THE EXTRA BURDEN: ACCOUNTING FOR EXTERNAL LOADS USING DIGITAL HUMAN MODELING FOR ERGONOMICS ASSESSMENTS

Tara Kajaks, PhD[1,2], Joy C. MacDermid, PhD[1,2,3], Vickie Galea, PhD[2], Brenda Vrkljan, PhD[2]

FIREWELL

KEY FINDINGS

Finding #1: Lifting a high-rise pack from the ground presents a high injury risk for firefighters wearing full bunker gear.

Finding #2: Virtual ergonomics tools provide a valuable, but limited, opportunity to account for external loads caused by personal protective equipment in firefighters.

Background

- Firefighting is a leading occupation for musculoskeletal (MSK) injuries in Ontario (WSIB, 2016).
- Fireground activities are a leading cause of injury (Hayne & Molis, 2016).
- Ergonomics assessments of high injury risk firefighting tasks can be challenging to conduct due to environmental and equipment constraints.
- The use of virtual ergonomics technologies may facilitate conducting ergonomics assessments.

Objectives

- To develop an ergonomics assessment protocol using biomechanical modeling and virtual ergonomics that considers external loads borne by firefighters.
- To conduct an ergonomics assessment of the firefighter high-rise pack lift task.

Methods

Participants:

12 active-duty, full-time firefighters from Hamilton, Ontario (6 female)

Equipment:

Microsoft Kinect® Motion Capture System, 3DSSPP DHM software (University of Michigan, Ann Arbor, MI, USA), Jack DHM software (Siemens PLM, Plano, TX, USA)

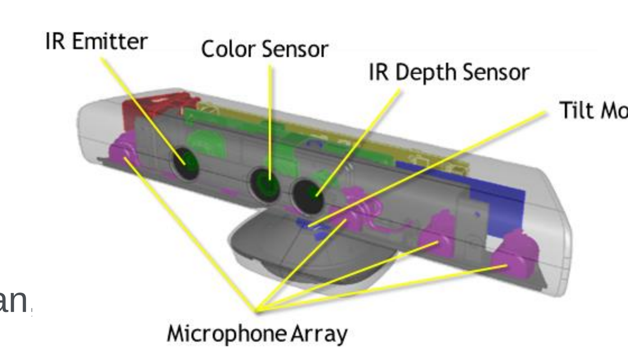


Figure 1: Microsoft Kinect® components

Protocol:

Each firefighter performed the high-rise pack lift and carry task one time while wearing full bunker gear including a helmet and self-contained breathing apparatus (SCBA) (bunker gear without SCBA: 8.3 kg, SCBA: 17.5 kg, high-rise pack: 19.5 kg).

Biomechanical Modeling:

Biomechanical modeling was used to estimate the external loads caused by the SCBA.

Analysis:

Ergonomic risk of the initial hose pick-up phase was assessed using: 1) Ovako Working Posture Analysing System (OWAS), 2) the NIOSH Action Limit (AL), and 3) Static Strength Prediction (SSP). Repeated Measures ANOVAs were used to compare the tool outputs.

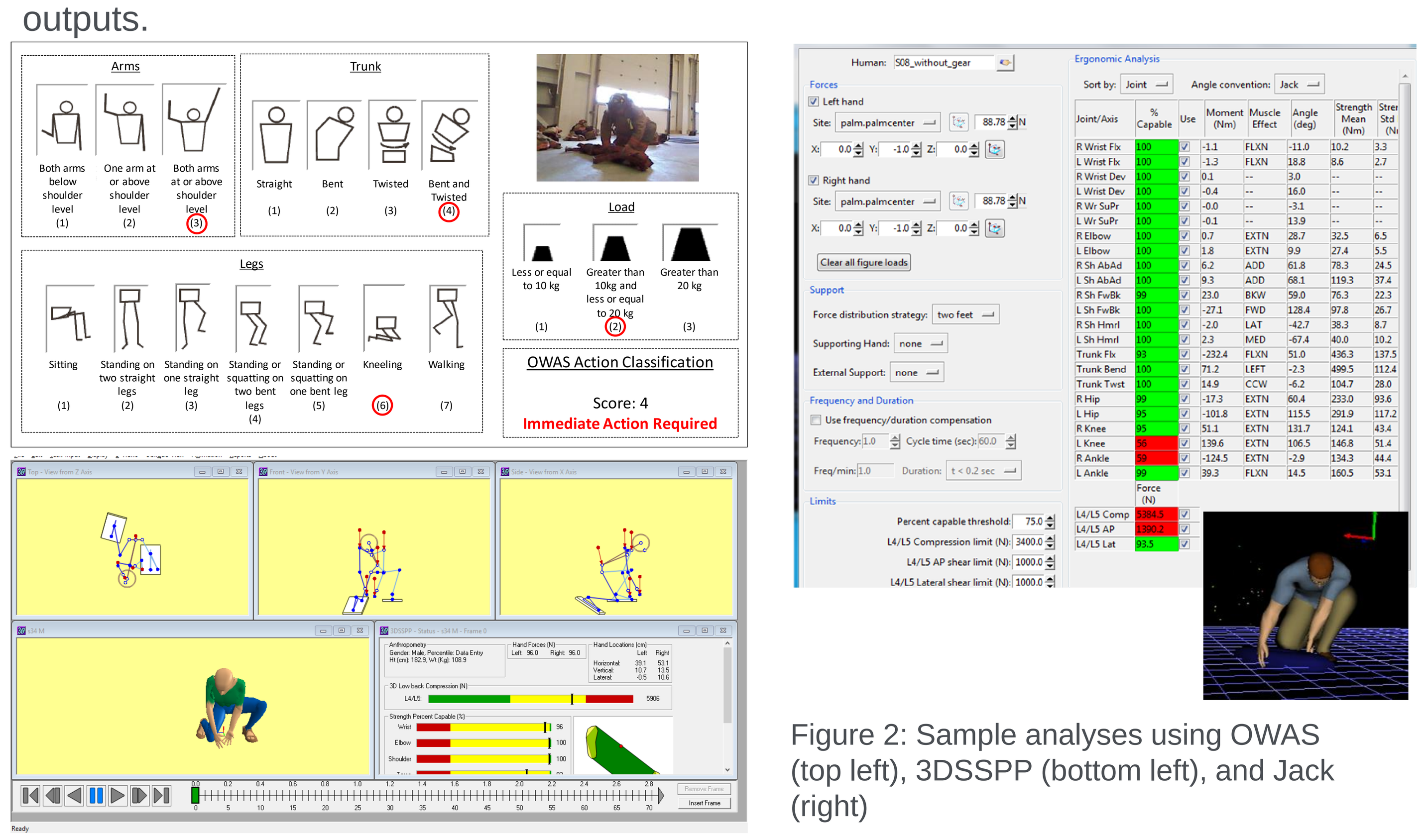
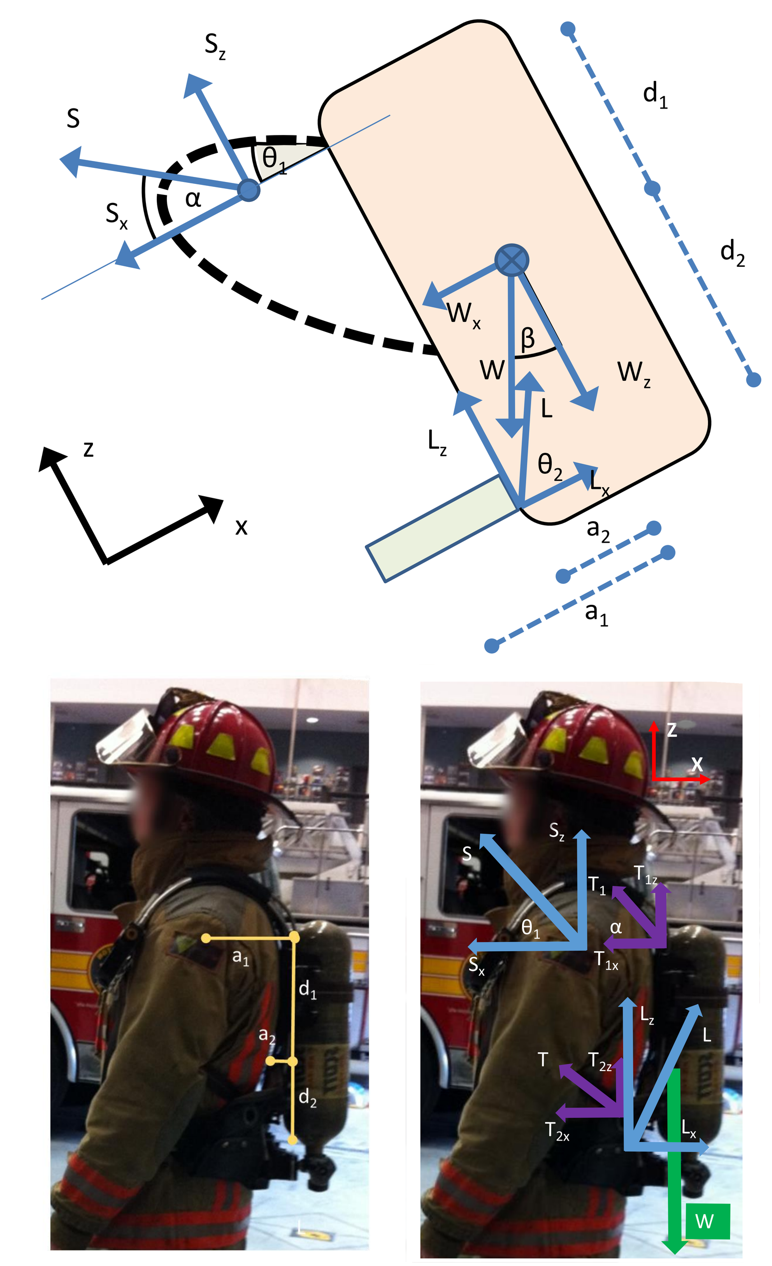


Figure 2: Sample analyses using OWAS (top left), 3DSSPP (bottom left), and Jack (right)

SCBA Biomechanical Model



α = Relative shoulder reaction force angle
β = Global SCBA/trunk angle
θ_1 = Angle between upper strap and x-axis
L = Lumbar Reaction Force
S = Shoulder Reaction Force
W = SCBA weight
d_1 = Vertical distance from SCBA centre of mass to shoulder centre
d_2 = Vertical distance from SCBA centre of mass to lumbar region
a_1 = Horizontal distance from SCBA centre of mass to shoulder centre
a_2 = Horizontal distance from SCBA centre of mass to lumbar region

The following equations of static equilibrium were used to develop the current biomechanical model:

Equation 1

$$L_x - W\sin\beta - S\cos\alpha = 0$$

Equation 2

$$L_z - W\cos\beta + S\sin\alpha = 0$$

Equation 3

$$S_x d_1 - S_z a_1 + L_x d_2 - L_z a_2 = 0$$

Equation 4

$$\alpha = 0.7451(\theta_1) + 10.749$$

Figure 3: Biomechanical model for SCBAs adapted from Pelot et al. (2000) (left) with dimension (middle) and angle (right) inputs shown on a sample firefighter. (Note: the distances, force vectors, and angles are not drawn to scale).

These equations were used to solve for the shoulder (S) and lumbar (L) reaction force using optimization criteria whereby the force distribution between the shoulder reaction force (S) and the lumbar lift force (L_z) is a ratio of 1:2 (Pelot et al., 2000). This assumption was derived based on expert opinion of load carriage modeling experts (Pelot et al., 1995) under the rationale that more of the lifting load should be placed on the waist rather than the shoulder.

Results

Table 1: Percent of postures deemed acceptable for each ergonomics software and assessment method. (* indicates main effect for method and ± indicates main effect for sex)

Percent Posture Acceptability								
	OWAS AC Score		Overall Percent Strength Capability *			NIOSH AL *±		
	Manual	Jack	Jack	3DSSPP (no SCBA)	3DSSPP (SCBA)	Jack	3DSSPP (no SCBA)	3DSSPP (SCBA)
Overall	0	0	75	17	8	25	8	0
Female	0	0	50	17	0	50	17	0
Male	0	0	100	17	17	0	0	0

Results

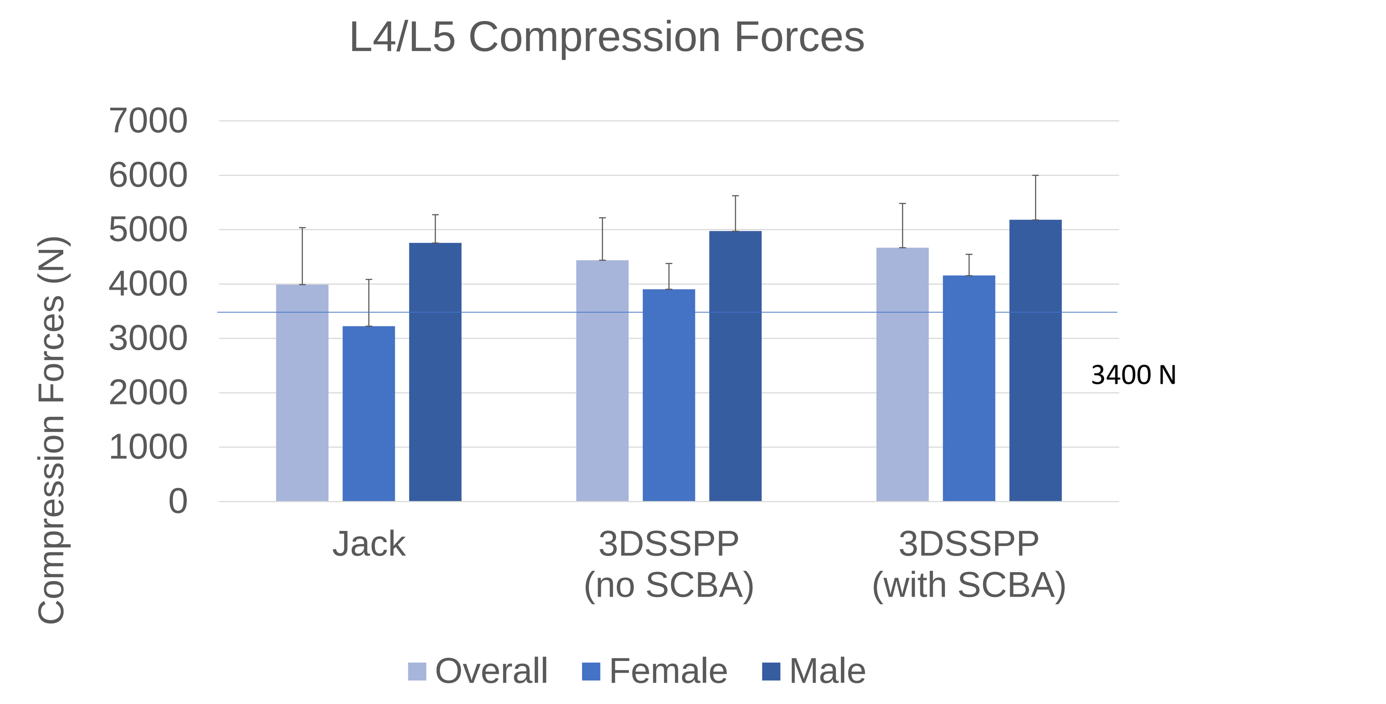


Figure 4: Average L_4/L_5 compression forces determined with each ergonomics assessment software

- The calculated L_4-L_5 compression forces between the three DHM software evaluations show a main effect for the evaluation method ($F(1.08, 10.76) = 15.09$, $p = 0.002$), and a main effect for sex ($F(1,10) = 653.87$, $p<0.001$), where females had significantly lower compression forces compared to male firefighters
- The minimum percent capable analyses between the DHM software evaluations show a main effect for the evaluation method ($F(2,20) = 23.676$, $p < 0.001$), but no effect for sex.

Discussion

- Most ergonomics assessment tools studied reported the high-rise pack lift to be of high injury risk for firefighters wearing full bunker gear, including an SCBA.
- In the small sample of female firefighters there are indications that females may adopt postures that are more protective with respect to injury risks than males.
- Discrepancies between tools are likely due to posture-matching precision and external load accountability.
- Our SCBA biomechanical model may be under-estimating the actual joint reaction forces given: 1) the omission of frictional forces, 2) the omission of the contribution of the lower shoulder strap to the model, and 3) the crude understanding of SCBA properties.

Conclusions

- This research serves as a starting point towards improving estimations of firefighter injury risks using virtual ergonomics software, where external loads due to personal protective equipment can be more easily considered.
- Virtual ergonomics tools may provide an interactive and effective means to train firefighters about safer movement strategies.
- Future work should consider using more advanced instrumentation, such as pressure maps, strain gauges, and load cells to measure the direct loads on the body.
- Efforts are needed to advance the state of ergonomics science beyond the analysis of static postures so that full movements, including the interaction with heavy, awkwardly shaped, and malleable loads, can be assessed for injury risk.

Author Affiliations: 1) Department of Kinesiology, McMaster University, Hamilton, ON; 2) School of Rehabilitation Sciences, McMaster University, Hamilton, ON; 3) School of Physical Therapy, Western University, London, ON; 4) Roth|McFarlane Hand and Upper Limb Centre, St Joseph's Health Care, London, ON

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