Study 2 reports a data method to evaluate the variations among weighted, unweighted, and normality transformed data to determine whether the original raw data from Study 1 reflect the demographic distribution of current firefighters and address nonnormality concerns and weighting needs in practical apparatus design applications. This is an important subject in anthropometry data usage that has not been well addressed in the literature. Different fire apparatus design applications require different anthropometric approaches for dimension specification; among them are univariate, bivariate, multivariate, and shape quantification approaches (Hsiao, 2013). Fire truck seat height can be defined mainly by popliteal height measurement. Seat belt design requires information on both trochanter-to-trochanter (bitrochanter) curve length and acromion-to-trochanter curve length. Turnout gear jacket design necessitates information on multiple dimensions, including chest breadth, chest depth, chest circumference, waist circumference, hip circumference, vertical trunk circumference, arm span, acromion–wrist length, and neck circumference. Similarly, data on multiple body dimensions are needed for fire truck cab design in that easy-to-reach controls, sufficient overhead clearance, and adequate visibility of both internal and external environments all are functions of the fire truck operator's body size and position in the cab. In addition, design and sizing of self-contained breathing apparatus straps require information on the size and shape of the torso. In short, multidimensional data in raw form are increasingly required in product design specifications. It is essential to either verify that the raw data collected in Study 1 are appropriate for unweighted use in design practices or inform the potential data users of the limitations of the data set in terms of normality constraint and weighting requirements in the product design process.

Study 1: U.S. Firefighter Anthropometry Survey

Objectives

The objectives of this study were to (a) establish a national anthropometric database of U.S. firefighters that reflects the variations in body sizes among firefighters, (b) provide

information on differences in firefighter body dimensions between in-gear and without-gear scenarios for fire apparatus and firefighter PPE design, and (c) verify the hypothesis that the size and physique of the U.S. firefighter population are different from those of the general U.S. population.

Method

Critical anthropometric measurements—A total of 71 measurements relevant to the design of seats, seat belts, cabs, turnout gear, ingress, gloves, and face masks are presented in this report. Definitions of these measurements are listed in Appendix A and are organized into three categories. Of the 71 measurements, 40 were collected from the participants in fitted shorts in both standing and seated postures (Figure 1a). Another 21 measurements were collected while the participants were wearing their personal turnout gear, including personal selection of tools stored in their pockets, in both standing and seated postures (Figure 1c). The remaining 10 measurements were hand- and head/face-related dimensions extracted from hand and head/face scans (Figure 1b).

Participants—This study used a stratified sampling plan (3 age × 3 race/ethnicity × 2 gender combinations) to collect anthropometric data across the United States. The sampling plan was based on 1,136,650 firefighters from the *U.S. Fire Department Profile Through 2005* (Karter, 2006), which was the best available and most updated information at the study planning stage in 2007. Of the population, the under-30 age group (ages 16–29) accounted for 287,450 (or 25.3% of all firefighters). The 30 to 39 age group accounted for 330,400 (29.1%), the 40 to 49 age group accounted for 296,450 (26.1%), and the above-50 age group accounted for 222,350 (19.5%). The data were recategorized into three groups (excluding those younger than 18) with an equal population distribution: 365,845 firefighters (32.8%) for ages 18 to 32, 379,505 (34.0%) for ages 33 to 44, and 370,575 (33.2%) for ages 45 to 65, for a total of 1,115,925 firefighters.

On the gender and ethnicity matters, the U.S. DOL Household Data Survey of 2000–2004 indicated a distribution of 4.2% female firefighters and 95.8% male firefighters, which consists of 9.3% Black (male), 7.3% Hispanic (male), and 79.2% White (male; U.S. DOL, 2006). Since female firefighters are relatively few in number, it is impractical to further divide them into different racial/ethnic groups. Therefore, a total of 12 cells (3 age × 3 race/ethnicity combinations for males plus 3 age groups for females) were arranged for the study to represent and compare anthropometric differences among U.S. firefighters.

The needed within-cell sample size was calculated using the following equation,

$$|\overline{X} - \upsilon| = \frac{\delta * \sigma}{\sqrt{n}},$$

where $|\bar{X} - \upsilon|$ is within-cell accuracy, $\bar{x}$ is the sample mean of the subgroup, υ is the true mean of the subgroup, n is the sample size, σ is the standard deviation of the subgroup, and δ is the eccentricity (1.96 for 5% two-sided probability; Chow & Liu, 1998). Based on the standard deviation of stature from the CAESAR U.S. database (79 mm for men and 73 mm for

women) and the desired cell accuracy of 18 mm for this study, the estimated sample size is 74 for males and 64 for females. Namely, at a 95% confidence level the sample sizes of 74 and 64 would have sufficient power for the sample mean to be within 18 mm of the true mean of the subgroup. Therefore, 75 subjects per cell was proposed. The “all other race/ethnicities” group was merged with the Hispanic group because its percentage was too small to be an independent racial/ethnic group and its racial diversity matches that of the Hispanic group. In short, a national sample size of 900 subjects would provide sufficient information for between-gender, between-race/ethnicity, and between-age assessments.

In practical applications of anthropometry for product design, the proportions of gender, race/ethnicity, and age populations need to be considered, and the sample size is adjusted accordingly. Based on the distribution of 4.2% women, 9.3% Black (male), 7.3% Hispanic (male), and 79.2% White (male) firefighters reported in the U.S. DOL Household Survey of 2000–2004 (U.S. DOL, 2006), a random national sampling of 900 firefighters would yield 713 White males, 84 Black males, 66 Hispanic males, and 38 female firefighters. On the other hand, to maintain the power to evaluate the anthropometric difference among the different ethnicity and gender groups of firefighters, a minimum of 75 subjects should be kept in each group. In addition, an oversampling of female firefighters would be necessary to address some fire apparatus design issues (such as fire engine operation and seat adjustment) that are unique to females. Therefore, a 70%, 10%, 10%, and 10% sample plan was proposed, which corresponded to 630 White males, 90 Black males, 90 Hispanic males, and 90 females. In this adjusted study design, the lowest cell accuracy for stature (non-Hispanic Black × age and Hispanic × age) is 28 mm, whereas the highest cell accuracy (White × age) is 11 mm. The cell accuracy is 26 mm for Female × age subgroups. The lowest ethnicity group accuracy is 15 mm.

To collect data nationwide, the continental United States was divided into four regions, as shown in Table 1. The number of participants in each region was assigned based on the size of the population in that region in the 2000 U.S. census (U.S. Census Bureau, 2001), with an assumption that the number of firefighters is proportional to the size of the population they serve. Table 2 shows the interim distribution plan of 900 subjects by gender, ethnicity, age, and region. This distribution was based on the assumption that all racial/ethnic populations were distributed equally across the four regions, which certainly was not representative and could result in recruiting bias or difficulty of certain racial/ethnic groups in certain regions. A further adjustment was made to reflect region-by-ethnicity distributions of firefighters (Table 3) and thus to define the number of subjects to be recruited from each region for the study.

This final adjustment (Table 3) took into account the geographic density of racial/ethnic distributions calculated from the 2000 U.S. census. The highest percentage of Black Americans lived in the South (44%), with 27.5% in the Northeast, 19.6% in the North Central/Great Lakes, and 8.8% in the Pacific West. For Hispanics, 43% lived in the Pacific West, with 31% in the South, 16.8% in the Northeast, and 9.1% in the North Central/Great Lakes regions. As a result of the geographic distributions of both racial/ethnic groups, the number of subjects in each cell was adjusted accordingly. White males and females were not further adjusted from the data in Table 2.

Facilities and participant recruitment—The measurement stations consisted of a briefing table, a changing area, and a space with sufficient lighting for traditional anthropometric measurements and three-dimensional surface scanning. Participants were approached through firefighter associations and leaders of regional fire stations at four data collection sites as identified in Table 3. At the middle stage of the 30-month study period, the Chicago site became unavailable. After a careful analysis on racial/ethnicity, age, and gender distributions of metropolitan firefighter populations in the Northeast and North Central regions, Philadelphia, Pennsylvania, was selected to replace Chicago. This was not an ideal situation but was scientifically reasonable and practical; a site in the North Central region with a similar firefighter population size and distribution to those in Chicago would have been ideal but was unavailable. Data collection was completed in Rockville, Maryland, Phoenix, Arizona, Philadelphia, Pennsylvania, and Fort Worth, Texas. The study was conducted at the rate of about eight persons a day.

Measurement devices—The firefighters were measured with and without their gear using traditional anthropometry methods as well as point digitizing and surface scanning anthropometry methods. The participants were measured in standing and seated postures to obtain dimensions pertaining to cabin design, seat configuration, seat belt design, and PPE fitting. Measurements were recorded using a FARO digitizing arm for vertical dimensions. Measurements of body depths were obtained using anthropometers, breadths using sliding calipers, and circumferences using tape measures. Other instruments included a weight scale, a stool for seated measurement, and a Smedley hand grip dynamometer for hand grip strength measurements.

Procedures—On arrival at the field laboratory at a fire station, firefighters were greeted and given a brief overview including the purpose of the study. Before data collection, participants signed a consent form and filled out a questionnaire pertaining to demographic information and experience with fire apparatus. The participants changed from street clothes into form-fitting shorts for the male firefighters or form-fitting shorts and a sports bra for the female firefighters (Figure 1a).

The firefighters first stood on a level footboard with their feet in the designated footprints. They were asked to stand in an upright, erect posture. This was done to ensure that all the firefighters were standing consistently in the same position while the standing measurements were taken. Anatomical landmarks were identified and marked on the subject prior to measurement (Figure 1a). Twenty dimensions were then measured. A measuring tape was used to take circumference measurements. Vertical heights were registered using a FARO digitizing arm, and other dimensions were recorded using calipers; the two methods were lab tested to be within a 0.4 mm difference, and the FARO digitizing was time efficient for vertical-height measurements, as were calipers for width and depth measurements. A weight scale was then used to measure body weight.

The next series of measurements were taken using the same tools while the firefighters were seated in shorts on a bench with a vertical back rest. The firefighters were positioned so that they were sitting erect; an adjustable block was placed under the firefighters' feet so that their knees were at a 90° angle. In all, 18 seated dimensions and a seated grip strength

measurement were then obtained. Overall, 40 without-gear anthropometric measurements were recorded (Table 6). A three-dimensional head and face scan (Figure 1b) and a two-dimensional hand scan were then recorded, from which four hand dimensions and six head and face measurements were extracted.

The firefighters were then asked to go to the changing area and to change back into the clothes that they would normally wear under their bunker gear. They were then asked to don their bunker gear. The firefighters were asked to keep all the equipment they usually carry in their pockets (e.g., hand tools, gloves, rope) and to keep any equipment attached to their bunker gear in the position that it is usually donned. The firefighters stood back on the footboard with the designated footprints to begin the measurements in gear. Seven dimensions were measured, followed by a body weight measurement. The firefighters were then positioned back on the bench for a series of 12 seated measurements in gear (Figure 1c) and a seated grip strength test with gloves. Overall, 21 in-gear measurements were collected (Table 6).

Data Analysis

Weighted sampling—Before data were analyzed, a weighting procedure was applied to the samples to ensure that the current sample represents the current firefighter population in age and race/ethnicity composition for men and age distribution for women. The weights were calculated as the relative frequency of a given cell in the firefighter population, divided by the relative frequency of the same cell in the survey sample (International Organization for Standardization, 2008). It can be expressed as,

$$\mathrm{Weight}_{i,j} = \left[N_{i,j} / \left(N_{1,1} + N_{1,2} + \ldots + N_{i,j}\right)\right] / \left[n_{i,j} / \left(n_{1,1} + n_{1,2} + \ldots + n_{i,j}\right)\right],$$

where N is the count from the age/race cell in the firefighter population, n is the count from the age/race cell in the survey sample, i is the subscript for the age group, and j is the subscript for the racial group. Samples were weighted across three age groups (18–32, 33–44, and 45–65) for both men and women and three race/ethnicity groups (non-Hispanic White, non-Hispanic Black, and Hispanics and Others) for men.

Descriptive analyses—Summary statistical analyses on the 71 body measurements were performed for the arithmetic mean, standard error of the mean, standard deviation, 5th percentile, and 95th percentile for each measurement. To confirm that measurements with and without gear were different, nine dimensions available in both without-gear and in-gear conditions were compared; a two-tailed *t* test with a *p* value of .05 as the significance level was performed for each of the nine dimensions.

Current firefighters compared with the general U.S. population—Measurements from the current study were compared with relevant measurements from the general U.S. population according to the CAESAR survey (Harrison & Robinette, 2002). In all, 24 body dimensions for men and 25 dimensions for women were compatible in definitions and

measurement approaches between this study and the CAESAR study. A two-tailed *t* test with a *p* value of .05 as the significance level was performed for each dimension.

Results

Sampled population and statistical weights—A total of 951 firefighters took part in the study, which exceeded the targeted sample size by 51 participants. A representation of the targeted versus final sampled population by age and race/ethnicity distribution is shown in Table 4, and the sampling weights are presented in Table 5. The sampling weight calculation method is defined in the Weighted Sampling subsection within the Data Analysis section. As an example, the weight for Black and age 18 to 32 group would be (34,024 / 1,069,056) / (26 / 863) = 1.05637, where the estimated count of Black male firefighters in the age 18 to 32 category is 34,024 and the estimated count of U.S. adult male firefighters is 1,069,056 (Karter, 2006; U.S. DOL, 2006). The actual count of male firefighters measured was 863; of them, 26 were Black male firefighters from age 18 to 32.

Summary statistics—Summary statistics (sum of weights, mean, and standard deviation) of the 71 body measurements are presented in Table 6. Additional information, including the 5th and 95th percentiles, standard error of the mean, and 95% confidence interval of the mean for each measurement, is listed in Appendix B. The tabulated data were calculated based on the weighted samples exhibited in Tables 4 and 5. There were a few missing data points for a few variables; pair-wise deletion of missing data, which means all valid data points were included in the analyses for the respective variables, was employed.

Measured without gear versus measured in gear—Nine dimensions measured in both the in-gear and without-gear scenarios were compared (Table 7), based on the weighted samples exhibited in Tables 4 and 5. There were a few missing data points scattered among a few variables; casewise deletion of missing data, excluding all cases that had missing data for at least one of the selected variables, was used in the analysis. This ensured that comparisons were from the same set of observations.

The statistical significance level was set at $p = .05/9 = .0056$ (two-tailed test) for nine paired comparisons, which was equivalent to $t_{.05}(9, 847) = \pm 2.83$ for men and $t_{.05}(9, 85) = \pm 2.84$ for women. The differences in means were significant for all dimensions ($p < .0056$). The differences in hip breadth between the without-gear and in-gear conditions were 160 mm for men and 150 mm for women. Similarly, the differences in bideltoid width between the without-gear and in-gear conditions were 135 mm for men and 155 mm for women. The results have a significant implication in seat/space arrangement. The differences in means for elbow–wrist length were 3 mm for men and 5 mm for women, reflecting the thickness of sleeves.

The differences in chest width (40 mm for men and 43 mm for women), chest depth (82 mm for both men and women), foot length (46 mm for men and 42 mm for women), and foot breadth (16 mm for men and 18 mm for women) between the in-gear and without-gear conditions (Table 7) have implications for protective clothing sizing, footwear design, and cab space configuration. The results also show that firefighters on average wear equipment and clothing of 11.8 kg for men and 10.5 kg for women. In addition, their average grip

strength was reduced by 9.8 kg for men and 8.6 kg for women comparing the with-glove to no-glove conditions.

Current firefighters versus general U.S. population—Table 8 shows the comparisons for the means of 24 body dimensions for men and 25 dimensions for women between current firefighters and the general U.S. population. For men, differences in the means of 16 out of 24 dimensions are statistically significant; of the 16, the differences in 2 dimensions are small enough to be of no practical importance in design practice, whereas the other 14 have significance for product sizing development. Although male firefighters on average have the same height as men in the general U.S. population, they are 9.8 kg heavier than men in the general U.S. population and are larger in body build with shorter lower extremities. Their chest circumference is 80 mm larger, waist circumference 76 mm larger, and bideltoid breadth 84 mm larger than those of men in the general U.S. population. Their crotch height is 12 mm shorter, standing knee height 16 mm shorter, and seated knee height 14 mm shorter.

For females, differences in the means of 14 out of 25 dimensions are statistically significant; of the 14, the difference in 1 dimension is small enough to be of no practical importance in design practice, whereas the other 13 have significance for protective gear sizing. Their mean weights are on average 2.6 kg different, but this is not statistically significant. However, female firefighters are significantly taller than women in the general U.S. population, by 29 mm on average. In addition, female firefighters have larger stature-related body dimensions (e.g., 31 mm for acromion height, 24 mm for axilla height, and 16 mm for buttock–knee length) than women in the general U.S. population. Moreover, their body builds are larger than those of women in the general U.S. population: waist circumference is 73 mm larger, bideltoid breadth is 58 mm larger, and under bust circumference is 33 mm larger.

In summary, these results show that the size and physique of the current firefighter population are not well represented by the general U.S. population. Male firefighters are heavier than men in the general U.S. population, and female firefighters are taller than women in the general U.S. population. Both male and female firefighters on average have larger upper-body builds than those of the general U.S. population.

Discussion

Anthropometric characteristics of the current U.S. firefighter population—Table 8 shows that male firefighters are heavier than males in the general U.S. population and female firefighters are taller than the females in the general U.S. population. Comparisons of the firefighter data to the recent vital and health statistics (body weight and height) of adults age 20 and older in the United States (Fryar et al., 2012) demonstrate similar trends. In addition, both male and female firefighters have larger upper-body builds than those of the general U.S. population. The results are consistent with Hsiao et al.'s (2002) findings that different occupational groups have distinctive anthropometric characteristics from the general U.S. population. This study provides additional detailed information to update the existing literature on the distinctive characteristics of firefighters.

The significant differences between in-gear and without-gear conditions for hip breadth and bideltoid width have implications for seat and cab space arrangement. Although seat pan and seat back widths of an automotive fire apparatus can be specified using the “without-gear” anthropometry information of hip breadth and bideltoid width, space needs to be provided between seats or between a seat and a door. This is where the in-gear measurements are critical as firefighters typically ride or operate an automotive apparatus while in gear. This study provides critical data to address the fire apparatus design and cab space arrangement issue, which is absent in the literature. The results also echo the required step of an anthropometric adjustment for clothing and gear in protective equipment design for public safety professionals (Hsiao, 2013).

The information on differences in chest width (40 mm for men and 43 mm for women), chest depth (82 mm for both men and women), foot length (46 mm for men and 42 mm for women), and foot breadth (16 mm for men and 18 mm for women) between in-gear and without-gear conditions (Table 7) provides the scientific basis and practical specifications for protective clothing sizing, footwear design, and cab space configuration, which helps to fill a knowledge gap on the subject in the current literature. It is also worth noting that the average equipment-and-clothing weights of 11.9 kg for men and 10.5 kg for women have physiological and biomechanical significance. They represent additional energy expenditure and heat generation, making them an additional heart burden; the literature has shown that heart attack and stress were the most frequent causes of firefighter deaths, accounting for 60.2% of incidents in 2011 (U.S. Fire Administration, 2012). Finally, the average grip strength was reduced by 9.8 kg for men and 8.9 kg for women comparing the with-glove to no-glove conditions. This also has physiological and biomechanical implications; increased effort and energy consumption are expected for producing the same amount of work or force when gloves are used versus no gloves. The development of lighter and better fitting protective clothing and gloves is in progress in the fire apparatus manufacturing industry, using the anthropometric data from this study.

Conclusion

A large-scale national anthropometry survey of U.S. firefighters was conducted, and data from 71 measurements were tabulated for advancing fire apparatus and protective-equipment designs. The data contain both in-gear and without-gear measurements that are the first available in the literature for various fire apparatus and firefighter PPE design applications. Male firefighters were on average 9.8 kg heavier and were larger in body build (80 mm larger for chest circumference, 76 mm larger for waist circumference, and 84 mm larger for bideltoid breadth) than men in the general U.S. population. Female firefighters were significantly taller by 29 mm on average and had larger physiques (73 mm larger for waist circumferences and 58 mm larger for bideltoid breadth) than women in the general U.S. population. Moreover, firefighters on average wear equipment and clothing that is 11.9 kg for men and 10.5 kg for women and average grip strength was reduced by 9.8 kg for men and 8.9 kg for women comparing the with-glove to no-glove conditions. This knowledge is critical for the fire apparatus design process for improved anthropometric accommodation and reduced physiological and biomechanical burden on firefighters.

Study 2: Implication of Data Weighting and Normality on Fire Apparatus Designs

Background

An anthropometric database is most useful for apparatus design when its composition accurately represents the demographic characteristics of the target population. Well-intended anthropometric surveys sometimes do not meet the original composition goal due to reduced or over-participation rates, and sampling weightings are commonly used to fill the gap. However, often designers have tabulated summary data but not necessarily the underlying information on weighting for making intelligent decisions. Also, multidimensional data in a raw data form are increasingly being used in product design specifications; normality transformation of raw data for some dimensions may be critical for adequate design practices. A systematic evaluation of the raw data (without weighting) from Study 1 for their representation of the demographic characteristics of the U.S. firefighter population would be valuable for both apparatus designers and human factors practitioners in specifying design requirements for various fire apparatus.

Objective

The objective of this study was to evaluate the differences of firefighter anthropometric data from Study 1 in original strata, weighted arrangements, and normality transformed modes to determine their implications and best usage in product design. The hypothesis is that the differences among original, weighted, and normality transformed data are small enough to be of no practical significance, which demonstrates that the methods used to collect the data in Study 1 have addressed nonnormality concerns and are compatible with weighted data and thus are acceptable and practical for direct usage (without weighting) for fire apparatus design applications.

Method

Data from 71 anthropometric dimensions from Study 1 (stratified sampling plan of 3 age × 3 race/ethnicity combinations for males and 3 age groupings for females) were used for this study. Data in original strata and weighted adjustment were compared for their differences in the mean and 5th and 95th percentiles to determine their deviation from each other. Of the 71 anthropometric dimensions for men in their unweighted original strata, 22 failed to meet the Kolmogorov–Smirnov one-sample normality criterion ($p < .05$). These data were transformed using the Box–Cox method to improve their normality distribution (Box & Cox, 1964). The formulas for Box–Cox transformation are summarized in Appendix C. The transformed means and 5th and 95th percentiles were back-transformed to the original scale (hereafter named normality transform modes) for comparisons with the corresponding values of the original unweighted and weighted data.

Similarly, the Shapiro–Wilks W tests rejected the hypothesis of data normality for 23 of the 71 anthropometric dimensions for women in their unweighted original data ($p < .05$). The Shapiro–Wilks W tests were used in that the sample size for women in this study was considered small. These data were transformed using the Box– Cox method to recover their

normality distribution (Appendix C). The means and 5th and 95th percentiles were then back-transformed to the original scale for comparisons with the corresponding values of the unweighted and weighted data.

The differences among weighted and unweighted (original) data and normality transformed data for the means and 5th and 95th percentiles were compared to the allowable observer errors as reported in the anthropometry literature (Gordon et al., 1989; Guan et al., 2012). If the differences among the weighted data, original unweighted data, and normality transformed data (if any) for a dimension for its mean and 5th and 95th percentiles are smaller or equal to the allowable observer error for that dimension, the differences are considered to be of no practical significance and thus no practical design implications.

Results

Anthropometric data of male firefighters—As seen in Table 9, for male firefighters, the weighted and unweighted means and 5th and 95th percentiles for all 71 body dimensions were equal; that is, their differences are within acceptable measurement error ranges. The normality transformation results (22 dimensions) were also equal to those of unweighted data (as well as weighted data), except for body weight without gear and body weight in gear. The skewness and kurtosis of each of the 20 dimensions are all small.

The differences in mean body weight for the weighted and normality transformed modes were 1.4 kg for the without-gear condition and 1.2 kg for the in-gear situation (Table 9). These differences are above the allowable observer error of 0.7 kg (Guan et al., 2012). Body weight data were skewed to the heavy side in this data set (skewness = 1.2 for the without-gear and 1.1 for the in-gear situations), although the skews are no more than moderate. In addition, it must be noted that 5 of the 22 Box–Cox transformed variables did not reach a satisfactory level for normality statistically: boot breadth (seated in gear), buttock–shoe tip length (seated in gear), bitrochanter length (seated in gear), hand breadth, and palm breadth. Given that their means and 5th and 95th percentiles were very close to those of weighted values, the skewness of these data distribution has no practical importance or concern in product design applications.

Anthropometric data of female firefighters—For female firefighters, the weighted and unweighted means for each body dimension were also very close to each other, as were the weighted and unweighted 5th and 95th percentiles for each body dimension, except for body weight in gear (95th percentile), which is above the allowable observer error of 0.7 kg for an amount of 2 kg (Table 10).

Comparisons of the normality transformation results of 23 dimensions with those of the unweighted data set (as well as weighted data set) for their means and 5th and 95th percentile anthropometry measurements showed that the differences in 9 of the 23 dimensions were above the allowable observer errors: chest circumference (standing without gear, 95th percentile), hip circumference (standing without gear, mean), vertical trunk circumference (standing without gear, mean), weight (without gear, mean), bideltoid breadth (sitting without gear, mean), sitting height (without gear, mean), weight (in gear, mean, 5th percentile, and 95th percentile), eye height (sitting in gear, mean), and buttock–shoe tip

length (sitting in gear, 95th percentile). Data users also need to know that 2 of the 23 Box–Cox transformed variables did not reach a satisfactory level for normality: buttock–shoe tip length (seated in gear) and abdominal breadth (seated in gear).

Discussion

Raw data versus weighted data in design applications—An anthropometric database is most useful for a product design application when its composition accurately represents the demographic characteristics of the target product user population. A well-intended and well-executed anthropometric survey can meet the composition goal. Many surveys often employ sampling weighting to correct potential sampling biases whether they resulted from reduced participation in certain sample categories or an unexpected overparticipation in a sample group. In addition, many product design applications involve multiple anthropometric parameters (Hsiao, 2013), which may require designers to use raw data instead of tabulated single-dimensional data for making intelligent decisions. This study verified that the differences among original data, weighted data, and normality transformed data for male firefighters are small enough to be of no practical significance, which demonstrates that the collected original raw data in Study 1 contain negligible nonnormality concerns or weighting requirements for practical fire apparatus design applications.

For female firefighter data, the similarity between the weighted and unweighted data suggests that this study sample was reasonably representative of the firefighter population in anthropometric dimensions, with an understanding that 9 of the reported 71 dimensions have a larger deviation than others. With a relatively small sample size of 88, caution needs to be exercised in using the original raw data. There were a few “outlier” participants in this database, and there is insufficient information to determine whether this is representative of the national female firefighter community. A normality transformation is desired if raw data on female chest circumference, hip circumference, vertical trunk circumference, weight, bideltoid breadth, sitting height, eye height, and buttock–shoe tip length are used for design purposes.

Conclusion

The anthropometry raw data of male firefighters from Study 1 represent the demographic characteristics of the current firefighter population reasonably well and can be directly employed into fire apparatus design applications. The original raw data (excluding body weight) have no major abnormality and weighting concerns in practical design cases. The study sample of female firefighters was reasonably representative of the firefighter population in anthropometric dimensions. With the relatively small sample size, a normality transformation is desired if raw data on chest circumference, hip circumference, vertical trunk circumference, weight, bideltoid breadth, sitting height, eye height, and buttock–shoe tip length are used for design purposes.

Overall Discussion

The “Natural” Distribution of Body Weight

Body weight data and its relevant dimensions (i.e., chest, waist, and hip circumferences) were skewed to the heavy side (a larger tail to the right) in this data set. Literature has shown that an increase in body weight appears to be a characteristic feature of a population as a whole and does not seem to be a separate problem of only heavier people (Hermanussen, Danker-Hopfe, & Weber, 2001). Although firefighters on average have larger body builds than those of the general U.S. population as demonstrated in the current study, they are not immune from the overweight prevalence. About 31.5% of the study participants' body mass indexes fall in the category of severe overweight ($\geq$31.1 kg/m^2 for men and $\geq$32.3 kg/m^2 for women), based on the criteria recommended in the consensus statement of the 1985 National Institute of Health Development Conference on the Health Implications of Obesity (Rowland, 1989). This information needs to be factored into protective gear design for firefighters, especially for protective jackets, pants, and the strap configurations of self-contained breathing apparatus.

Study limitations

This study used a stratified sampling plan of 3 age × 3 race/ethnicity × 2 gender combinations to collect anthropometric data in four geographical regions, centered in four metro areas and their vicinities. Expanding data collection in rural areas would improve the sample representation of national firefighters in that most career firefighters serve in metro areas and most volunteer firefighters serve on departments that protect communities of fewer than 10,000 residents (Karter, 2013). However, adding the additional stratum (i.e., career vs. volunteer) in this already-complicated study was cost prohibitive. Career and volunteer firefighters were therefore considered as a group in this study and extra efforts were extended to reach out to volunteer firefighters in the vicinity of the four study areas to participate in the study. An analysis of key dimensions (i.e., stature, body weight, and some circumference measurements) of male firefighters between career and volunteer groups in this study did not demonstrate a significant difference in means between the groups. Considering career and volunteer firefighters as a group in this study was scientifically reasonable and financially practical, although volunteer firefighters were underrepresented. Sample sizes of female firefighters from these studies were too small for a meaningful comparison of their anthropometric difference between career and volunteer groups.

Recognizing the challenge in recruiting participants who resided 30 miles away from data collection sites and the space constraints at rural fire departments for setting up study scanners, the National Institute for Occupational Safety and Health has developed a new data collection trailer equipped with multiple three-dimensional scanning devices for future anthropometry studies. Until then, the firefighter anthropometry data from this study remain the best available national data for fire apparatus design applications.

Acknowledgments

The authors would like to thank Robert Ferri, Bradley Newbraugh, John Powers, Rick Current, Darlene Weaver, Joyce Zwiener, Jinhua Guan, Alfred Amendola, Gene Hill, and Cathy Rotunda for their tireless support of this

project, including transporting, installing, and calibrating the scanning equipment for all four geographic sites, organizing scientific literature, and providing logistical and administrative upkeep. The authors would also like to thank Ron Siarnicki for his insightful input and vital selection of measurement sites. We are in debt to many fire station managers who provided unfailing subject recruitment and scheduling of subjects as well as excellent facilities in support of this endeavor: Andy Johnston, Chief Michael Clemens, and Chief Kevin Frazier of the Montgomery Fire Department in Rockville, Maryland; Chief Mike Smith and Captain Mike Gafney of the Phoenix Fire Department in Phoenix, Arizona; Chief Henry Costo and Captain Jesse Wilson of the Philadelphia Fire Department; Captain Homer Robertson and Chief Mark Marshall of the Fort Worth Fire Department; Firefighter Mary Ann Hubbard of the Austin Fire Department; and Chief Brooke Hildreth of the San Antonio Fire Department. Thanks also go to the National Fallen Firefighters Foundation (NFFF), International Association of Fire Chiefs (IAFC), International Association of Fire Fighters (IAFF), Fire Apparatus Manufacturers Association (FAMA), and National Fire Protection Association (NFPA) for their support and insightful suggestions in project planning and execution.

Appendix A

Description of Anthropometric Measurements

Measured Without Gear (Standing)

(01) **Acromial height, standing:** The vertical distance between a standing surface and the acromion landmark on the tip of the right shoulder. The subject stands erect looking straight ahead. The heels are together with the weight distributed equally on both feet. The shoulders and upper extremities are relaxed. The measurement is made at the maximum point of quiet respiration.

(02) **Ankle height, standing** (lateral malleolus, right): The vertical distance is measured between a standing surface and the lateral malleolus landmark on the outside of the right ankle. The subject stands erect with the heels together and the weight distributed equally on both feet.

(03) **Axilla height, standing:** The vertical distance between a standing surface and the anterior point of the axilla is measured with an anthropometer. The subject stands erect looking straight ahead. The heels are together with the weight distributed equally on both feet. The shoulders and upper extremities are relaxed. The measurement is made at the maximum point of quiet respiration.

(04) **Calf circumference, standing:** The maximum horizontal circumference of the right calf is measured with a tape. The subject stands erect with the heels approximately 10 cm apart and the weight distributed equally on both feet.

(05) **Cervicale height, standing:** The vertical distance between a standing surface and the cervicale landmark on the back of the head. The subject stands erect looking straight ahead. The heels are together with the weight distributed equally on both feet. The shoulders and upper extremities are relaxed. The measurement is made at the maximum point of quiet respiration.

(06) **Chest breadth, standing:** The maximum horizontal breadth of the chest at the level of the right bust point on women or the nipple on men is measured with a beam caliper. The subject stands erect looking straight ahead with the heels together, the weight distributed equally on both feet. The measurement is taken at the maximum point of quiet respiration.

(07) **Chest circumference, standing:** The maximum horizontal circumference of the chest at the fullest part of the breast is measured with a tape. The subject stands erect looking straight ahead. The shoulders and upper extremities are relaxed. The measurement is taken at the maximum point of quiet respiration.

(08) **Chest depth, standing:** The horizontal distance between the chest, at the level of the right bust point on women or the nipple on men, and the back at the same level is measured with a beam caliper. The subject stands erect looking straight ahead. The shoulders and upper extremities are relaxed. The measurement is taken at the maximum point of quiet respiration.

(09) **Crotch height, standing:** Vertical distance from the standing surface to the crotch. Subject stands erect with feet slightly apart.

(10) **Foot breadth, standing:** The subject stands with the weight distributed equally on both feet. The maximum horizontal distance across the right foot perpendicular to its long axis is measured between the inside and the outside of the foot.

(11) **Foot length, standing:** The subject stands with the weight distributed equally on both feet. The distance between the back-most point of the right heel and the tip of the longest toe is measured to the long axis of the foot.

(12) **Functional arm span, standing:** The subject stands erect with the back against a wall. The subject outstretches the arms horizontally at shoulder height. The distance between the tips of the middle fingers of the outstretched arms is measured.

(13) **Hip circumference, standing:** Maximal horizontal circumference over the buttocks. The subject stands erect with heels together.

(14) **Knee height, standing:** The vertical distance between a standing surface and the point at knee crease is measured. The subject stands erect looking straight ahead. The heels are together with the weight distributed equally on both feet. The shoulders and upper extremities are relaxed. The measurement is made at the maximum point of quiet respiration.

(15) **Stature:** Vertical distance from the standing surface to the highest point of the head (vertex). Subject stands erect with feet placed on premarked footprints with approximately ten centimeters apart at the inside of the heel and 33° rotation at the toes.

(16) **Thigh circumference, standing:** Circumference of the right thigh at its juncture with the buttock. The subject stands erect with legs spread apart just enough so that the thighs do not touch.

(17) **Under bust circumference, standing:** The horizontal circumference of the chest directly below the bust is measured with a tape. The subject stands erect looking straight ahead. The shoulders and upper extremities are relaxed. The measurement is taken at the maximum point of quiet respiration.

(18) **Vertical trunk circumference, standing:** The subject stands erect looking straight ahead. The arms hang relaxed at the sides, and the feet are shoulder width apart with the weight distributed equally on both feet. The vertical circumference of the torso is

measured by passing a tape over the right shoulder, nipple (or most forward point of the bra), through the crotch, and over the most protrusive point of the right buttock. On men, the tape follows the surface contours of the body. On women, it follows the body contours except from the most protrusive point of the bra to the crotch.

(19) **Waist circumference, standing:** Horizontal circumference of the waist at the level of the center of preferred waist height. The subject stands erect with heels together.

(20) **Waist height, standing:** The vertical distance between a standing surface and the point at the subject's preferred waist. The subject stands erect looking straight ahead. The heels are together with weight distributed equally on both feet. The shoulders and upper extremities are relaxed. The measurement is made at the maximum point of quiet respiration.

(21) **Weight:** Weight of the subject. Subject stands on the scale fully erect with weight distributed equally on both feet.

Measured Without Gear (Seated)

(22) **Acromion breadth, sitting:** The subject sits erect on a flat surface looking straight ahead. The upper arms are hanging relaxed at the sides with the forearms and hands on the thighs. The breadth measurement is from the right acromion to the left acromion.

(23) **Acromion–grip length, sitting:** The subject sits erect with back against a flat surface. The right arm is extended straight ahead while a dowel rod is held vertically in it. The horizontal measurement is taken from the right acromion to the top middle point of the dowel rod.

(24) **Acromion height, sitting:** The subject sits erect on a flat surface looking straight ahead. The vertical distance is measured between the sitting surface and the tip of the right shoulder (acromion).

(25) **Acromion–wrist length, sitting:** The subject sits erect with back against a flat surface. The right arm is extended straight ahead while a dowel rod is held vertically in it. The horizontal measurement is taken from the right acromion to the most lateral point (radial styloid) of the right wrist.

(26) **Bideltoid breadth, sitting:** The subject sits erect on a flat surface looking straight ahead. The upper arms are hanging relaxed at the sides with the forearms and hands on the thighs. The maximum horizontal distance is measured between the outside of the upper arms at the level of the deltoid muscle and as low as the level of the elbows.

(27) **Bitragion arc length, sitting:** The surface distance from right to left tragion across the most superior point in the head measured with a tape measure.

(28) **Buttock–knee length, sitting:** The subject sits erect on a flat surface looking straight ahead. The thighs are parallel, and the feet are in line with the thighs on a surface adjusted so that the knees are bent 90°. The horizontal distance is measured from the most protrusive point of the right buttock to the most forward point of the right knee.

(29) **Elbow height, sitting:** The subject sits erect on a flat surface looking straight ahead. Upper arms hang freely downward and forearms are horizontal. The vertical measurement is taken from the horizontal sitting surface to the lowest bony point of the elbow.

(30) **Elbow–wrist length, sitting:** The subject sits erect with back against a flat surface. The right arm is extended straight ahead while a dowel rod is held vertically in it. The horizontal measurement is taken from the right elbow to the most lateral point of the right wrist.

(31) **Functional leg length, sitting:** The calculated sum of the buttock–knee length seated measurement and the popliteal height seated measurement.

(32) **Grip strength, sitting:** The subject squeezes the dynamometer (a force measuring instrument) with their predominant hand using his/her maximum force.

(33) **Head arc length, sitting:** Surface length along contours of head from glabella to nuchal measured with a tape measure.

(34) **Head circumference, sitting:** Maximum circumference of the head above the attachment of the ears to the head, just above the ridges of the eyebrows, and around the back of the head.

(35) **Hip breadth, sitting:** The subject sits erect on a flat surface. The maximum horizontal breadth across the hips or thighs is measured.

(36) **Knee height, sitting:** The subject sits erect on a flat surface. The thighs are parallel, and the feet are in line with the thigh on a surface adjusted so that the knees are bent at 90°. The vertical distance is measured between the foot surface and the top of the right knee.

(37) **Neck circumference, sitting:** Horizontal circumference of the neck above the laryngeal prominence measured with a tape measure.

(38) **Nuchal height, sitting:** The subject sits erect looking straight ahead. The vertical distance is measured between the seated plane and the most protrusive point of the nuchal.

(39) **Popliteal height, sitting:** The subject sits erect on a flat surface. The thighs are parallel, and the feet are in line with the thighs on a surface adjusted so that the knees are bent 90°. The vertical distance is measured between the foot surface and the lowest point of the bottom of the thigh at the juncture with the calf behind the knee (popliteal fossa).

(40) **Sitting height:** The subject sits erect on a flat surface looking straight ahead with the head in the Frankfort plane. The vertical distance is measured between the sitting surface and the top of the head.

Measured in Gear (Standing)

(01) **Boot breadth, standing:** The subject stands with the weight distributed equally on both feet in the turnout gear. The maximum horizontal distance across the right boot perpendicular to its long axis is measured between the inside and outside of the boot.

(02) **Boot length, standing:** The subject stands with the weight distributed equally on both feet in the turnout gear. The distance between the back-most point of the right heel of the boot and the most anterior part of the boot is measured parallel to the long axis of the foot.

(03) **Chest depth, standing:** The subject stands erect looking straight ahead in the turnout gear. The horizontal depth of the chest is measured from the front to back at the level of the most protrusive point of the right bra pocket on women or of the right nipple on men.

(04) **Chest width, standing:** The subject stands erect looking straight ahead in the turnout gear. The arms hang relaxed at the sides. The horizontal breadth of the chest is measured at the level of the nipples on men or the most protrusive point of a bra on women.

(05) **Overhead reach, standing:** The subject stands erect in turnout gear with the right arm extended overhead to maximum height while left arm is relaxed to the side. The vertical distance between a standing surface and the tip of the right middle finger is measured.

(06) **Waist depth, standing:** The subject stands erect looking straight ahead in the turnout gear. The feet are shoulder width apart with the weight distributed equally on both feet. The abdominal muscles are relaxed. The maximum horizontal distance is measured between the back and the front of the waist at the level of the greatest indentation.

(07) **Waist width, standing:** The subject stands erect looking straight ahead in the turnout gear. The arms hang relaxed at the sides, and the heels are together with the weight distributed equally on both feet. The breadth of the torso is measured in the region of the waist at the level of its greatest indentation.

(08) **Weight in gear:** The subject wears turnout gear including tools in pockets and stands on a scale with the feet parallel and the weight distributed equally on both feet.

Measured in Gear (Seated)

(09) **Abdominal breadth, sitting:** The subject sits erect on a flat surface in turnout gear looking straight ahead. The abdominal muscles are relaxed. The horizontal breadth of the torso is measured at the level of the most protrusive point of the gear at the abdomen.

(10) **Abdominal depth, sitting:** The subject sits erect on a flat surface in turnout gear looking straight ahead. The abdominal muscles are relaxed. The horizontal distance is measured between the back and the most protrusive point of the gear at the abdomen.

(11) **Acromion–trochanter length, sitting:** The subject sits on a flat surface in turnout gear. The thighs are parallel, and the feet are in line with the thighs on a surface adjusted so that the knees are bent 90°. The contour distance from the right acromion to the left trochanter is measured across the gear.

(12) **Bideltoid breadth/width, sitting** (Maximum torso breadth): The subject sits erect on a flat surface in turnout gear. The upper arms are hanging relaxed at the sides. The maximum horizontal distance of the turnout gear is measured between the outside of the upper arms at the level of the deltoid muscles and as low as the level of the elbows.

(13) **Bitrochanter length, sitting** (curve): The subject sits on a flat surface in turnout gear. The thighs are parallel, and the feet are in line with the thighs on a surface adjusted so that the knees are bent 90°. The maximum distance on the turnout gear from the right trochanter to the left trochanter is measured going above the legs.

(14) **Buttock–shoe tip length, sitting:** The subject sits on a flat surface in turnout gear. The thighs are parallel, and the feet are in line with the thighs on a surface adjusted so that the knees are bent 90°. The horizontal straight-line distance is measured between the back right buttock and the most anterior part of the boot.

(15) **Elbow–wrist length, sitting:** The subject sits erect looking straight ahead in turnout gear. The right upper arm is hanging relaxed at the side with the forearm and hand extended horizontally with the palms facing each other. The horizontal distance is measured between the back of the tip of the elbow and the wrist.

(16) **Eye height, sitting:** The subject sits erect in turnout gear on a flat surface looking straight ahead. The vertical distance is measured between the sitting surface and a corner of the right eye.

(17) **Grip strength, sitting:** The subject squeezes the dynamometer (a force measuring instrument) with their predominant hand using his/her maximum force while wearing an extrication glove.

(18) **Hip breadth, sitting:** The subject sits erect on a flat surface in turnout gear. The maximum horizontal breadth of the turnout gear across the hips is measured.

(19) **Shoulder–elbow length, sitting:** The subject sits erect looking straight ahead in turnout gear, the upper arms hang relaxed at the sides with the forearms and hands extended forward horizontally and the palms facing each other. The vertical distance is measured between the tip of the right shoulder and the underside of the bent elbow.

(20) **Shoulder–grip length, sitting:** The subject sits erect looking straight ahead in turnout gear. The buttocks and the shoulder blades touch a back rest. The right arm is extended forward horizontally. The dowel rod is held vertically. The horizontal distance is measured between the (back) wall and the top, middle point of the dowel rod.

(21) **Thigh clearance, sitting:** The subject sits on a flat surface in turnout gear. The thighs are parallel, and the feet are in line with the thighs on a surface adjusted so that the knees are bent 90°. The vertical distance is measured between the sitting surface and the topmost point of the thigh.

Extracted Head–Face and Hand Dimensions

(01) **Bigonion breadth:** The straight-line distance between the right and left gonion landmarks on the corners of the jaw is measured calculating point to point distance using 3D visualization software.

(02) **Biinfraorbitale breadth:** The straight-line distance between the right and left infraorbitale landmarks on the bottom edge of the bony eye sockets under the eyes is measured calculating the point to point distance using 3D visualization software.

(03) **Face breadth:** The straight-line distance between the right and left tragion landmarks on the cartilaginous flaps in front of the each ear hole is measured calculating point to point distance using 3D visualization software.

(04) **Face length:** The straight-line distance between the menton landmark at the bottom of the chin and the sellion landmark on the deepest point of the root of the nose measured as a point to point distance in 3D visualization software.

(05) **Hand breadth:** Breadth of the right hand between the landmarks at metacarpale II and metacarpale V. The fingers are parallel to the long axis of the forearm.

(06) **Hand length:** Length of the right hand between the distal crease at the wrist and the tip of the middle finger. The middle finger is parallel to the long axis of the forearm.

(07) **Head breadth:** The maximum horizontal breadth of the head above the attachment of the ears is measured using the virtual calipers in 3D visualization software.

(08) **Midtragion to head top length:** The vertical distance between midtragion, as calculated from right and left tragion, to the top of head.

(09) **Palm breadth:** The palm breadth is the distance between the point to the left of the distal transverse crease and the point to the right of the proximal transverse crease.

(10) **Palm length:** The length of the palm is measured between the base of the middle finger and the distal crease at the wrist.

Appendix B

Summary Statistics for Firefighter Anthropometry (Weighted; In millimeters)

Dimension	Sum of Weights	*M*	*SD*	5th Percentile	95th Percentile	*SE* of *M*	95% CI-L	95% CI-U
Dimension without gear (men; standing)								
(01) Acromion height	863	1458	62	1356	1565	2.1	1454	1462
(02) Ankle height	863	72	7	61	83	0.2	72	73
(03) Axilla height	863	1322	61	1226	1426	2.1	1318	1326
(04) Calf circumference	863	398	29	353	449	1.0	396	400
(05) Cervical height	863	1519	62	1417	1621	2.1	1515	1523
(06) Chest breadth	863	358	28	315	409	1.0	356	360
(07) Chest circumference	863	1104	91	968	1268	3.1	1098	1110

Dimension	Sum of Weights	*M*	*SD*	5th Percentile	95th Percentile	*SE* of *M*	95% CI-L	95% CI-U
(08) Chest depth	861	281	27	238	327	0.9	279	283
(09) Crotch height	863	785	44	713	858	1.5	782	788
(10) Foot breadth	863	104	6	95	113	0.2	104	105
(11) Foot length	863	270	13	248	292	0.4	269	271
(12) Functional arm span	859	1817	80	1690	1952	2.7	1812	1823
(13) Hip circumference	863	1077	75	965	1208	2.6	1072	1082
(14) Knee height	863	477	29	430	525	1.0	475	479
(15) Stature	863	1769	67	1660	1881	2.3	1765	1773
(16) Thigh circumference	863	619	47	543	701	1.6	616	622
(17) Under bust circum.	863	1031	91	894	1190	3.1	1025	1037
(18) Vertical trunk circum.	863	1775	91	1635	1935	3.1	1769	1781
(19) Waist circumference	863	971	105	828	1165	3.6	964	978
(20) Waist height	861	1032	52	946	1118	1.8	1028	1035
(21) Weight (kg)	863	93.0	14.8	71.3	120.4	0.5	92.0	93.9
Dimension without gear (men; seated)								
(22) Acromion breadth	863	397	19	366	429	0.7	396	398
(23) Acromion–grip length	861	633	31	583	685	1.1	631	635
(24) Acromion height	863	614	30	563	664	1.0	612	616
(25) Acromion–wrist length	861	567	29	521	616	1.0	565	569
(26) Bideltoid breadth	862	574	52	497	663	1.8	570	577
(27) Bitragion arc length	860	364	13	343	384	0.4	363	365
(28) Buttock–knee length	860	630	32	578	685	1.1	628	632
(29) Elbow height	863	242	27	197	290	0.9	240	244
(30) Elbow–wrist length	862	299	15	275	325	0.5	298	300
(31) Functional leg length	863	1069	51	987	1152	1.7	1066	1072
(32) Grip strength (kg)	863	43.9	8.9	30.0	58.5	0.3	43.3	44.5
(33) Head arc length	863	356	18	328	386	0.6	355	358
(34) Head circumference	861	578	14	553	601	0.5	577	579
(35) Hip breadth	862	437	34	384	498	1.2	434	439
(36) Neck circumference	863	413	28	372	465	1.0	411	415
(37) Knee height	863	544	28	500	589	0.9	542	546
(38) Nuchal height	863	787	36	729	847	1.2	784	789
(39) Popliteal height	863	439	25	399	481	0.8	438	441
(40) Sitting height	863	924	35	866	987	1.2	922	927
Dimension in gear (men; standing)								
(01) Boot breadth	863	120	5	111	127	0.2	119	120
(02) Boot length	863	316	17	290	345	0.6	315	317
(03) Chest depth	863	363	35	302	420	1.2	361	366
(04) Chest width	863	398	32	352	459	1.1	395	400
(05) Overhead grip reach	858	2265	103	2099	2430	3.5	2258	2272
(06) Waist depth	863	381	40	321	452	1.4	379	384
(07) Waist width	862	458	36	400	522	1.2	455	460

Dimension	Sum of Weights	*M*	*SD*	5th Percentile	95th Percentile	*SE* of *M*	95% CI-L	95% CI-U
(08) Weight in gear (kg)	863	104.8	15.0	82.5	133.2	0.5	103.8	105.8
Dimension in gear (men; seated)								
(09) Abdominal breadth	863	463	42	406	540	1.4	460	466
(10) Abdominal depth	862	364	40	304	436	1.4	361	367
(11) Acromion–troch length	863	900	62	806	1013	2.1	896	904
(12) Bideltoid breadth	863	709	54	613	796	1.9	705	712
(13) Bitrochanter length	863	880	100	740	1062	3.4	874	887
(14) Buttock–shoe tip length	863	727	72	596	824	2.4	723	732
(15) Elbow–wrist length	863	302	17	275	330	0.6	301	303
(16) Eye height	863	812	34	755	871	1.2	810	814
(17) Grip strength (kg)	852	34.1	7.5	22.0	46.5	0.3	33.6	34.6
(18) Hip breadth	863	597	50	515	678	1.7	593	600
(19) Shoulder–elbow length	863	381	21	346	416	0.7	380	383
(20) Shoulder–grip length	861	612	33	558	668	1.1	610	615
(21) Thigh clearance	861	198	20	166	233	0.7	196	199
Dimension extracted (men; face and hand)								
(01) Bigonion breadth	863	127	11	111	149	0.4	126	128
(02) Biinfraorbitale breadth	861	107	9	91	121	0.3	106	107
(03) Face breadth	863	150	6	139	160	0.2	149	150
(04) Face length	863	124	7	113	136	0.2	123	124
(05) Hand breadth	858	97	5	90	105	0.2	97	98
(06) Hand length	857	198	9	183	213	0.3	197	198
(07) Head breadth	862	161	7	151	172	0.2	161	162
(08) Midtragion to head top length	860	145	8	132	158	0.3	144	145
(09) Palm breadth	858	96	5	88	103	0.2	96	96
(10) Palm length	858	114	6	105	123	0.2	113	114
Dimension without gear (women; standing)								
(01) Acromion height	86	1374	53	1294	1459	5.8	1362	1385
(02) Ankle height	87	67	6	58	76	0.6	66	69
(03) Axilla height	86	1257	54	1171	1343	5.8	1246	1269
(04) Calf circumference	88	376	30	331	434	3.2	370	383
(05) Cervical height	86	1429	55	1344	1523	6.0	1417	1440
(06) Chest breadth	88	313	28	278	360	3.0	307	319
(07) Chest circumference	88	973	94	845	1166	10.0	953	992
(08) Chest depth	88	263	31	214	319	3.3	256	269
(09) Crotch height	86	742	41	670	805	4.4	733	751
(10) Foot breadth	88	95	5	87	105	0.5	94	96
(11) Foot length	88	247	13	224	272	1.3	244	250
(12) Functional arm span	88	1688	74	1564	1814	7.9	1672	1704
(13) Hip circumference	88	1058	88	945	1232	9.4	1040	1077
(14) Knee height	86	448	26	395	491	2.8	442	453

Dimension	Sum of Weights	*M*	*SD*	5th Percentile	95th Percentile	*SE* of *M*	95% CI-L	95% CI-U
(15) Stature	87	1667	60	1575	1764	6.4	1654	1680
(16) Thigh circumference	88	615	59	529	726	6.3	603	628
(17) Under bust circumference	88	835	80	732	991	8.6	818	852
(18) Vertical trunk circumference	88	1607	84	1489	1771	9.0	1590	1625
(19) Waist circumference	88	869	99	732	1050	10.6	848	890
(20) Waist height	86	994	53	909	1075	5.7	982	1005
(21) Weight (kg)	88	72.2	12.8	56.6	97.7	1.4	69.4	74.9
Dimension without gear (women; seated)								
(22) Acromion breadth	88	355	20	327	393	2.2	350	359
(23) Acromion–grip length	88	597	30	544	645	3.2	591	604
(24) Acromion height	88	583	27	542	625	2.9	577	589
(25) Acromion–wrist length	88	532	27	488	577	2.8	526	538
(26) Bideltoid breadth	88	489	47	430	597	5.0	479	499
(27) Bitragion arc length	87	347	12	327	366	1.3	344	349
(28) Buttock–knee length	88	604	27	561	654	2.9	599	610
(29) Elbow height	88	237	28	187	284	3.0	231	243
(30) Elbow–wrist length	88	275	14	251	298	1.5	272	278
(31) Functional leg length	88	1011	43	942	1080	4.6	1002	1020
(32) Grip strength (kg)	88	29.7	6.3	21.0	41.0	0.7	28.3	31.0
(33) Head arc length	88	342	20	306	371	2.2	338	346
(34) Head circumference	87	558	14	538	582	1.6	555	561
(35) Hip breadth	87	425	39	372	489	4.1	417	434
(36) Knee height	88	510	24	475	552	2.5	505	515
(37) Neck circumference	88	340	25	308	382	2.6	335	345
(38) Nuchal height	88	746	33	693	797	3.5	739	753
(39) Popliteal height	88	407	23	370	447	2.5	402	412
(40) Sitting height	88	874	31	832	923	3.3	867	881
Dimension in gear (women; standing)								
(01) Boot breadth	88	113	5	105	121	0.5	112	114
(02) Boot length	88	288	15	262	315	1.6	285	292
(03) Chest depth	88	345	35	285	399	3.8	337	352
(04) Chest width	88	355	30	314	411	3.2	349	361
(05) Overhead grip reach	88	2117	99	1950	2271	10.5	2096	2138
(06) Waist depth	88	349	40	288	408	4.3	341	358
(07) Waist width	88	421	45	351	494	4.7	411	430
(08) Weight in gear (kg)	88	82.6	13.2	66.5	107.0	1.4	79.8	85.4
Dimension in gear (women; seated)								
(09) Abdominal breadth	88	428	44	364	515	4.7	418	437
(10) Abdominal depth	88	328	35	284	398	3.7	321	336
(11) Acromion–troch length	88	860	66	767	980	7.1	846	874
(12) Bideltoid width	88	644	44	568	722	4.7	635	653

Dimension	Sum of Weights	*M*	*SD*	5th Percentile	95th Percentile	*SE* of *M*	95% CI-L	95% CI-U
(13) Bitrochanter length	88	845	95	715	1015	10.2	824	865
(14) Buttock–shoe tip length	88	700	69	566	786	7.3	685	715
(15) Elbow–wrist length	88	279	17	252	309	1.8	276	283
(16) Eye height	88	767	32	722	815	3.4	761	774
(17) Grip strength (kg)	86	20.8	5.8	11.0	30.5	0.6	19.6	22.0
(18) Hip breadth	88	577	46	513	658	4.9	567	587
(19) Shoulder–elbow length	88	361	23	324	401	2.5	356	366
(20) Shoulder–grip length	88	585	41	522	655	4.3	577	594
(21) Thigh clearance	88	190	17	157	214	1.8	187	194
Dimension extracted (women; face and hand)								
(01) Bigonion breadth	87	108	8	98	125	0.9	107	110
(02) Biinfraorbitale breadth	88	100	9	83	116	0.9	98	101
(03) Face breadth	88	138	5	129	147	0.6	137	139
(04) Face length	88	115	6	105	124	0.6	113	116
(05) Hand breadth	88	87	4	81	94	0.4	87	88
(06) Hand length	88	183	8	169	197	0.9	181	185
(07) Head breadth	88	159	6	149	169	0.6	157	160
(08) Midtragion to head top length	88	141	8	129	154	0.8	139	142
(09) Palm breadth	88	85	4	79	92	0.4	84	86
(10) Palm length	88	104	5	94	114	0.6	103	105

Note. 95% CI-L = lower 95% confidence interval of the mean; 95% CI-U = upper 95% confidence interval of the mean. Units are in mm except for weight and grip strength, which are in kg.

Appendix C

Formulas for Box–cox transformation in Study 2

Transformed Variables (unit: mm, if not specified)	*M*	*SD*	Formula Used for Box–Cox Transformation
Men			
Abdominal breadth, sitting, in gear	0.4848617	0.0000003	((Data^(-2.062437))-1)/(-2.062437)
Abdominal depth, sitting, in gear	1.3906357	0.0016925	((Data^(-0.707957))-1)/(-0.707957)
Acromion–trochanter, sitting, in gear	0.7794272	0.0000111	((Data^(-1.282784))-1)/(-1.282784)
Bideltoid breadth, sitting, no gear	1.6489283	0.0020798	((Data^(-0.592315))-1)/(-0.592315)
Bigonion breadth	0.7540405	0.0001435	((Data^(-1.323995))-1)/(-1.323995)
Bitroch curve length, sitting, in gear	1.8310559	0.0030747	((Data^(-0.531155))-1)/(-0.531155)
Boot width, standing, in gear	93188.926	9536.005	((Data^(2.588937))-1)/(2.588937)
Buttock–shoe tip length, sitting, in gear	360576556.3	104802445	((Data^(3.159800))-1)/(3.159800)
Chest breadth, standing, no gear	1.3742655	0.0011590	((Data^(-0.716886))-1)/(-0.716886)
Chest breadth, standing, in gear	0.8084888	0.0000492	((Data^(-1.236113))-1)/(-1.236113)
Grip strength, sitting, no glove (kg)	16.8732160	2.4886604	((Data^(0.662322))-1)/(0.662322)
Hand breadth	318.3619209	19.753814	((Data^(1.320401))-1)/(1.320401)

Transformed Variables (unit: mm, if not specified)	*M*	*SD*	Formula Used for Box–Cox Transformation
Hand length	2.4998851	0.0082036	((Data^(-0.330130))-1)/(-0.330130)
Head breadth	0.3497346	0.0000000	((Data^(-2.859310))-1)/(-2.859310)
Neck circumference, sitting, no gear	1.1811338	0.0004256	((Data^(-0.841288))-1)/(-0.841288)
Palm length	2.3737864	0.0103613	((Data^(-0.334929))-1)/(-0.334929)
Palm width	1859.571224	156.6453	((Data^(1.774964))-1)/(1.774964)
Under bust circumference, standing, no gear	1.5779344	0.0011393	((Data^(-0.625439))-1)/(-0.625439)
Waist circumference, standing, no gear	0.6760220	0.0000040	((Data^(-1.479184))-1)/(-1.479184)
Waist depth, standing, in gear	1.2747222	0.0010332	((Data^(-0.776673))-1)/(-0.776673)
Weight in gear (kg)	3.7397099	0.0909615	((Data^(-0.096605))-1)/(-0.096605)
Weight, standing, no gear (kg)	3.4635301	0.0902505	((Data^(-0.123348))-1)/(-0.123348)
Women			
Abdominal breadth, sitting, in gear	6.33231E-01	7.0321E-06	((Data^(-1.579090))-1)/(-1.579090)
Abdominal depth, sitting, in gear	3.47796E-01	5.7303E-09	((Data^(-2.875246))-1)/(-2.875246)
Acromion height, sitting, no gear	2.40890E+09	3.942E+08	((Data^(3.591081))-1)/(3.591081)
Acromion–trochanter, sitting, in gear	3.98786E-01	3.2971E-09	((Data^(-2.507608))-1)/(-2.507608)
Bideltoid breadth, sitting, no gear	3.02960E-01	1.1764E-10	((Data^(-3.300767))-1)/(-3.300767)
Bigonion breadth	2.58649E-01	9.1814E-10	((Data^(-3.866249))-1)/(-3.866249)
Buttock–shoe tip length, sitting, in gear	3.77731E+08	1.114E+08	((Data^(3.186713))-1)/(3.186713)
Calf circumference, standing, no gear	7.43445E-01	2.7388E-05	((Data^(-1.344623))-1)/(-1.344623)
Chest breadth, standing, no gear	2.86585E-01	1.6111E-10	((Data^(-3.489367))-1)/(-3.489367)
Chest circumference, standing, no gear	4.44983E-01	1.8049E-08	((Data^(-2.247275))-1)/(-2.247275)
Chest depth, standing, no gear	9.71663E-01	3.9042E-04	((Data^(-1.025713))-1)/(-1.025713)
Eye height, sitting, in gear	1.23619E+11	2.008E+10	((Data^(4.054254))-1)/(4.054254)
Hand breadth	3.13634E-01	3.0257E-08	((Data^(-3.188423))-1)/(-3.188423)
Hip breadth, sitting, in gear	4.72079E-01	1.0775E-07	((Data^(-2.118288))-1)/(-2.118288)
Hip breadth, sitting, no gear	7.34274E-01	2.3784E-05	((Data^(-1.361526))-1)/(-1.361526)
Hip circumference, standing, no gear	3.11760E-01	1.5843E-11	((Data^(-3.207598))-1)/(-3.207598)
Neck circumference, sitting	2.55696E-01	8.4634E-12	((Data^(-3.910894))-1)/(-3.910894)
Sitting height, no gear	4.76213E+09	5.798E+08	((Data^(3.473531))-1)/(3.473531)
Under bust circumference, standing, no gear	3.10175E-01	3.4041E-11	((Data^(-3.223989))-1)/(-3.223989)
Vert. trunk circumference, standing, no gear	2.25575E-01	3.0608E-16	((Data^(-4.433122))-1)/(-4.433122)
Waist circumference, standing, no gear	5.15775E-01	2.2062E-07	((Data^(-1.938825))-1)/(-1.938825)
Weight in gear (kg)	7.77865E-01	5.4014E-04	((Data^(-1.280921))-1)/(-1.280921)
Weight, standing, no gear (kg)	8.05475E-01	8.6446E-04	((Data^(-1.234967))-1)/(-1.234967)

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Key Points

- A first-available large-scale national anthropometry survey of U.S. firefighters was conducted and 71 anthropometric measurements were collected for advancing fire apparatus and protective equipment designs. Male firefighters were on average 9.8 kg heavier and larger in upper-body builds than males in the general U.S. population. Female firefighters were significantly taller than females in the general U.S. population by 29 mm on average and have larger physiques than those of females of the general U.S. population.
- The sampling process and data method for the national firefighter anthropometry survey set a model for facilitating similar anthropometry studies of other occupational groups (e.g., law enforcement officers and emergency medical service persons) aiming for an array of safety equipment design.
- Firefighters on average wear equipment and clothing of 11.9 kg for men and 10.5 kg for women and their average grip strength was reduced for 9.8 kg for men and 8.6 kg for women comparing the with-glove to no-glove conditions. Research on reducing equipment weight and improving glove design to maintain good grip strength is desirable to lessen potential physiological and biomechanical burden on firefighters.
- The anthropometry raw data of male firefighters from Study 1 represent the demographic characteristics of the current firefighter population and can be directly employed into fire apparatus design applications with no major weighting or abnormality concerns. With the relatively small sample size of female firefighters, a normality transformation is desired if raw data of female firefighter chest circumference, hip circumference, vertical trunk circumference, weight, bideltoid breadth, sitting height, eye height, and buttock–shoe tip length are used for design purposes.

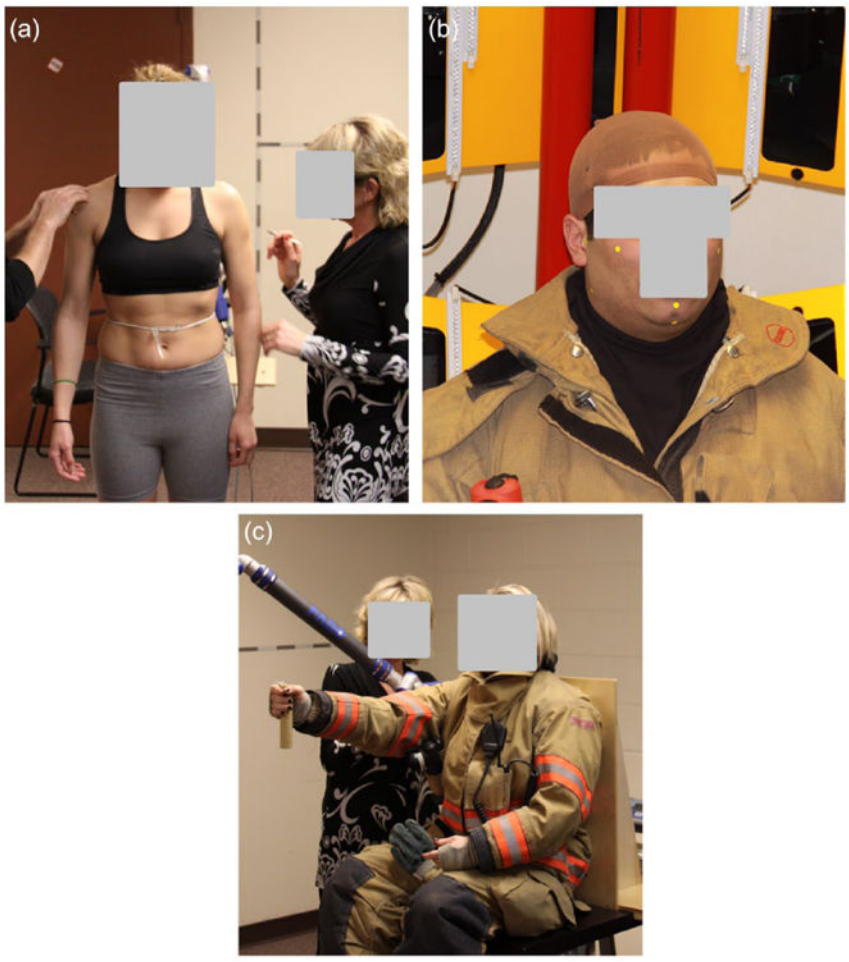

Figure 1.

(a) Anatomical landmarks were first identified and anthropometric measurements without gear were then made. (b) Facial dimensions were registered and extracted from a three-dimensional head and face scan. (c) Anthropometric measurements in-gear were also collected.

Table 1
Sample Distribution to Match Populations in Data Collection Regions

Region	Site	States Represented	U.S. Total (%)	Sample Size
I. Pacific West	Phoenix, AZ	WA, OR, ID, MT, WY, CA, NV, AZ, CO, UT, NM	21.95	198
II. North Central	Chicago, IL	MN, IA, MO, ND, SD, NE, KS, WI, IL, MI, IN, OH, KY	24.48	220
III. Northeast	Rockville, MD	ME, NH, VT, MA, RI, CT, NY, NJ, PA, DE, MD, WV, VA, DC	24.72	222
IV. South	Fort Worth, TX	TN, NC, SC, GA, FL, AL, MS, TX, OK, AR, LA	28.85	260
Total			100.00	900

Table 2

Sampling Plan With Equal Racial/Ethnic Distribution Across the Four Regions

	Age												
	Male												
	White			Black			Hispanic/Other			Female			Total
Data Collection Site	18–32	33–44	45–65	18–32	33–44	45–65	18–32	33–44	45–65	18–32	33–44	45–65	
Phoenix, AZ	45	45	45	7	7	7	7	7	7	7	7	7	198
Chicago, IL	52	52	52	7	7	7	7	7	7	7	7	7	219
Rockville, MD	53	53	53	7	7	7	7	7	7	7	7	7	222
Fort Worth, TX	60	60	60	9	9	9	9	9	9	9	9	9	261
Total		630			90			90			90		900

Table 3

Final Sampling Plan, Accounting for Geographic Density of Racial/Ethnic Distributions

	Age												
	Male												
	White			Black			Hispanic/Other			Female			Total
Data Collection Site	18–32	33–44	45–65	18–32	33–44	45–65	18–32	33–44	45–65	18–32	33–44	45–65	
Phoenix, AZ	45	45	45	3	3	3	13	13	13	7	7	7	204
Chicago, IL	52	52	52	6	6	6	3	3	3	7	7	7	204
Rockville, MD	53	53	53	8	8	8	5	5	5	7	7	7	219
Fort Worth, TX	60	60	60	13	13	13	9	9	9	9	9	9	273
Total		630			90			90			90		900

Table 4

Actual Firefighters Measured Versus Original Study Sampling Plan

	Age												
	Male												
	White			Black			Hispanic/Others			Female			Total
Data Collection Site	18–32	33–44	45–65	18–32	33–44	45–65	18–32	33–44	45–65	18–32	33–44	45–65	
Phoenix, AZ	46	47	43	3	3	3	13	17	13	7	7	8	210
Philadelphia, PA	49	55	52	6	5	11	4	5	2	7	8	5	209
Rockville, MD	63	62	63	10	8	9	8	9	6	8	13	5	264
Fort Worth, TX	55	72	59	7	14	14	9	9	9	5	10	5	268
Total measured	213	236	217	26	30	37	34	40	30	27	38	23	951
Target population	210	210	210	30	30	30	30	30	30	30	30	30	900
Additional subject	3	26	7	−4	0	7	4	10	0	−3	8	−7	51

Table 5
Statistical Weights for Ethnicity and Age Groups by Gender

		Age		
Gender	**Race/Ethnicity**	**18–32**	**33–44**	**45–65**
Male	White	1.09813	1.02811	1.09182
	Black	1.05637	0.94971	0.75191
	Hispanic/other	0.63409	0.55910	0.72793
Female	White, Black, and Hispanic/other	1.06852	0.78756	1.27056

Table 6

Summary Statistics for Measured Dimensions (weighted; unit: mm unless otherwise specified)

	Men			Women		
Dimension	**Sum of Weights**	***M***	***SD***	**Sum of Weights**	***M***	***SD***
Dimension without gear (standing)						
(01) Acromion height	863	1458	62	86	1374	53
(02) Ankle height	863	72	7	87	67	6
(03) Axilla height	863	1322	61	86	1257	54
(04) Calf circumference	863	398	29	88	376	30
(05) Cervical height	863	1519	62	86	1429	55
(06) Chest breadth	863	358	28	88	313	28
(07) Chest circumference	863	1104	91	88	973	94
(08) Chest depth	861	281	27	88	263	31
(09) Crotch height	863	785	44	86	742	41
(10) Foot breadth	863	104	6	88	95	5
(11) Foot length	863	270	13	88	247	13
(12) Functional arm span	859	1817	80	88	1688	74
(13) Hip circumference	863	1077	75	88	1058	88
(14) Knee height	863	477	29	86	448	26
(15) Stature	863	1769	67	87	1667	60
(16) Thigh circumference	863	619	47	88	615	59
(17) Under bust circumference	863	1031	91	88	835	80
(18) Vertical trunk circum.	863	1775	91	88	1607	84
(19) Waist circumference	863	971	105	88	869	99
(20) Waist height	861	1032	52	86	994	53
(21) Weight (kg)	863	93.0	14.8	88	72.2	12.8
Dimension without gear (seated)						
(22) Acromion breadth	863	397	19	88	355	20
(23) Acromion–grip length	861	633	31	88	597	30
(24) Acromion height	863	614	30	88	583	27
(25) Acromion–wrist length	861	567	29	88	532	27

	Men			Women		
Dimension	**Sum of Weights**	***M***	***SD***	**Sum of Weights**	***M***	***SD***
(26) Bideltoid breadth	862	574	52	88	489	47
(27) Bitragion arc length	860	364	13	87	347	12
(28) Buttock–knee length	860	630	32	88	604	27
(29) Elbow height	863	242	27	88	237	28
(30) Elbow–wrist length	862	299	15	88	275	14
(31) Functional leg length	863	1069	51	88	1011	43
(32) Grip strength (kg)	863	43.9	8.9	88	29.7	6.3
(33) Head arc length	863	356	18	88	342	20
(34) Head circumference	861	578	14	87	558	14
(35) Hip breadth	862	437	34	87	425	39
(36) Neck circumference	863	413	28	88	340	25
(37) Knee height	863	544	28	88	510	24
(38) Nuchal height	863	787	36	88	746	33
(39) Popliteal height	863	439	25	88	407	23
(40) Sitting height	863	924	35	88	874	31
Dimension in gear (standing)						
(01) Boot breadth	863	120	5	88	113	5
(02) Boot length	863	316	17	88	288	15
(03) Chest depth	863	363	35	88	345	35
(04) Chest width	863	398	32	88	355	30
(05) Overhead grip reach	858	2265	103	88	2117	99
(06) Waist depth	863	381	40	88	349	40
(07) Waist width	862	458	36	88	421	45
(08) Weight in gear (kg)	863	104.8	15.0	88	82.6	13.2
Dimension in gear (seated)						
(09) Abdominal breadth	863	463	42	88	428	44
(10) Abdominal depth	862	364	40	88	328	35
(11) Acromion–troch length	863	900	62	88	860	66
(12) Bideltoid breadth	863	709	54	88	644	44
(13) Bitrochanter length	863	880	100	88	845	95

	Men			Women		
Dimension	**Sum of Weights**	***M***	***SD***	**Sum of Weights**	***M***	***SD***
(14) Buttock–shoe tip length	863	727	72	88	700	69
(15) Elbow–wrist length	863	302	17	88	279	17
(16) Eye height	863	812	34	88	767	32
(17) Grip strength (kg)	852	34.1	7.5	86	20.8	5.8
(18) Hip breadth	863	597	50	88	577	46
(19) Shoulder–elbow length	863	381	21	88	361	23
(20) Shoulder–grip length	861	612	33	88	585	41
(21) Thigh clearance	861	198	20	88	190	17
Dimension extracted (face and hand)						
(01) Bigonion breadth	863	127	11	87	108	8
(02) Biinfraorbitale breadth	861	107	9	88	100	9
(03) Face breadth	863	150	6	88	138	5
(04) Face length	863	124	7	88	115	6
(05) Hand breadth	858	97	5	88	87	4
(06) Hand length	857	198	9	88	183	8
(07) Head breadth	862	161	7	88	159	6
(08) Midtragion to head top length	860	145	8	88	141	8
(09) Palm breadth	858	96	5	88	85	4
(10) Palm length	858	114	6	88	104	5

Table 7

Comparisons for the Means of Body Dimensions Between Without-Gear and In-Gear Conditions for the U.S. Firefighter Population (weighted; casewise deletion of missing data was used in the analysis)

	Measured Without Gear				Measured in Gear					
Dimension	**Sum of W**	***M***	***SE* of *M***	***SD***	**Sum of W**	***M***	***SE* of *M***	***SD***	**Difference in Mean**	***t***
4a. Men										
Bideltoid width, sitting	847	574	1.8	52	847	710	1.9	54	136 mm*	83.6
Body weight (kg)	847	92.9	0.5	14.7	847	104.8	0.5	14.9	11.8 kg*	192.2
Chest depth, standing	847	281	0.9	27	847	363	1.2	35	82 mm*	79.9
Chest width, standing	847	358	1.0	28	847	398	1.1	33	40 mm*	41.6
Elbow–wrist length, sitting	847	299	0.5	15	847	302	0.6	17	3 mm*	7.5
Foot breadth, standing	847	104	0.2	6	847	120	0.2	5	16 mm*	75.5
Foot length, standing	847	270	0.4	13	847	316	0.6	17	46 mm*	106.6
Grip strength, sitting (kg)	847	43.90	0.3	8.8	847	34.1	0.3	7.4	−9.8 kg*	−40.0
Hip breadth, sitting	847	437	1.2	34	847	597	1.7	50	160 mm*	95.4
4b. Women										
Bideltoid width, sitting	85	489	5.2	48	85	644	4.8	45	155 mm*	33.5
Body weight (kg)	85	72.1	1.4	13.1	85	82.6	1.5	13.5	10.5 kg*	74.8
Chest depth, standing	85	262	3.4	32	85	344	3.8	35	82 mm*	25.8
Chest width, standing	85	313	3.1	29	85	356	3.2	30	43 mm*	16.1
Elbow–wrist length, sitting	85	275	1.5	14	85	280	1.8	17	5 mm*	3.7
Foot breadth, standing	85	95	0.6	5	85	113	0.5	5	18 mm*	30.6
Foot length, standing	85	247	1.4	13	85	289	1.6	15	42 mm*	36.2
Grip strength, sitting (kg)	85	29.8	0.7	6.3	85	21.2	0.6	5.8	−8.6 kg*	−15.2
Hip breadth, sitting	85	425	4.2	39	85	576	5.0	46	151mm*	30.6

*Note.*Unit: mm unless otherwise specified. Sum of W: sum of weights.

*Denotes statistical significance where $p < .05/9 = .0056$ (two-tailed test), which is equivalent to $t_{.05}(9, 847) = \pm 2.83$ for men and $t_{.05}(9, 85) = \pm 2.84$ for women for nine paired tests.

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Table 8

Comparisons for the Means of Body Dimensions Between the Current Firefighters and the General U.S. Population (weighted)

	U.S. Firefighters				General U.S. Population				
Dimension	**Sum of W**	***M***	***SE* of *M***	***SD***	**Sum of W**	***M***	***SE* of *M***	***SD***	**Difference in Mean**
5a. Men, 24 out of 40 dimensions without gear									
(01) Acromion height, standing	863	1458	2.1	62	1114	1445	2.3	76	13*
(02) Ankle height, standing	863	72	0.2	7	1114	71	0.2	7	1*+
(03) Axilla height, standing	863	1322	2.1	61	1114	1322	2.1	70	0
(05) Cervical height, standing	863	1519	2.1	62	1114	1523	2.3	75	−4
(07) Chest circumference, standing	863	1104	3.1	91	1119	1024	3.4	113	80*
(09) Crotch height, standing	863	785	1.5	44	1119	797	1.6	55	−12*
(10) Foot breadth, standing	863	104	0.2	6	1114	104	0.2	8	0
(11) Foot length, standing	863	270	0.4	13	1119	267	0.5	15	3*+
(13) Hip circumference, standing	863	1077	2.6	75	1119	1032	2.9	98	45*
(14) Knee height, standing	863	477	1.0	29	1114	493	0.9	31	−16*
(15) Stature	863	1769	2.3	67	1119	1767	2.4	81	2
(16) Thigh circumference, standing	863	619	1.6	47	1119	600	1.9	63	19*
(18) Vertical trunk circumference	863	1775	3.1	91	1118	1705	3.2	108	70*
(19) Waist circumference, standing	863	971	3.6	105	1118	895	3.8	126	76*
(20) Waist height, standing	861	1032	1.8	52	1119	1037	1.9	63	−5
(21) Weight (kg)	863	93.0	0.5	14.8	1119	83.2	0.5	17.4	9.8*
(24) Acromion height, sitting	863	614	1.0	30	1119	602	1.1	38	12*
(26) Bideltoid breadth, sitting	862	574	1.8	52	1119	490	1.1	38	84*
(28) Buttock–knee length, sitting	860	630	1.1	32	1119	614	1.1	36	16*
(29) Elbow height, sitting	863	242	0.9	27	1119	239	1.1	35	3
(34) Head circumference, sitting	861	578	0.5	14	1119	577	0.5	18	1
(35) Hip breadth, sitting	862	437	1.2	34	1117	376	1.1	38	61*
(36) Knee height, sitting	863	544	0.9	28	1119	558	1.0	32	−14*

	U.S. Firefighters				General U.S. Population				
Dimension	**Sum of W**	***M***	***SE* of *M***	***SD***	**Sum of W**	***M***	***SE* of *M***	***SD***	**Difference in Mean**
(40) Sitting height	863	924	1.2	35	1119	921	1.3	43	3
5b. Women, 25 out of 40 dimensions without gear									
(01) Acromion height, standing	86	1374	5.8	53	1257	1343	2.0	70	31*
(02) Ankle height, standing	87	67	0.6	6	1258	66	0.2	7	1
(03) Axilla height, standing	86	1257	5.8	54	1258	1233	1.9	67	24*
(05) Cervical height, standing	86	1429	6.0	55	1257	1407	2.0	71	22*
(07) Chest circumference, standing	88	973	10.0	94	1261	964	4.0	141	9
(09) Crotch height, standing	86	742	4.4	41	1260	748	1.5	53	−6
(10) Foot breadth, standing	88	95	0.5	5	1258	93	0.2	9	2*+
(11) Foot length, standing	88	247	1.3	13	1261	239	0.4	14	8*
(13) Hip circumference, standing	88	1058	9.4	88	1258	1061	4.0	143	−3
(14) Knee height, standing	86	448	2.8	26	1258	445	0.8	29	3
(15) Stature	87	1667	6.4	60	1261	1638	2.2	78	29*
(16) Thigh circumference, standing	88	615	6.3	59	1261	611	2.4	87	4
(17) Under bust circumference	88	835	8.6	80	1261	802	3	108	33*
(18) Vertical trunk circumference	88	1607	9.0	84	1261	1577	3.3	117	30*
(19) Waist circumference, standing	88	869	10.6	99	1259	796	4.4	154	73*
(20) Waist height, standing	86	994	5.7	53	1261	1007	1.8	63	−13
(21) Weight (kg)	88	72.2	1.4	12.8	1261	69.6	0.6	19.9	2.6
(24) Acromion height, sitting	88	583	2.9	27	1261	568	0.9	32	15*
(26) Bideltoid breadth, sitting	88	489	5.0	47	1261	431	1.1	39	58*
(28) Buttock–knee length, sitting	88	604	2.9	27	1260	588	1.1	40	16*
(29) Elbow height, sitting	88	237	3.0	28	1260	237	0.8	30	0
(34) Head circumference, sitting	87	558	1.6	14	1260	552	0.5	18	6*
(35) Hip breadth, sitting	87	425	4.1	39	1259	410	1.5	53	15*
(36) Knee height, sitting	88	510	2.5	24	1261	508	0.9	31	2
(40) Sitting height	88	874	3.3	31	1260	864	1.1	39	10

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Note. Unit: mm unless otherwise specified. Sum of W: sum of weights.

*Denotes statistical significance at $p = .05/24 = .00208$ for men and $p = .05/25 = .002$ for women for two-tailed independent t tests with Bonferroni correction, which were equivalent to $t_{.05}(24, >1000) = \pm 3.08$ for men and $t_{.05}(25, >1000) = \pm 3.09$ for women.

+Denotes no practical importance.

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Table 9

Differences of Firefighter (Men) Anthropometric Data in Original Strata, Weighted Adjustments, and Normality Transformed Modes

	Weighted (Sum of Weights = 852∼863)			Unweighted (N = 857∼863)			Box–Cox Normality Trans. (N = 857∼863)			
Dimension	***M***	**5th Percentile**	**95th Percentile**	***M***	**5th Percentile**	**95th Percentile**	***M***	**5th Percentile**	**95th Percentile**	**Allowable Observer Error**
Men, dimension without gear (standing)										
(01) Acromion height	1458	1356	1565	1457	1355	1563				7^{+}, $5^{\ddagger}$
(02) Ankle height	72	61	83	72	61	83				3^{+}, $3^{\ddagger}$
(03) Axilla height	1322	1226	1426	1321	1224	1425				10^{+}
(04) Calf circumference	398	353	449	398	352	449				5^{+}, $6^{\ddagger}$
(05) Cervical height	1519	1417	1621	1518	1417	1621				7^{+}
(06) Chest breadth	358	315	409	358	315	409	356	315	408	8^{+}, $15^{\ddagger}$
(07) Chest circumference	1104	968	1268	1105	966	1268				15^{+}
(08) Chest depth	281	238	327	281	238	327				4^{+}, $8^{\ddagger}$
(09) Crotch height	785	713	858	785	713	858				10^{+}
(10) Foot breadth	104	95	113	104	96	113				2^{+}
(11) Foot length	270	248	292	270	248	291				3^{+}
(12) Functional arm span	1817	1690	1952	1818	1690	1952				10^{+}
(13) Hip circumference	1077	965	1208	1077	965	1208				12^{+}
(14) Knee height	477	430	525	477	430	525				6^{+}
(15) Stature	1769	1660	1881	1768	1660	1881				11^{+}, $4^{\ddagger}$
(16) Thigh circumference	619	543	701	619	543	701				6^{+}, $13^{\ddagger}$
(17) Under bust circum.	1031	894	1190	1031	894	1190	1024	893	1190	16^{+}
(18) Vertical trunk circum.	1775	1635	1935	1775	1635	1932				24^{+}
(19) Waist circum.	971	828	1165	970	826	1164	957	824	1161	11^{+}, $18^{\ddagger}$
(20) Waist height	1032	946	1118	1031	944	1121				7^{+}
(21) Weight (kg) *	**93.0**	71.3	120.4	92.9	71.2	**120.4**	**91.6**	71.0	**119.2**	$0.7^{\ddagger}$
Men, dimension without gear (seated)										

	Weighted (Sum of Weights = 852∼863)			Unweighted (N = 857∼863)			Box–Cox Normality Trans. (N = 857∼863)			
Dimension	***M***	**5th Percentile**	**95th Percentile**	***M***	**5th Percentile**	**95th Percentile**	***M***	**5th Percentile**	**95th Percentile**	**Allowable Observer Error**
(22) Acromion breadth	397	366	429	397	366	430				8^{+}, $6^{\ddagger}$
(23) Acromion– grip length	633	583	685	633	583	685				
(24) Acromion height	614	563	664	614	563	662				9^{+}, $5^{\ddagger}$
(25) Acromion– wrist length	567	521	616	567	521	616				6^{+}
(26) Bideltoid breadth	574	497	663	574	497	663	570	495	665	8^{+}
(27) Bitragion arc length	364	343	384	364	343	385				7^{+}
(28) Buttock– knee length	630	578	685	630	577	685				6^{+}, $10^{\ddagger}$
(29) Elbow height	242	197	290	242	196	289				10^{+}, $12^{\ddagger}$
(30) Elbow–wrist length	299	275	325	299	275	325				
(31) Functional leg length	1069	987	1152	1069	986	1154				17^{+}
(32) Grip strength (kg)	43.9	30.0	58.5	44	30	58	44	30	59	
(33) Head arc length	356	328	386	356	327	386				
(34) Head circumference	578	553	601	577	553	601				5^{+}
(35) Hip breadth	437	384	498	437	383	498				6^{+}, $8^{\ddagger}$
(36) Knee height	544	500	589	544	500	589				2^{+}, $8^{\ddagger}$
(37) Neck circumference	413	372	465	413	371	465	411	370	461	6^{+}
(38) Nuchal height	787	729	847	786	728	847				
(39) Popliteal height	439	399	481	439	399	481				7^{+}, $8^{\ddagger}$
(40) Sitting height	924	866	987	923	866	986				6^{+}, $5^{\ddagger}$
Men, dimension in gear (standing)										
(01) Boot breadth §	120	111	127	120	112	127	120	112	127	$3^{\ddagger}$
(02) Boot length	316	290	345	316	290	345				$3^{\ddagger}$
(03) Chest depth	363	302	420	363	302	420				4^{+}
(04) Chest width	398	352	459	398	352	460	395	350	456	8^{+}
(05) Overhead reach	2265	2099	2430	2264	2098	2430				
(06) Waist depth	381	321	452	382	321	453	378	322	454	8^{+}

Dimension	Weighted (Sum of Weights = 852∼863)			Unweighted (N = 857∼863)			Box–Cox Normality Trans. (N = 857∼863)			Allowable Observer Error
	M	5th Percentile	95th Percentile	*M*	5th Percentile	95th Percentile	*M*	5th Percentile	95th Percentile	
(07) Waist width	458	400	522	458	400	522				6+
(08) Weight in gear (kg) *	**104.8**	82.5	**133.2**	104.7	82.4	**132.5**	**103.6**	82.2	**131.3**	0.7‡
Men, dimension in gear (seated)										
(09) Abdominal breadth	463	406	540	463	406	540	458	405	539	12‡
(10) Abdominal depth	364	304	436	364	304	436	360	304	437	10+, 11‡
(11) Acromion– troch length	900	806	1013	899	806	1010	895	806	1009	
(12) Bideltoid breadth	709	613	796	709	613	796				8+
(13) Bitrochanter length §	880	740	1062	880	739	1062	872	731	1059	
(14) Buttock– shoe tip length §	727	596	824	727	598	824	735	598	832	6+, 10‡
(15) Elbow–wrist length	302	275	330	302	275	330				3+
(16) Eye height	812	755	871	811	755	871				8+, 7‡
(17) Grip strength (kg)	34.1	22.0	46.5	34.1	22.0	46.0				
(18) Hip breadth	597	515	678	597	514	678				8+
(19) Shoulder–elbow length	381	346	416	381	346	416				6+, 7‡
(20) Shoulder–grip length	612	558	668	612	559	668				10‡
(21) Thigh clearance	198	166	233	198	166	233				3+, 5‡
Men, dimension extracted (face and hand)										
(01) Bigonion breadth	127	111	149	127	111	149	126	111	148	
(02) Biinfraorbitale breadth	107	91	121	107	91	121				
(03) Face breadth	150	139	160	150	140	161				2+
(04) Face length	124	113	136	124	113	136				
(05) Hand breadth §	97	90	105	97	90	105	97	90	105	2+, 2‡
(06) Hand length	198	183	213	198	183	214	197	183	213	3+, 4‡
(07) Head breadth	161	151	172	161	151	172	161	151	173	2+
(08) Midtragion to head top	145	132	158	145	132	158				

Dimension	Weighted (Sum of Weights = 852∼863)			Unweighted (N = 857∼863)			Box–Cox Normality Trans. (N = 857∼863)			Allowable Observer Error
	M	5th Percentile	95th Percentile	*M*	5th Percentile	95th Percentile	*M*	5th Percentile	95th Percentile	
(09) Palm breadth §	96	88	103	96	88	103	96	88	103	
(10) Palm length	114	105	123	114	105	123	114	105	124	

Note. Unit: mm unless otherwise specified.

* Denotes that the difference between weighted and unweighted mean, 5th percentile or 95th percentile (**bolded**), is greater than allowable observer error.

§ Denotes that the Box–Cox transformation did not reach a satisfactory level for normality: boot breadth (seated in gear), buttock–shoe tip length (seated in gear), bitrochanter length (seated in gear), hand breadth, and palm breadth.

‡ Guan et al. (2012).

+ Gordon et al. (1989).

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Table 10

Differences of Firefighter (Women) Anthropometric Data in Original Strata, Weighted Adjustments, and Normality Transformed Modes

	Weighted (Sum of Weights = 86∼88)			Unweighted (N = 86∼88)			Box–Cox Normality Trans. (N = 87∼88)			
Dimension	***M***	**5th Percentile**	**95th Percentile**	***M***	**5th Percentile**	**95th Percentile**	***M***	**5th Percentile**	**95th Percentile**	**Allowable Observer Error**
Women, dimension without gear (standing)										
(01) Acromion height	1374	1294	1459	1373	1294	1459				7^{+}, $5^{\ddagger}$
(02) Ankle height	67	58	76	67	58	76				3^{+}, $3^{\ddagger}$
(03) Axilla height	1257	1171	1343	1257	1176	1343				10^{+}
(04) Calf circumference	376	331	434	377	331	434	374	332	431	5^{+}, $6^{\ddagger}$
(05) Cervical height	1429	1344	1523	1428	1344	1523				7^{+}
(06) Chest breadth	313	278	360	313	280	365	308	277	366	8^{+}, $15^{\ddagger}$
(07) Chest circumference *	973	845	1166	973	845	**1166**	**959**	843	1150	15^{+}
(08) Chest depth	263	214	319	262	211	319	259	217	320	4^{+}, $8^{\ddagger}$
(09) Crotch height	742	670	805	741	670	805				10^{+}
(10) Foot breadth	95	87	105	95	87	105				2^{+}
(11) Foot length	247	224	272	247	228	272				3^{+}
(12) Functional arm span	1688	1564	1814	1686	1564	1814				10^{+}
(13) Hip circumference#	1058	945	1232	**1060**	945	1232	**1045**	940	1228	12^{+}
(14) Knee height	448	395	491	448	397	491				6^{+}
(15) Stature	1667	1575	1764	1666	1575	1764				11^{+}, $4^{\ddagger}$
(16) Thigh circumference	615	529	726	616	529	726				6^{+}, $13^{\ddagger}$
(17) Under bust circum.	835	732	991	836	732	996	821	732	989	16^{+}
(18) Vertical trunk circum.	1607	1489	1771	**1608**	1489	1771	**1554**	1462	1691	24^{+}
(19) Waist circum.	869	732	1050	871	732	1050	855	735	1060	11^{+}, $18^{\ddagger}$
(20) Waist height	994	909	1075	993	909	1075				7^{+}
(21) Weight (kg) * #	72.2	56.6	97.7	**72.3**	**56.6**	98.0	**70.0**	55.4	97.2	$0.7^{\ddagger}$
Women, dimension without gear (seated)										

	Weighted (Sum of Weights = 86∼88)			Unweighted (N = 86∼88)			Box–Cox Normality Trans. (N = 87∼88)			
Dimension	***M***	**5th Percentile**	**95th Percentile**	***M***	**5th Percentile**	**95th Percentile**	***M***	**5th Percentile**	**95th Percentile**	**Allowable Observer Error**
(22) Acromion breadth	355	327	393	355	327	393				8^{+}, $6^{\ddagger}$
(23) Acromion– grip length	597	544	645	596	544	645				
(24) Acromion height	583	542	625	583	542	625	585	536	625	9^{+}, $5^{\ddagger}$
(25) Acromion– wrist length*	532	488	577	531	**488**	577				6^{+}
(26) Bideltoid breadth #	489	430	597	**489**	430	597	**480**	429	576	8^{+}
(27) Bitragion arc length	347	327	366	347	327	366				7^{+}
(28) Buttock– knee length	604	561	654	604	561	654				6^{+}, $10^{\ddagger}$
(29) Elbow height	237	187	284	238	194	284				10^{+} $12^{\ddagger}$
(30) Elbow– wrist length	275	251	298	274	251	298				
(31) Functional leg length	1011	942	1080	1011	942	1080				17^{+}
(32) Grip strength (kg)	29.7	21.0	41.0	29.8	21.0	41.0				
(33) Head arc length	342	306	371	342	306	371				
(34) Head circumference	558	538	582	558	538	582				5^{+}
(35) Hip breadth *	425	372	489	425	372	**489**	421	368	496	6^{+}, $8^{\ddagger}$
(36) Knee height	510	475	552	509	474	552				2^{+}, $8^{\ddagger}$
(37) Neck circumference	340	308	382	341	310	382	337	308	387	6^{+}
(38) Nuchal height	746	693	797	745	693	796				
(39) Popliteal height	407	370	447	406	370	447				7^{+}, $8^{\ddagger}$
(40) Sitting height #	874	832	923	873	**832**	923	875	**820**	922	6^{+}, $5^{\ddagger}$
Women, dimension in gear (standing)										
(01) Boot breadth	113	105	121	113	105	121				$3^{\ddagger}$
(02) Boot length	288	262	315	288	263	315				$3^{\ddagger}$
(03) Chest depth	345	285	399	344	285	399				4^{+}
(04) Chest width	355	314	411	355	314	411				8^{+}
(05) Overhead reach	2117	1950	2271	2115	1950	2280				
(06) Waist depth	349	288	408	349	290	408				8^{+}

	Weighted (Sum of Weights = 86∼88)			Unweighted (N = 86∼88)			Box–Cox Normality Trans. (N = 87∼88)			
Dimension	***M***	**5th Percentile**	**95th Percentile**	***M***	**5th Percentile**	**95th Percentile**	***M***	**5th Percentile**	**95th Percentile**	**Allowable Observer Error**
(07) Waist width *	421	351	494	420	351	494				6+
(08) Weight in gear (kg) * #	82.6	66.5	**107.0**	**82.8**	66.5	**109.7**	**80.6**	65.1	108.2	0.7‡
Women, dimension in gear (seated)										
(09) Abdominal breadth §	428	364	515	427	364	515	422	365	509	12‡
(10) Abdominal depth *	328	284	398	329	286	398	323	284	396	10+, 11‡
(11) Acromion– troch length	900	806	1013	899	806	1010	895	806	1009	
(12) Bideltoid breadth	644	568	722	644	568	722				8+
(13) Bitrochanter length	845	715	1015	849	715	1015				
(14) Buttock– shoe tip length # §	700	566	786	700	566	**786**	707	574	**801**	6+, 10‡
(15) Elbow–wrist length	279	252	309	280	252	309				3+
(16) Eye height * #	767	722	815	767	**722**	815	769	**712**	815	8+, 7‡
(17) Grip strength (kg)	34.1	22.0	46.5	34.1	22.0	46.0				
(18) Hip breadth	577	513	658	577	513	658	572	513	659	8+
(19) Shoulder–elbow length	361	324	401	360	324	399				6+, 7‡
(20) Shoulder–grip length	585	522	655	585	522	655				10‡
(21) Thigh clearance	190	157	214	190	159	214				3+, 5‡
Women, dimension extracted (face and hand)										
(01) Bigonion breadth	108	98	125	109	98	125	107	98	123	
(02) Biinfraor-bitale breadth	100	83	116	99	83	116				
(03) Face breadth	138	129	147	138	129	147				2+
(04) Face length	115	105	124	115	105	124				
(05) Hand breadth	87	81	94	87	81	94	87	81	95	2+, 2‡
(06) Hand length	183	169	197	183	169	197				3+, 4‡
(07) Head breadth	159	149	169	159	149	169				2+
(08) Midtragion to head top	141	129	154	141	129	154				
(09) Palm breadth	85	79	92	85	79	92				

	Weighted (Sum of Weights = 86∼88)			Unweighted (N = 86∼88)			Box–Cox Normality Trans. (N = 87∼88)			
Dimension	***M***	**5th Percentile**	**95th Percentile**	***M***	**5th Percentile**	**95th Percentile**	***M***	**5th Percentile**	**95th Percentile**	**Allowable Observer Error**
(10) Palm length	104	94	114	104	94	114				

Note. Unit: mm unless otherwise specified.

[*] Denotes that the difference between weighted and unweighted mean, 5th percentile or 95th percentile, is greater (bolded) than allowable observer error.

[#] Denotes that the difference between unweighted and normality transformed mean, 5th percentile or 95th percentile, is greater (bolded) than allowable observer error.

[§] Denotes that the Box–Cox transformation did not reach a satisfactory level for normality: seated buttock–shoe tip length and seated abdominal breadth.

[‡] Guan et al. (2012).

[+] Gordon et al. (1989).