



## Different Impacts of Boot Height and Air Bottles on the Mobility of Tall and Short Firefighters

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**Introduction.** Wearing personal protective equipment (PPE) is the only and irreplaceable protection for firefighters working in dangerous conditions with multiple hazards. However, wearing PPE, including turnout ensemble, helmet, gloves, fireboots and an air tank adds a physical burden and restricts body movements. Recent studies (Park et al., 2010 & 2015) showed that air tanks and fireboots are the two major contributors to fireground injuries through impeding mobility. In particular, firefighters carry air tanks (about 18-20lbs), which are the heaviest and bulkiest equipment, with only one size available regardless of the firefighter's body sizes. Similarly, the National Fire Protection Association Standard 1971 requires the PPE boot height to be a minimum of 10 inches (25cm) from the footbed, which has led manufacturers to market one boot height regardless of the wearer's knee height and/ or leg length. This study investigated the impact of carrying air tanks and wearing different boot heights on firefighters' mobility by investigating static and dynamic range of motion in job-related tasks.

**Methodology.** Fourteen healthy firefighters (11 males; 3 females) were recruited from the local fire department (age:  $32.7 \pm 12.3$  years, body height:  $177.3 \pm 4.7$ cm, weight:  $79.2 \pm 13.4$ , BMI:  $25.7 \pm 4.1$ ) after obtaining Institutional Review Board approval. Each participant had prior experience wearing the standard firefighter's PPE. To identify the impact of wearing the same size air tank on firefighters' upper body mobility, the participants were each 3D scanned while performing hyperextension of the neck and trunk forward flexion while wearing the given fireboots, helmet, and air tank. To investigate the impact of boot height on firefighters' mobility, the participants' range of motion (ROM) at the hip, knee, and ankle were analyzed using a 3D motion capture system (with 17 inertial sensors), while they performed duck-walking (6 steps) and ladder climbing (4 steps ascending and 4 steps descending). The leather test boots were classified based on their height into Low (25.4cm), Medium (30.48cm) and High (35.56cm). The participants wore their own turn-out ensembles. The duck-walking and ladder climbing were each repeated three times for each boot height condition. The order of the test boot heights was counter-balanced. The data were statistically analyzed using a one way-ANOVA for 3D body scans and mixed models for repeated measures for lower extremity kinematics variables ( $p < .05$ ). Results and Conclusion. Impact of airpack: Neck hyperextension ranges were significantly reduced with firegear that included a helmet and air tank (mean difference:  $25.3^\circ \pm 4.6^\circ$ ;  $p < .001$ ;  $F(1,26) = 30.661$ ). No significant reduction was observed in trunk flexion ranges (mean difference:  $8.3^\circ \pm 6.1^\circ$ ). Moderate correlations were observed between neck hyperextension and trunk flexion ranges to height ( $r = 0.42-0.53$ ), suggesting that body height influences the degree of restriction with the gear on and that shorter people may potentially have greater mobility restrictions with firegear.

*Impact of boot height:* ROM for hip in the sagittal plane was significantly greater in firefighters with shorter knee height (<47cm) than with taller knee height (>52cm). There was a significant interaction between boot height and knee height in ROM for the knee in the sagittal plane; firefighters with shorter knee height showed a significantly smaller ROM for the knee in the sagittal plane in High boots (56.47 degrees) than in Low boots (61.04 degrees), while firefighters with taller knee height were not affected by boot height while duck walking. This indicates that an increase in boot height limits shorter firefighters' knee motion. Decreased sagittal plane ranges at the hip and knee during duck-walking supports the hypothesis that High boots can cause greater restrictions when firefighters try to achieve the deep squat position. There was a significant interaction between boot height and knee height in ROM for the ankle during ascension of the ladder; firefighters with taller knee height showed a significantly smaller ROM for the ankle in the frontal plane in High boots (15.35 degrees) than in Low boots (17.53 degrees). Although not tested here but this may be related to a greater calf circumference for taller firefighters, which may restrict the maximal ankle plantarflexion range more than for shorter firefighters.

The findings of this study showed that an increase in boot height and wearing an air tank could create noticeable resistance and have significant impacts on firefighters' mobility. These altered mechanics can lead to musculoskeletal injuries or an increased risk of falls, especially when such movements are performed for long periods of time while firefighters are carrying heavy weights and working with heavy equipment on unfavorable fireground. The findings of this study also imply that shorter firefighters may have greater negative impacts from wearing a fixed-size air tank and taller boots in selected job-related motions.

## Reference

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