

Ergonomic Assessment of Male versus Female Firefighter Protective Clothing for Fit/Function Analysis Protocol Validation

Introduction/Background

Firefighters rely on personal protective equipment (PPE) to protect them and perform their job to the best of their ability. As the fire service remains male-dominated, PPE is still primarily designed around male anthropometrics, yet assumed to function equally for women. Prior research demonstrates that ill-fitting PPE has persisted for 80% of female firefighters for close to 30 years (USFA, 1993; Hulett, 2008; McQuerry et al., 2023), despite a continued increase in the number of women - now close to 100,000 - in the U.S. fire service (Women in Fire, 2025). Further findings suggest that the use of male patterns in structural turnout gear may compromise range of motion (ROM) and mobility for female firefighters, increasing their injury risk by as much as 33% compared to their male counterparts (McQuerry, 2020; Liao, 2001).

This study aims to define differences in female firefighters' ROM when wearing female versus male-cut structural turnout suits. This work highlights the value of improving the fit accuracy of protective clothing and determines the extent to which female-specific patterns are needed to accommodate occupational-specific tasks.

Methods

Participants: Five, active-duty female firefighters (age: 32.0 ± 5.3 years; height: 166.0 ± 4.7 cm; weight: 76.8 ± 6.8 kg; experience: 8.2 ± 6.5 years).

Design & Materials: Ergonomic testing was conducted during a single test session using two de-identified structural turnout suits (Figure 1: B) Female Structural Turnout Suit, C) Male Structural Turnout Suit) with material, suit design, and size held constant. Specific female versus male pattern differences are proprietary.



Figure 1. A) Base Layer, B) Female Structural Turnout Suit, C) Male Structural Turnout Suit

Procedure: Participants completed a consent form and changed into form fitting base layers (Figure 1: A) Base Layer). In base layers, electro-goniometers (Figure 2) were adhered to the dominant shoulder, elbow, hip, and knee (Figure 3), and connected to a DataLog software to measure joint ROM. In time with a 27-beat-per-minute metronome, 9 ROM movements (Figures 4-9) were completed: Shoulder Abduction/Adduction (1), Shoulder Vertical Flexion (2), Shoulder Vertical Extension (3), Shoulder Horizontal Flexion (4), Shoulder Horizontal Extension (5), Elbow Flexion/Extension (6), Trunk Flexion (7), Hip Flexion (8), Knee Flexion (9). After each movement, subjective upper and lower-body ease-of-movement (EOM) ratings were collected (0 = No Restriction; 4 = Heavily Restricted). After all movements were complete, a comfort and fit survey was administered while still in the PPE. The procedure was repeated in the alternate suit.

Methods (continued)

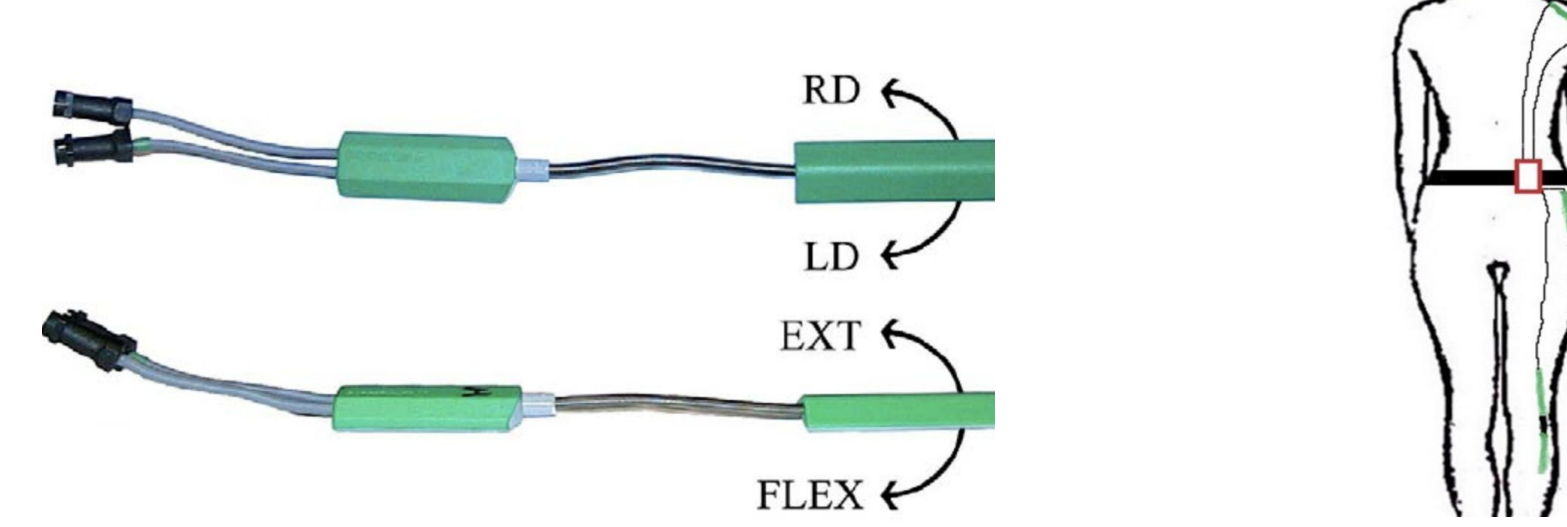


Figure 2.

Electro-goniometer

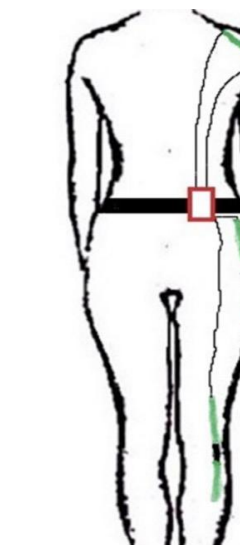


Figure 3.

Electro-goniometer Placement



Figure 4. Shoulder Abduction/Adduction



Figure 5. Shoulder Vertical Flexion/Extension



Figure 6. Elbow Flexion/Extension



Figure 7. Shoulder Horizontal Flexion/Extension



Figure 8. Trunk Flexion



Figure 9. Hip/Knee Flexion

Results

Perceived EOM rating differences were minimal between female and male-cut structural PPE. For lower body movements, the female-cut gear averaged one point lower for hip and knee flexion, with p-values ranging from 0.154 to 0.298.

Although upper body means indicated greater perceived restriction, no statistically significant differences were found between gear types ($p = 0.12-0.866$). Differences between female and male-cut PPE were limited.

Specific Movements	Female Turnout Gear				Male Turnout Gear			
	Upper Body Average	Upper Body St. Dev.	Lower Body Average	Lower Body St. Dev.	Upper Body Average	Upper Body St. Dev.	Lower Body Average	Lower Body St. Dev.
Shoulder Abduction/Adduction	2.00	± 1	0	± 0	1.3	± 0	0	± 0
Shoulder Vertical Flexion	2.30	± 1.20	0	± 0	1.7	± 0.67	0	± 0
Shoulder Vertical Extension	2.00	± 10.67	0	± 0	1.1	± 1.02	0	± 0
Shoulder Horizontal Flexion	2.30	± 0.67	0	± 0	1.6	± 1.14	0	± 0
Shoulder Horizontal Extension	1.40	± 0.71	0	± 0	1.3	± 1.30	0	± 0
Elbow Flexion/Extension	1.50	± 0.71	0	± 0	1	± 1	0	± 0
Trunk Flexion	1.00	± 1	2.8	± 1.67	1.8	± 1.75	1.8	± 1.34
Hip/Knee Flexion	0.20	± 0.45	3.6	± 1.9	0.8	± 1.30	2.6	± 1.61

Table 1. Female Turnout Gear v. Male Turnout Gear Perceived Upper and Lower Body Mean values in degrees of arc and \pm St. Dev. for each EOM

Descriptive statistics (mean \pm SD) were calculated for all electro-goniometer data. Paired-sample t-tests were run to compare absolute ROM between the female and male-cut structural turnout suits. Statistical significance was set at $\alpha = 0.05$.

While most of the movements did not exhibit significant differences in ROM between the female and male-cut structural turnout suits, there was a significant statistical difference between the means of ROM while performing the shoulder horizontal flexion in male versus female PPE ($\alpha = 0.040$).

Results (continued)

This indicates that female structural turnout gear demonstrated slightly greater ROM in the upper-body region, whereas the male-cut structural turnout gear exhibited greater ROM in the lower-body regions.

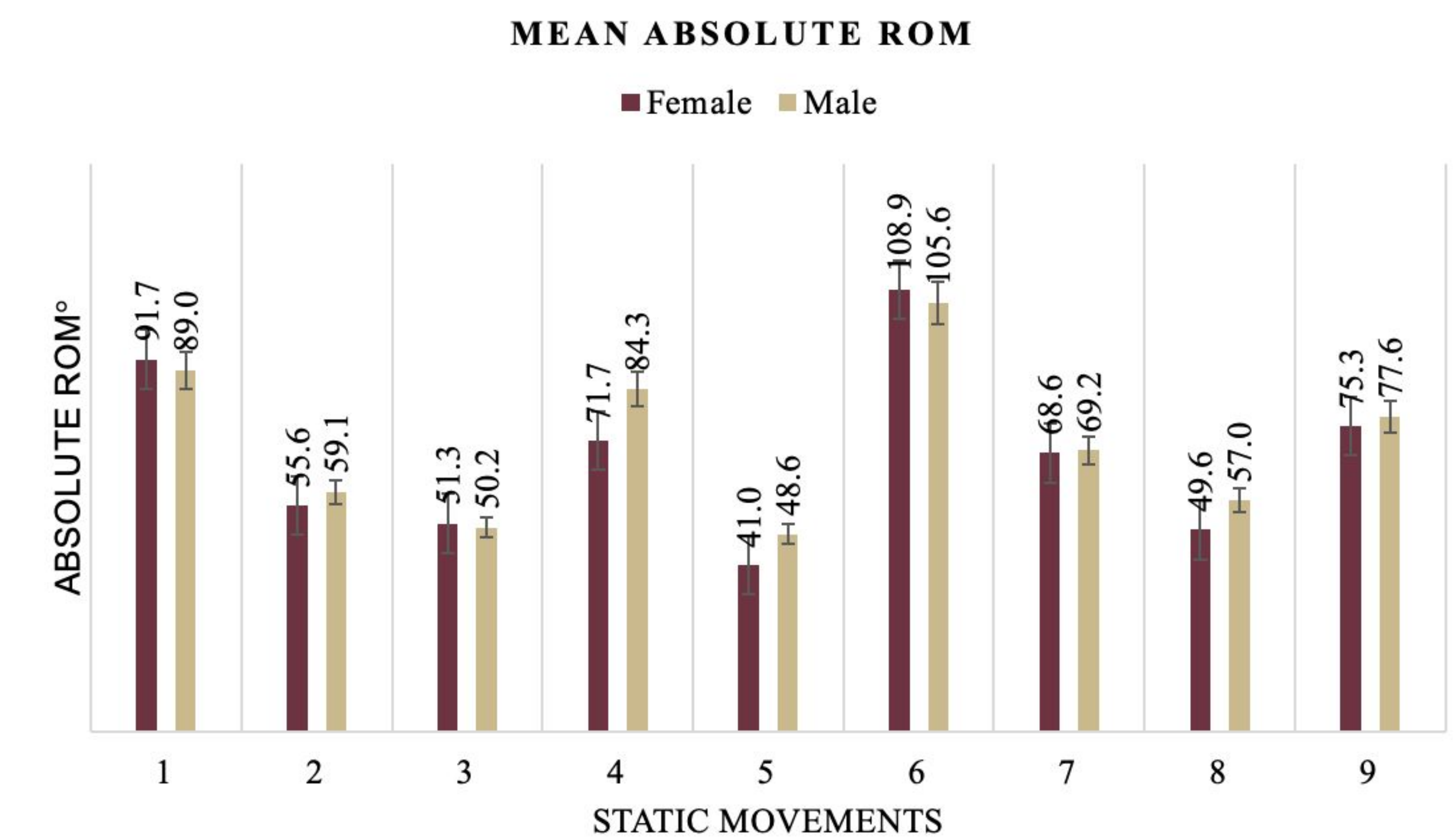


Figure 10. Female Turnout Gear v. Male Turnout Gear mean values in degrees of arc \pm st. dev. for each ROM measure.

Conclusion

Results indicated that male structural PPE provided a greater ROM during movements involving the lower-body region. In contrast, female structural PPE allowed for greater ROM in upper-body movements, specifically shoulder horizontal flexion.

While this study produced quantitative insight on the difference between female- and male- cut PPE, limitations include the small sample size, potential measurement error in electro-goniometer readings, and use of self-reported data. A limited generalizability and subject to reporting bias was a matter of interest.

Future research will examine relationships among suit fit, air gaps, carcinogen exposure, developments of health complications, and long-term health outcomes. Doing such could improve efficiency and health within the fire service.

Acknowledgements

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References

