Investigation of Female versus Male Firefighter Anthropometrics and Ergonomic Mobility

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The number of female firefighters continues to grow from 1% in the 1980s, to 7% as of 2014 (Campbell, 2017). Despite the growing number of women in firefighting, structural turnout suits are predominately designed and manufactured to fit the male human form (Boorady et al., 2013; Park et al., 2014). 80% of female firefighters experience issues with ill-fitting PPE, which is four times greater than their male counterparts (20.9%) (Hulett, Bendick, Thomas, & Moccio, 2008). Sizing data demonstrates vast differences in waist to hip variation among men and women (Boorady et al., 2013; SizeUSA, 2003) (Figure 1). Improper fitting suits may lead to restricted range-of-motion (ROM) when performing critical tasks, especially in the chest and hip areas, where body dimensions vary greatly between men and women (SizeUSA, 2003). Previous research (Langseth-Schmidt, 2014; Park et al., 2014) has not quantified female firefighter mobility for the full structural turnout ensemble (turnout coat, pants, thermal hood, helmet, and self-contained breathing apparatus (SCBA)). Therefore, the purpose of this research was to assess the current fit and ergonomic mobility for female versus male firefighters when wearing a structural turnout ensemble. The following research objectives were established:

Figure 1

1. To measure male and female firefighter body dimensions and quantify structural turnout suit fit using three-dimensional body scanning technology.
2. To conduct an ergonomic ROM wear trial to identify and analyze gender differences in firefighter mobility when wearing structural firefighter turnout suits.

After IRB approval, 16 local firefighters (six females and ten males) were recruited (age (36 +/- 7.5yrs); height (1.74m +/- .07); weight (199 lbs. +/- 53.9)). Subjects were invited to campus for a single test session to be body scanned and conduct a ROM protocol while wearing all three garment configurations: base layers (BL), turnout suit (TS), and turnout ensemble (TE). All participants wore the same style of turnout gear assigned by the local fire department; material differences were held constant. Garment sizing information was recorded for each individual participant's ensemble elements.

Three-dimensional body scanning was conducted using an Image Twin body scanner by TC^2 to assess the bulkiness and fit of turnout gear for each participant and garment configuration (BL & TS). Measurements included arm and pant length, crotch height, chest and waist circumference, sleeve length, etc. Participants then conducted a ROM protocol in each suit configuration to assess mobility in four joint locations (elbow, shoulder, hip, and knee) using electro-goniometers to measure flexion, extension, and abduction. The average absolute value of

10 repetitions of each movement was calculated. A subjective comfort survey assessed fit and ease of movement in each test garment. Body scans when wearing the TS were compared to BL measurements to determine differences in fit between garment configurations and gender. Significant differences in ROM between gender and garments were analyzed using two-sample t-tests (Ciesielska-Wróbel, DenHartog, & Barker, 2016).

Figure 2 illustrates 3-D body scans of a male subject wearing a) BL, b) TS; and a female subject wearing c) BL, d) TS. On average, data from the three-dimensional body scanning illustrated significant differences *($p<0.05$)* in crotch height (TS), bust girth (BL) and chest girth (BL), between gender. Table 1 provides the mean values in degrees of arc ± st. dev. for ROM of subjects by gender when wearing different garment configurations and performing selected movements. Regardless of gender, ROM was significantly lower when wearing turnout gear for shoulder abduction, vertical flexion, elbow flexion and extension, hip flexion, and knee flexion (*below indicates overall sign. diff. between groups per one-way ANOVA; p-value <0.05).

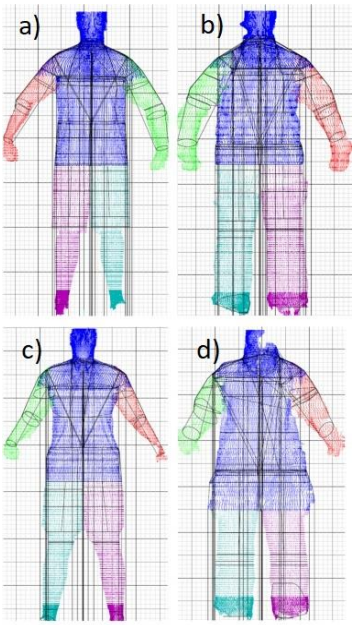

Figure 2

Table 1. Average ROM for each garment configuration by gender.

ROM at specific joints	BL ± St. Dev.		TS ± St. Dev.		TE ± St. Dev.	
	Male	Female	Male	Female	Male	Female
Shoulder abduction*	95.6 ± 14.9	102.6 ± 31.3	87.4 ± 31	101 ± 16.5	76.7 ± 28	79.8 ± 15.7
Shoulder vertical flexion*	86.3 ± 9.2	84.1 ± 9.9	71.6 ± 12.4	73 ± 10.5	62.4 ± 18.8	58.5 ± 13.8
Shoulder vertical ext.	60.9 ± 11.2	68.2 ± 5.3	57.8 ± 12	65.8 ± 7.5	56 ± 16.2	64.4 ± 9.2
Shoulder horiz. flex.	77.2 ± 17.3	89 ± 13.2	74.8 ± 12.4	81.5 ± 15.2	72 ± 11.6	76.3 ± 14.8
Shoulder horiz. ext.	45.8 ± 8.9	45.2 ± 5.7	41.6 ± 12	46.5 ± 9.3	39 ± 11.7	50.5 ± 6.3
Elbow*	134 ± 13.7	139 ± 15.9	126 ± 17.6	136.3 ± 13.2	116.9 ± 19.2	130.3 ± 16.1
Trunk flexion	64.4 ± 12.8	72.6 ± 23.8	56.6 ± 14.5	66.9 ± 25.7	61.9 ± 17.5	71.4 ± 17.4
Trunk extension	24.4 ± 8.9	30.4 ± 12.5	23.3 ± 8.9	25.8 ± 9.7	25.3 ± 6.1	29.5 ± 9.6
Hip flexion*	67.2 ± 15	71.7 ± 20.6	56.9 ± 13.4	57.1 ± 18.1	56.2 ± 14.1	58.3 ± 14.8
Hip extension	20 ± 5.9	25.8 ± 9.7	18.4 ± 6.3	23.6 ± 8.7	25.5 ± 7.9	25.1 ± 8
Knee*	104.8 ± 8.2	115.5 ± 11	94.7 ± 7.6	102.6 ± 8.5	95.1 ± 4.5	101.9 ± 9.1

In conclusion, significant differences in ROM were found between garment configurations for both male and female firefighters. Surprisingly, female firefighters tended to have, on average, a higher static ROM than their male counterparts. This may be due to the additional bulk and ease in their oversized gear, compared to male firefighters. Most notable differences between gender were found in the post-wear trial perception assessments in which female firefighters reported it more difficult and more uncomfortable when performing the static ROM movements. Future research should expand this study by measuring dynamic ROM and energy cost under real working conditions through simulated protocols and field trials.

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