Novel Suspension System for a Military-Issued Rucksack To Limit Overuse Injuries and Improve Walking Dynamics

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CLINICAL PROBLEM

- Musculoskeletal injuries (MSKI) constitute 80% of all army injuries [1,2,3,4,5].
- Female and Male trainees sustain overuse injuries such as femoral neck fractures and rucksack palsy (brachial plexus palsy) [3,6,7,8].

Current Rucksack Loading Mechanics

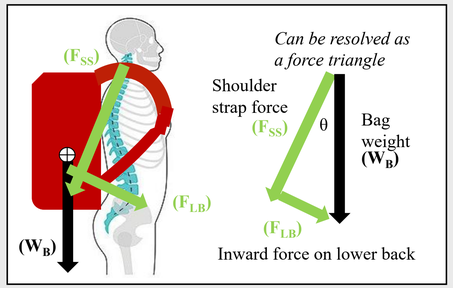


Figure 1: Loading mechanics of rucksack.

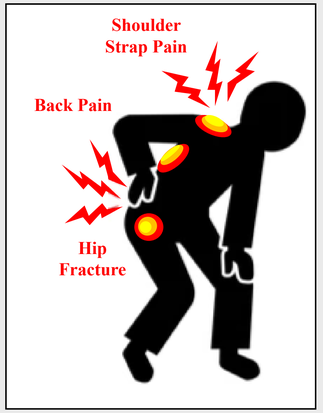


Figure 2: Overuse injuries resulting from rucking.

SOLUTION: EXPERIMENTAL SUSPENSION SYSTEM

- The Experimental Suspension System (ESS) was designed to replace the standard hip belt.
  - Directs a greater portion of the shoulder and spine loads to the pelvic region via a counter-moment mechanism.
- An additive manufacturing platform (AMP) was developed to fabricate the ESS.

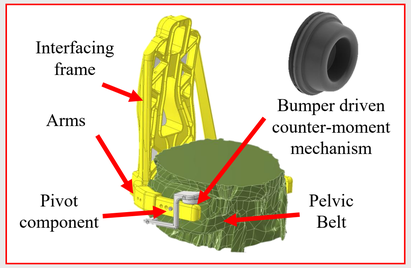


Figure 3: ESS CAD model and component diagram.

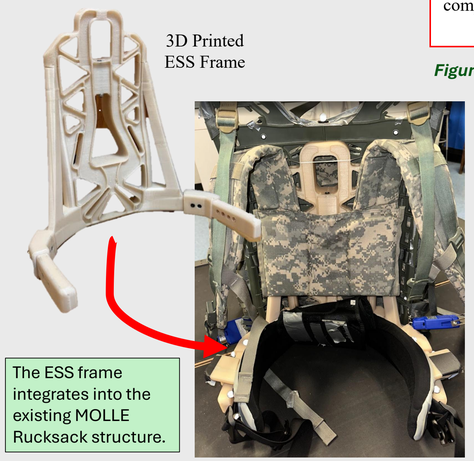


Figure 4: ESS printed and assembled.

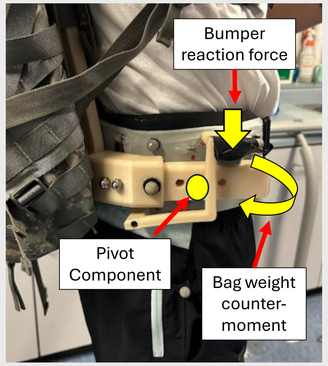


Figure 5: Counter-moment mechanism diagram.

STUDY 1: QUIET STANCE

Objective: To characterize the shoulder and strap mechanics of the TRS and ESS during quiet stance.

Methods: Tested three conditions:
- TRS without hip belt secured
- TRS with hip belt secured
- ESS

Measured shoulder loads with force-sensing pads (Novel) and strap tension with portable tensiometers.

Statistically analyzed with repeated measures ANOVA ($p<0.05$) and Cohen's D effect size.

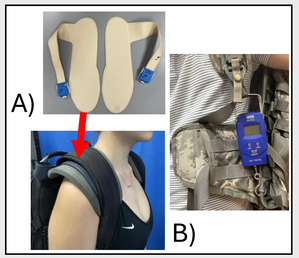


Figure 6: A) Novel Loadsol insoles and B) Tensiometers were used to measure shoulder and strap loads.

Results: The ESS saw large effect reduction between ESS and both TRS conditions in shoulder and strap loads.

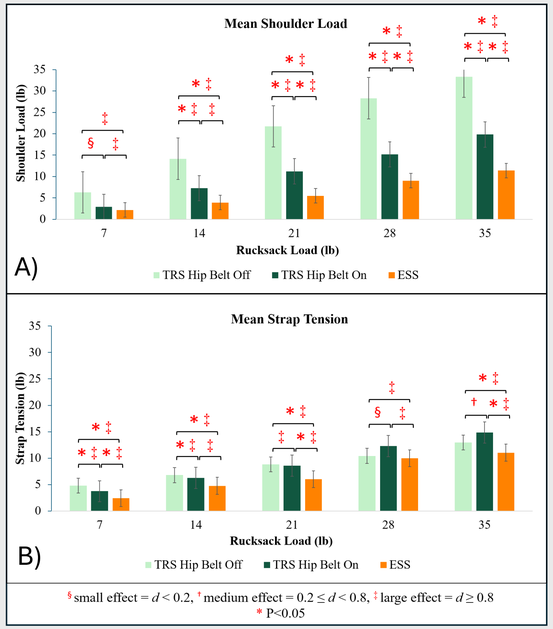


Figure 7: Graphs detailing A) Mean shoulder load and B) Mean strap tension.

STUDY 2: DYNAMIC WALKING

Objective: To quantify the biomechanics of the ESS and TRS during level walking.

Methods: Analyzed two conditions:
- TRS with hip belt secured
- ESS

Measurements included: muscle activity, gross metabolic power, comfort and functionality scores, and hip joint moment, power, and work. Movement data, oxygen consumption, and muscle activity were captured through a 3-D motion capture system with anatomical markers, force plates, split-belt treadmill, metabolic cart, and surface electromyography (sEMG) sensors.

Statistically analyzed with paired t-test ($p<0.05$) and Cohen's D effect size.

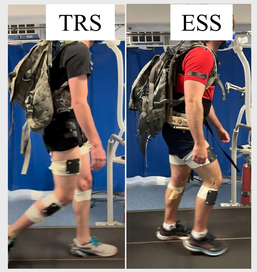


Figure 8: ESS and TRS conditions.

Results: The ESS had a significant and/or medium effect size reduction in peak and mean hip moment, peak hip power, eccentric hip work, and paraspinal muscle activity.

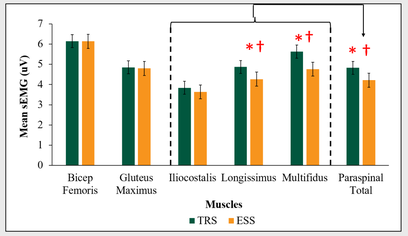
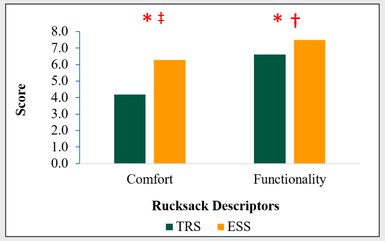


Figure 9: sEMG results per muscle group.

Figure 10: ESS and TRS comfort and functionality scores; the higher the score, the more comfortable or functional.



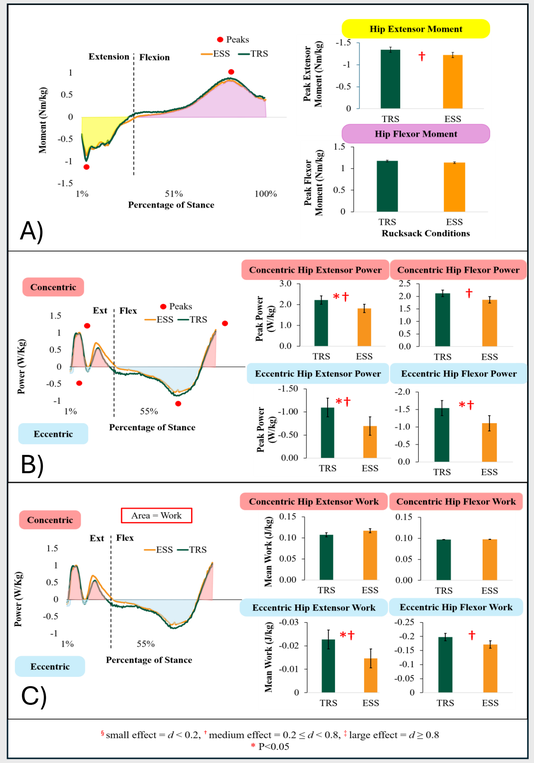


Figure 11: A) Peak hip extensor and flexor moment, B) Concentric and eccentric hip flexor and extensor power, and C) Concentric and eccentric hip flexor and extensor work.

CONCLUDING STATEMENTS AND COLLABORATIVE OPPORTUNITIES

Conclusions

The ESS offloaded the upper body, i.e., shoulders and lumbar spine, and improved lower body dynamics. These outcomes should translate into a reduction in upper and lower body overuse injuries and therefore reduce limited duty days.

Seeking Collaborations

The next steps of this project involve refining the ESS design and deploying it to real world training situations to evaluate ESS performance in the field. If you are interested, please scan the QR code and fill out the form provided.

GOAL STATEMENT

The goal of this project was to evaluate upper body mechanics and lower body dynamics of the printed Experimental Suspension System (ESS) versus a traditional rucksack (TRS) during quiet stance and walking.

References

[1] Hughes, J. M., et al. (2019). A prospective field study of U.S. Army trainees to identify the physiological bases and key factors influencing musculoskeletal injuries: A study protocol. BMC Musculoskeletal Disorders, 20(1), 282. [2] Wang, H., et al. (2013). The Effects of Load Carriage and Muscle Fatigue on Lower-Extremity Joint Mechanics. Research Quarterly for Exercise and Sport, 84(3), 305–312. [3] STRUBE, E. M., et al. (2017). The Effect of Military Load Carriage on Postural Sway, Forward Trunk Lean, and Pelvic Girdle Motion. International Journal of Exercise Science, 10(1), 25–36. [4] Orr, R. M., et al. (2014). Soldier occupational load carriage: A narrative review of associated injuries. International Journal of Injury Control and Safety Promotion, 21(4), 388–396. [5] Knapik, J. J., et al. (2004). Soldier Load Carriage: Historical, Physiological, Biomechanical, and Medical Aspects. Military Medicine, 169(1), 45–56. [6] Kupferer, K. R., et al. (2014). Femoral Neck Stress Fracture in Air Force Basic Trainees. Military Medicine, 179(1), 56–61. [7] Seçer, M., et al. (2009). Brachial Plexus Injury Related To Carrying A Rucksack: Two Cases Report. Journal of Neurological Sciences, 26. [8] Roy, T. C., et al. (2012). Risk Factors for Musculoskeletal Injuries for Soldiers Deployed to Afghanistan.