Backpack Motion Relative to the Torso Is Affected by Walking Slope

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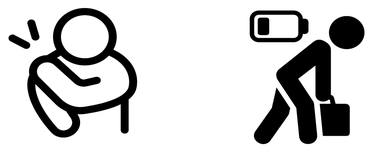
Objective

Characterize the relative backpack motion compared with the torso for multiple walking slope conditions while carrying heavy loads with and without use of a hip-belt attachment.

Introduction

- Military personnel often carry backpacks with heavy loads on varying terrains
- Military backpacks with hip belts can support up to 30% of the vertical force from the backpack [1]
- Current hip belt designs do not offload enough force to prevent strain-induced injury at the shoulder [2]
- Effects of using a hip belt and varied terrain on relative backpack-torso motion is unknown

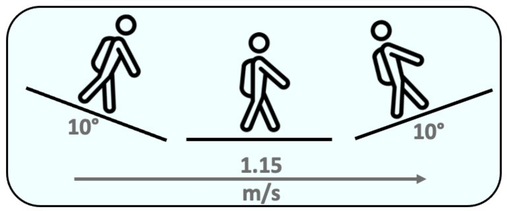
Relative displacement >14 mm leads to decreased walking efficiency and greater risk of injury [3]



Methods

Active Duty Military (3M, 1F)	
Age (years)	25±6
Weight (kg)	73.0±8.5
Height (m)	1.72±0.10

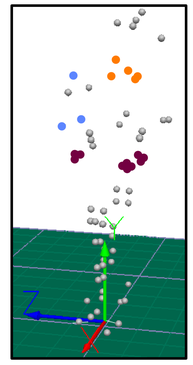
Three Slope Conditions



Dynamic Model (Visual3D)*

Torso model

- Optical motion captured (120 Hz)
- Orange = Torso markers
- Blue = Backpack markers
- Purple = Pelvis markers



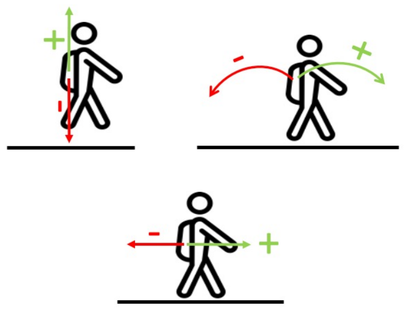
Two Loading Conditions

Hip-Belt Assisted (Hip-belt)
- Body armor, helmet, and backpack
- 40% body weight total

Shoulder Borne (Shoulder)
- Body armor, helmet, and backpack
- 40% body weight total

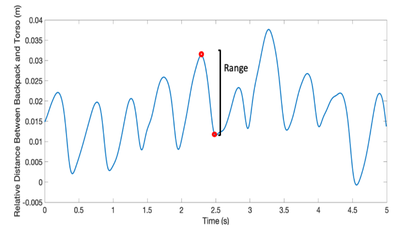
Photos courtesy of NHRC

Three Relative Displacements

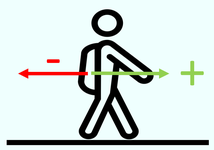


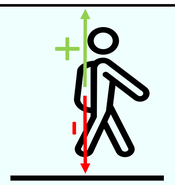
Analysis

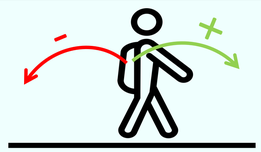
- 5-s walking time per walking condition
- Linear mixed-effects models
- ANOVA (α = 0.05), pairwise comparisons using Tukey's honestly significant difference test
- Pack, Slope, Pack × Slope, participants as random intercepts
- Analysis performed using R (R Core Team, 2022; https://www.R-project.org/)



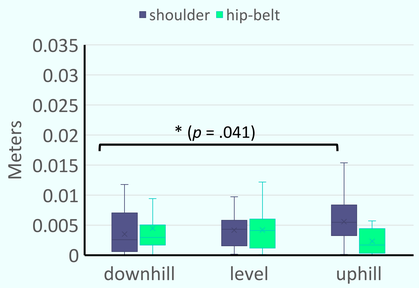
Results





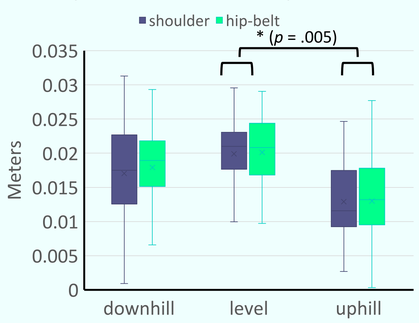


backpack-torso anterior/posterior displacement



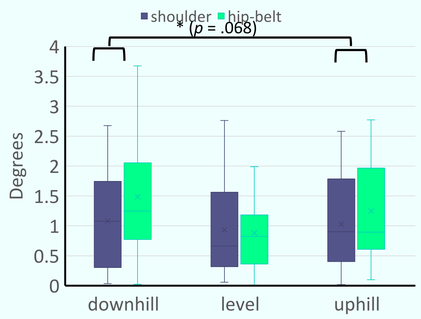
~Mean Values (m)		
	Shoulder	Hip-Belt
Uphill	0.008	0.004
Level	0.004	0.004
Downhill	0.003	0.004

backpack-torso vertical displacement



~Mean Values (m)		
	Shoulder	Hip-Belt
Uphill	0.015	0.015
Level	0.020	0.020
Downhill	0.017	0.018

backpack-torso x-angle displacement



~Mean Values (degrees)		
	Shoulder	Hip-Belt
Uphill	1.0	1.0
Level	1.0	1.0
Downhill	1.0	1.5

Hip belt does not influence:
- Relative vertical motion of the backpack
- Relative forward/ backward tilt motion

Greatest relative displacements:
- Ant/Post = ~8 mm
- Vertical = ~20 mm
- X-Angle = ~1.5°

Pack × Slope interaction for horizontal displacement (p = .086)
- Horizontal displacement was not affected by slope during Hip-Belt but was affected during Shoulder

Slope effects on relative displacement:
- Vertical (p = .007) and rotational (p = .068) relative displacement were affected by slope

Conclusions

- Lower vertical range of motion during downhill and uphill compared with level suggest that relative stiffness of backpack attachments is modulated with slope
- Relative motion of the backpack was significantly influenced by walking slope, not by backpack carrying configuration
- It is likely that postural adaptations were used to reduce peak vertical forces from the backpack during uphill and downhill walking (forces experienced during level walking are tolerated with larger ranges of motion between the backpack and torso)

References

[1] LaFiandra et al. (2004), *Med Sci Sports Exerc*, 36(3), 460-7.
[2] Hadid et al. (2015), *J Biomech*, 48(15), 4160-5.
[3] Bryant et al. (2004), *Ergon Des*, 12(1), 12-17.
[4] Foissac et al. (2009), *J Biomech*, 42(2), 125-30.
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Black and white figures from thenounproject.com