Firefighter Anthropometry for Fire Apparatus and Equipment Design

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Introduction

Firefighter anthropometry for fire apparatus and equipment design (e.g., cabs, seats, body restraints, protective ensembles) has been identified as a pressing issue to protect 1.1 million firefighters from being injured or killed in crashes and rollover incidents, falls from vehicles, and excessive thermal and chemical exposures. A NIOSH study in 2002 found that on average firefighters were 6.8 kg heavier than other occupations combined for males and 10 kg heavier for females, while current fire apparatus are designed based on the body size information of military personnel of the 70s and 80s. A data-and-knowledge gap has existed for a long time. This presentation reports a comprehensive national survey of firefighter anthropometry for updating fire apparatus design criteria and standards. The survey was conducted by NIOSH through partnership with firefighter associations, fire apparatus manufacturers, and other stakeholders. Three equipment design subjects are discussed in this presentation: (1) anthropometric differences among firefighters and other occupational groups, (2) head and face anthropometry for respirator sizing, and (3) seated whole body anthropometry for fire-truck-seat design and space arrangement.

Methods

The survey used a stratified sampling plan (3-age x 3-race/ethnicity × 2-gender combinations) to collect anthropometric data across the U.S. It took into account the geographic density of racial/ethnic distributions calculated from U.S. Census 2000. A total of 951 subjects participated in the study to complete traditional anthropometry data and 3-dimensional face scans while they were seated and standing with and without protective gear. One hundred ninety-five firefighters, representing the various combinations of body size and shape of the 951-subject pool, were identified to participate in the second-phase study which involved 3-dimensional whole body scans and digitization for cab workspace, seat belt, and bunker-gear design applications.

Results

Anthropometric Differences between Firefighters and Other Respirator Users

Eighty-six body measurements were recorded in the study (Hsiao et al, 2009). Body weight , stature, and four selected measurements relevant to head and face protection are tabulated in the table on the right and were compared to the best available respirator-user data (Zhuang & Bradtmiller 2005). The results indicate that the body and head-and-face sizes of firefighters are significantly different from those of other respirator user groups ($p < 0.05$). For both men and women, firefighters have larger stature-related measurements than the weighted average of other respirator users combined. Male firefighters also have a greater mean weight than all other respirator-user groups combined, while female firefighters have no significant difference from other respirator-user groups combined in mean body weight.

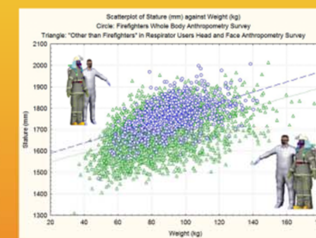
Firefighters Whole Body Anthropometry Survey (Weighted)

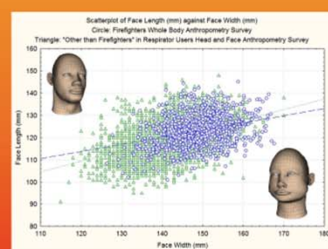
	MEN							WOMEN						
Hsiao et al (2009)	N	Mean	Std Dev	Mn L95 CI	Mn U 95 CI	Sig	Mn Diff	N	Mean	Std Dev	Mn L95 CI	Mn U95 CI	Sig	M Diff
Stature (mm)	863	1767.8	67	1763.3	1772.3	Y	25.5	87	1668.3	61.2	1655.3	1681.4	Y	45.2
Weight (kg)	863	92.9	14.8	91.9	93.9	Y	5.0	88	72.3	13.3	69.5	75.2	N	-1.6
Head Length (mm)	863	205.5	7.4	205.0	206.0	Y	9.7	88	203.5	11.5	201.0	205.9	Y	16.4
Head Breadty (mm)	862	161.2	6.7	160.8	161.7	Y	8.8	88	158.9	5.9	157.6	160.1	Y	12.0
Face Length (mm)	842	123.8	7.0	123.3	124.3	Y	2.2	87	114.8	5.9	113.5	116.0	Y	2.0
Face Width (mm)	862	149.7	6.4	149.3	150.2	Y	6.4	88	138.2	5.3	137.1	139.3	Y	3.3

Respirator Users Head and Face Anthropometry Survey (Weighted;Other than Firefighters)

	MEN							WOMEN						
Zhuang et al (2005)	N	Mean	Std Dev	Mn L95 CI	Mn U 95 CI			N	Mean	Std Dev	Mn L95 CI	Mn U95 CI		
Stature (mm)	1526	1742.3	69.2	1738.8	1745.7			1241	1623.1	66.1	1619.4	1626.8		
Weight (kg)	1525	87.9	18.1	87.0	88.8			1235	73.9	18.6	72.9	75.0		
Head Length (mm)	1526	195.8	7.5	195.5	196.2			1241	187.1	7.3	186.7	187.5		
Head Breadty (mm)	1526	152.5	6.1	152.1	152.8			1241	146.9	5.6	146.5	147.2		
Face Length (mm)	1526	121.6	7.0	121.2	121.9			1241	112.8	5.9	112.5	113.2		
Face Width (mm)	1525	143.4	7.2	143.0	143.7			1241	134.9	6.5	134.5	135.2		

N: Sample size, Mean: Weighted Mean, Std Dev: Standard deviation, Mn L95 CI: Lower end of 95% confidence interval of mean, Mn U95 CI: Upper end of 95% confidence interval of mean, Sig: Significant or not (Y=Yes, N=No), Mn Diff: Mean difference





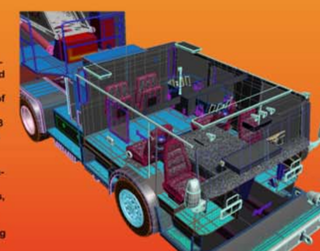
Head-and-Face Anthropometry for Respirator Sizing

There are 3.3 million respirator users in the private sector in the United States (BLS 2003). There are also an estimated 1.1 million firefighters who use respirators on the job (National Fire Protection Association 2006). While respirator fit testing is required in determining respirator fit performance, two indices are commonly used for the design, sizing, and selection of respirators: face length (Menton-Sellion length) and face width (Bizygomatic breadth).

Univariate independent sample t-tests of the data from this study and the Respirator Users study revealed that firefighters have larger face length and width than the weighted average of other respirator user groups combined. Using industrial respirator user head-and-face anthropometric data would be inadequate for describing the face anthropometric variability of the current firefighter work force.

Seated Whole Body Anthropometry for Seat Design and Space Arrangement

Enhanced seat configurations that can accommodate firefighters with variations in body sizes will help protect head and body and thus increase post-crash survivability. Preliminary results suggest (1) minimum seat cushion width of 498 mm (currently 460 mm in the National Fire Protection Association 1901 standard), (2) back cushion width of 663 mm at shoulder height (currently 460 mm), (3) seat height adjustment range of 370~481 mm, and (4) seat head height of 986 mm (no helmet use) above the seat to accommodate 95% of the current firefighters. These calculations do not account for the thickness of coats, portable radios, hand lights, escape ropes, harnesses, extra gloves, and whatever tools the firefighters have placed in the pockets; minimum seating space (including seat cushion width) of 678 mm and back/shoulder area space (including back cushion width) of 796 mm at shoulder height is suggested.



Summary

This study responded to a need for an anthropometric database on firefighters in the U.S. for the design of ergonomically efficient fire-engine cabs, seats, restraint systems, egress, and bunker gear. The database consists of anthropometric data for 951 firefighters and workspace data for 195 firefighters, who were selected as representative of the U. S. firefighter population in age, gender, and race/ethnicity. The database includes traditional anthropometric measurements, digital scans in various postures, and fire-truck cab workspace measurements. Preliminary results of 3 equipment-design subjects are discussed in this presentation: (1) anthropometric differences among firefighters and other respirator user groups, (2) head-and-face anthropometry for respirator sizing, and (3) seated whole-body anthropometry for fire-truck-seat design and space arrangement. Comparisons of data from this study to industrial respirator users revealed that using industrial worker anthropometric data would be inadequate for describing the anthropometric variability of the current firefighter work force. Some suggestions are presented for fire apparatus manufacturers and national standards committees' possible use to update seat and respirator configurations. NIOSH is working closely with partners and stakeholders to update cab, seat, restraint system, egress, and bunker gear designs for reducing firefighter exposure to work-related risk factors for fatalities and injuries.

Acknowledgments

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