Evaluation of Exoskeletons for Construction

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CPWR
THE CENTER FOR CONSTRUCTION RESEARCH AND TRAINING

Disclosures

We have no personal financial conflicts of interest to disclose.

VIRGINIA TECH™

Learning Objectives

- Define the burden of musculoskeletal disorders (MSDs) in Construction
- Describe passive exoskeletons (EXOs) & understand how they augment human capacity
- Summarize the evidence of the effectiveness and efficacy of EXOs in other industries
- Discuss CPWR research project designed to understand how to effectively use passive EXOs in construction

Burden of MSDs among Construction Workers

Construction workers continue to experience high rates of work-related musculoskeletal disorders (WMSDs): **11% higher** than all other industry sectors in 2016[1,2].

Back and the **shoulder** are the most impacted body regions

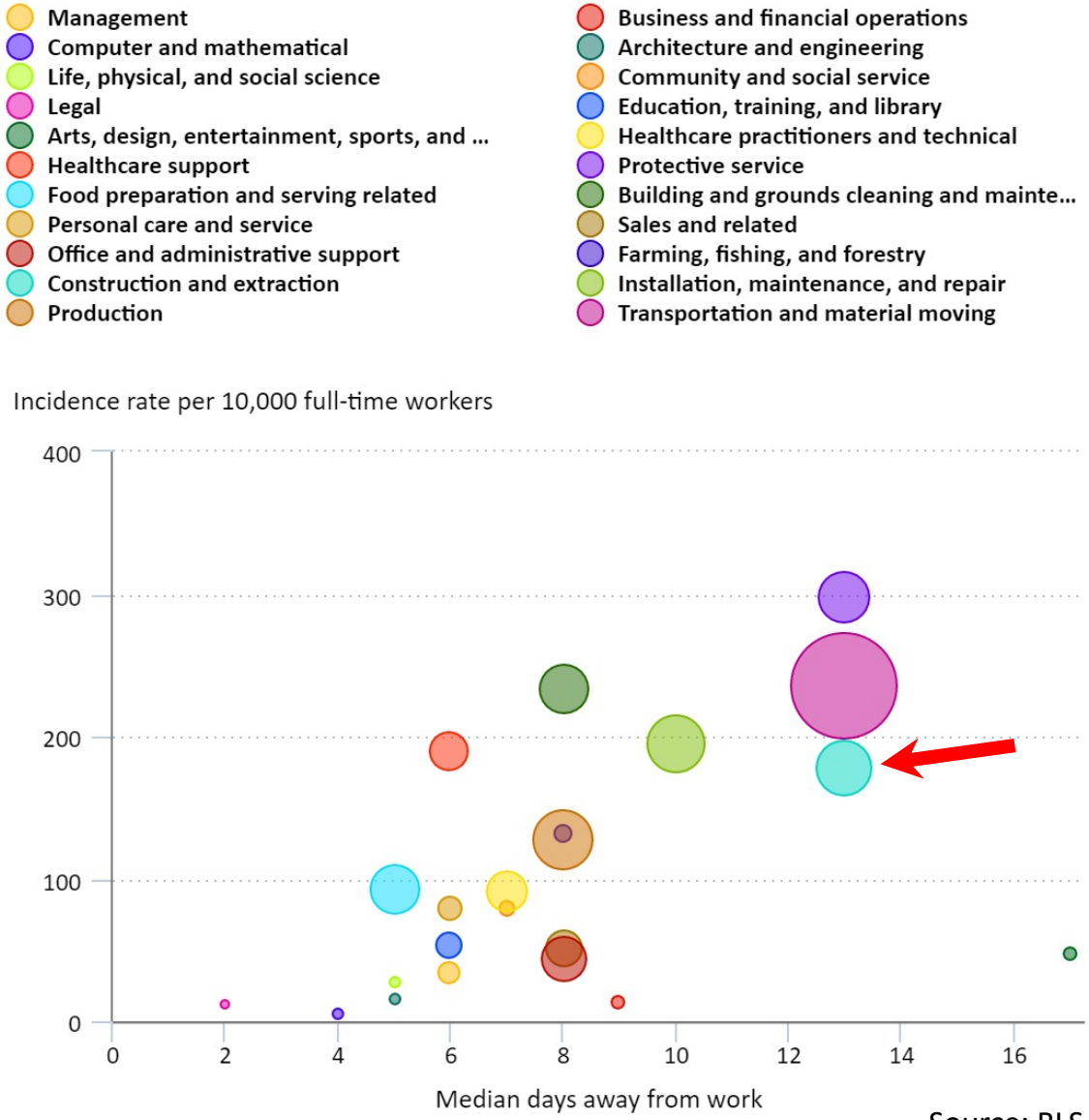
Back injuries account for 43% of all cases; median of 8 lost work days[1].	Shoulder injuries account for 16% of all cases; median of 25 lost work days[1].

1. Bureau of Labor Statistics. Nonfatal Occupational Injuries and Illnesses Requiring Days Away from Work. 2018.
2. Wang X, Dong XS, Choi SD, Dement J. Work-related musculoskeletal disorders among construction workers in the United States from 1992 to 2014. *Occup Environ Med*. 2017;74(5):374-380.

Nonfatal Workplace Injuries

Number, incidence rate, and median days away from work for nonfatal work injuries and illnesses involving days away from work by major occupation group, private industry and state and local government, 2017

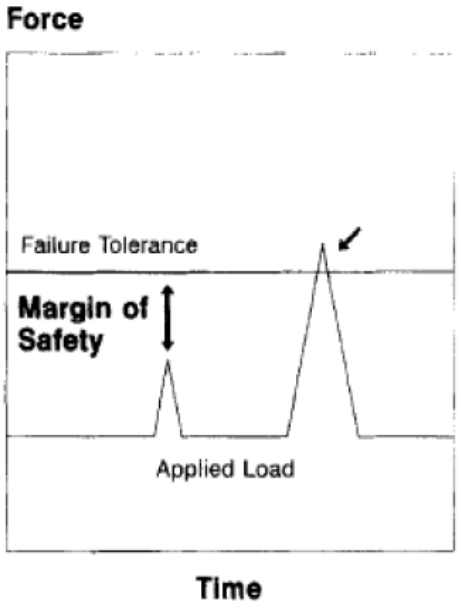
Bubble size represents number of cases.



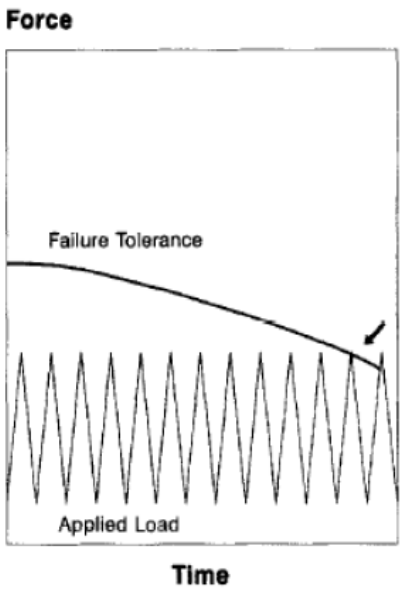
Source: BLS

Risk Factors for Back Injuries

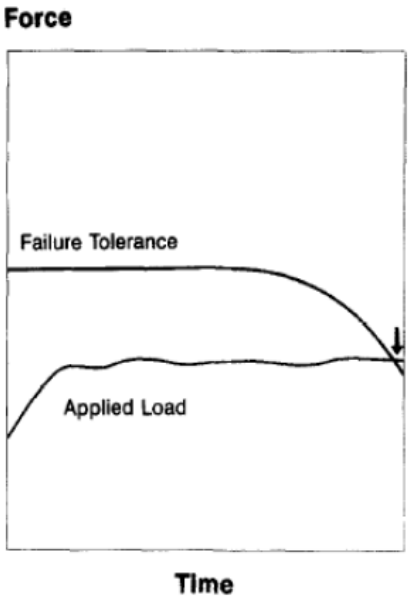
Excessive Load[2]



Repetitive Load[2,3]



Sustained Load[1-4]



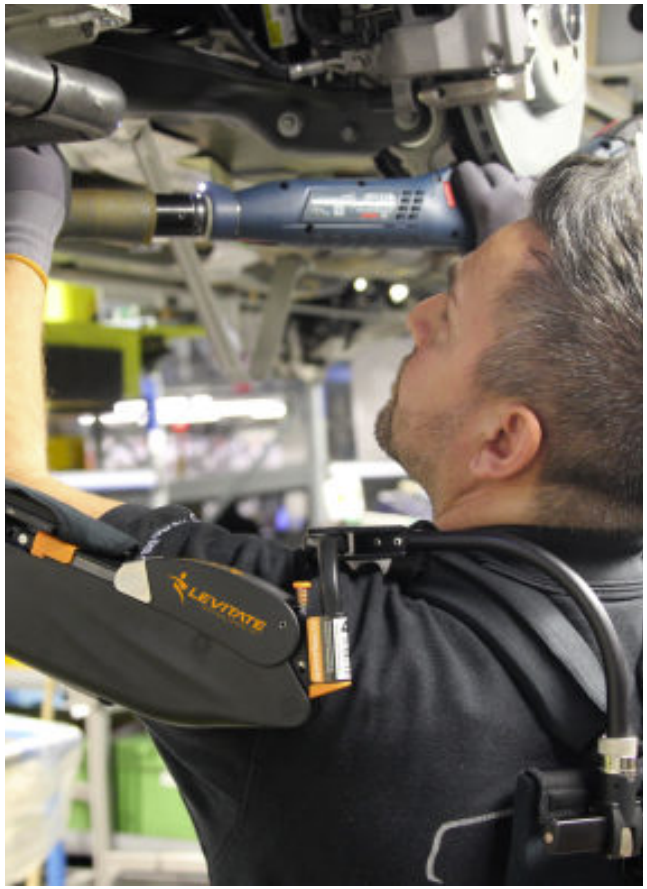
[1] S. McGill, "The Biomechanics of Low Back Injury: Implications on Current Practice in Industry and the Clinic," *Biomechanics*, vol. 30, no. 5, pp. 465, 475, 1997.
[2] B. R. Da Costa and E. R. Vieira, "Risk factors for work-related musculoskeletal disorders: A systematic review of recent longitudinal studies," *Am. J. Ind. Med.*, vol. 53, no. 3, pp. 285–323, 2010.
[3] W. E. Hoogendoorn *et al.*, "Flexion and Rotation of the Trunk and Lifting at Work Are Risk Factors for Low Back Pain," *Spine (Phila. Pa. 1976).*, vol. 25, no. 23, pp. 3087–3092, 2003.
[4] L. C. Brereton and S. M. McGill, "Effects of physical fatigue and cognitive challenges on the potential for low back injury," *Hum. Mov. Sci.*, vol. 18, no. 6, pp. 839–857, 1999.

Non-Neutral Posture

Forceful Exertion

Repetitive or Sustained Reach

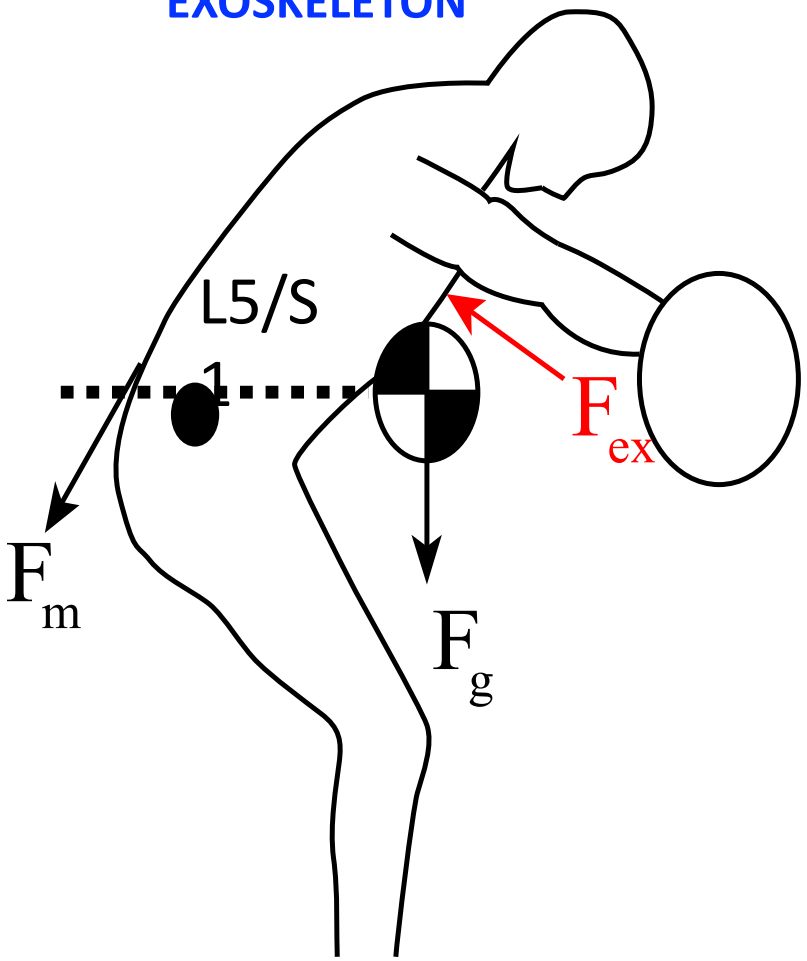
Risk Factors for Shoulder Injuries

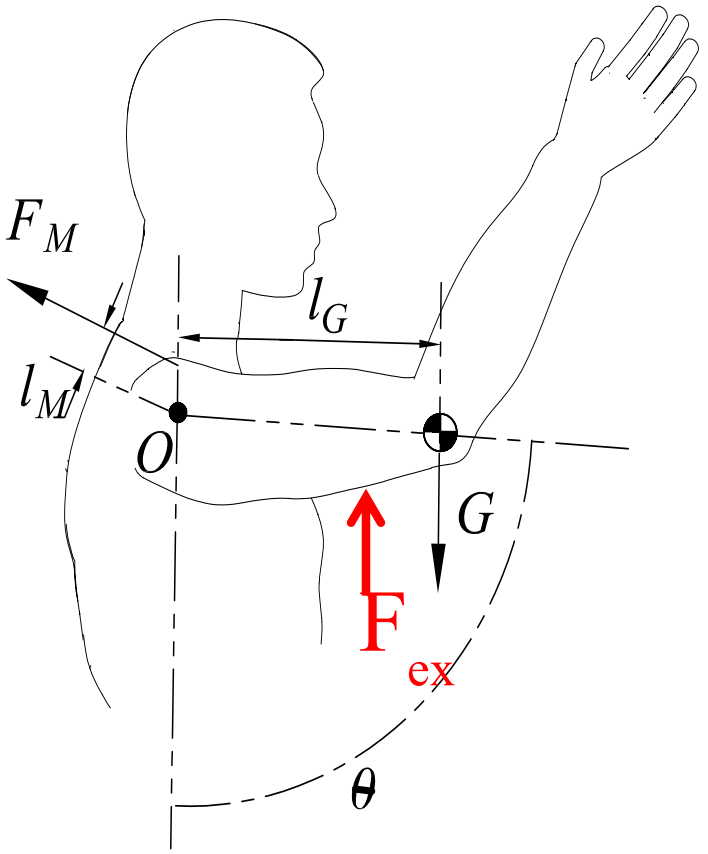
"A wearable device that augments, enables, assists, and/or enhances physical activity through mechanical interaction with the body" -ASTM

Passive Exoskeletons

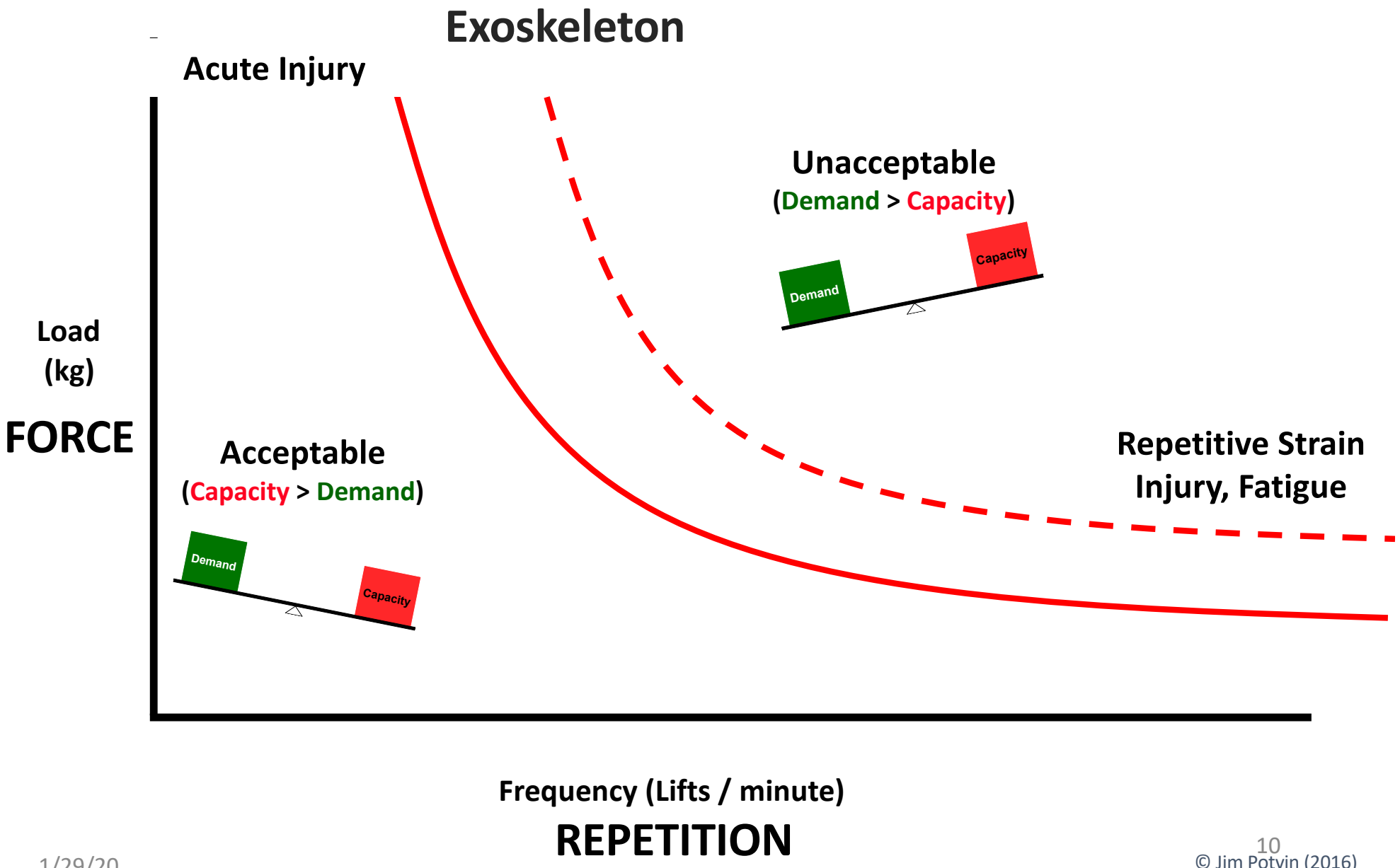
TRUNK-SUPPORT EXOSKELETON



ARM-SUPPORT EXOSKELETON



A way to Augment Capacity



Industrial Exoskeletons

exoskeletonreport.com

Industrial

Exoskeletons for work and industry.

Showing all 21 results

Sort by price: low to high

25 products per page

Arm Support (6)

Back Support (8)

Leg Support (3)

Power Glove (2)

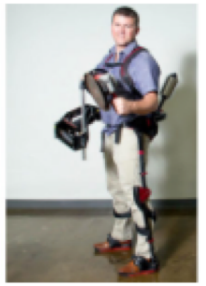
Tool Holding Exoskeleton (2)

FORTIS

Lockheed Martin

Daiya Glove

Daiya



Ekso Works

Ekso Bionics

Highlights of Existing Evidence: From the Lab

Laevo™ (low-back support)[1,2,3,4]

- Decreased low-back muscle activity and discomfort, increased endurance, reduced energy expenditure
- In static and dynamic tasks[1,2,3,4]

SuitX™ (low-back support)[3,4]

- Reduced low-based muscle activity
- Reduced muscle fatigue
- Reduced energy expenditure
- In static and dynamic tasks

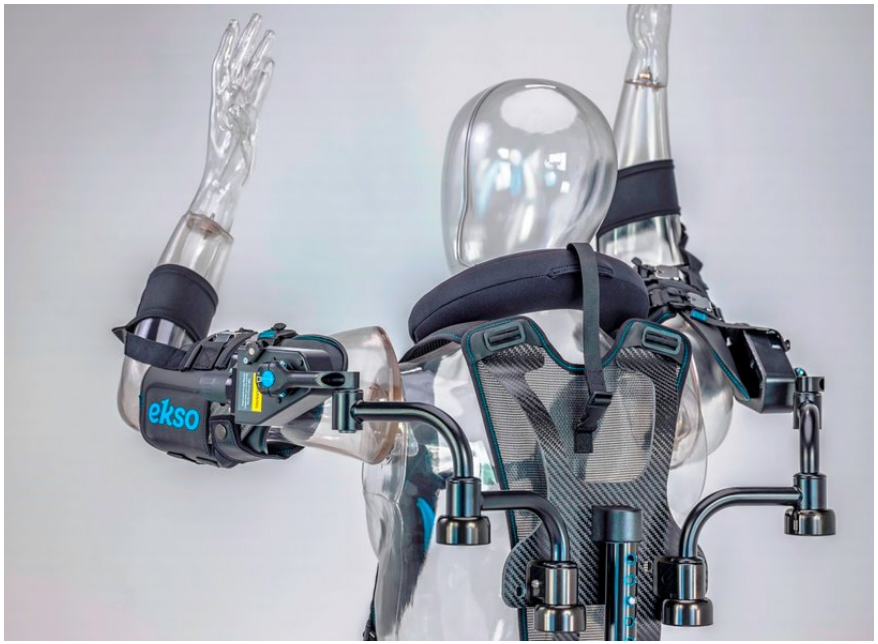
[1]Bosch et al. 2016; [2]Koopman et al. 2019; [3]Madinei et al. In Press; [4]Alemi et al. In Press

Highlights of Existing Evidence: From the Lab

EksoBionics EksoVest™

(arm support)

- Decreased shoulder muscle activity[1] and spine loads[2] in simulated overhead work



SuitX™ (arm support)[3]

- Decreased shoulder muscle activity
- Effective vs. ineffective support levels
- Preferred support varied between people and tasks

[1/2]Kim et al. 2018; [3]VanEngelhoven et al., 2019

Highlights of Existing Evidence: From the Field

- **Personal Lift Augmentation Device (PLAD)** (low-back support)
  - Well received in automotive assembly, decreased muscle activity & perceived exertion[1]
- **Laevo™** (low-back support)
  - Decreased low back discomfort (some increased chest discomfort) during static-bending tasks in auto assembly[2]
  - Increased muscle activity (trapezius) and discomfort (back, chest, thigh) in manufacturing[3]
  - Decreased back muscle activity in order picking[4]
- **Levitate AirFrame** (arm support)
  - Decreased shoulder muscle activity in manufacturing[5]
  - Decrease in shoulder pain among surgeons during/after an operation[6]

[1]Graham et al. 2009; [2]Hensel & Keil, 2019; [3]Amandels et al. 2019;
[4]Motmans et al. 2019; [5]Gillette & Stephenson, 2019; [6]Liu et al. 2018

What are the potential benefits/limitations of different industrial exoskeleton technologies?

Opportunity: physical demands; performance

Risks: load transfer; safety

Challenges: no practical guidelines; limited evidence overall & in construction specifically

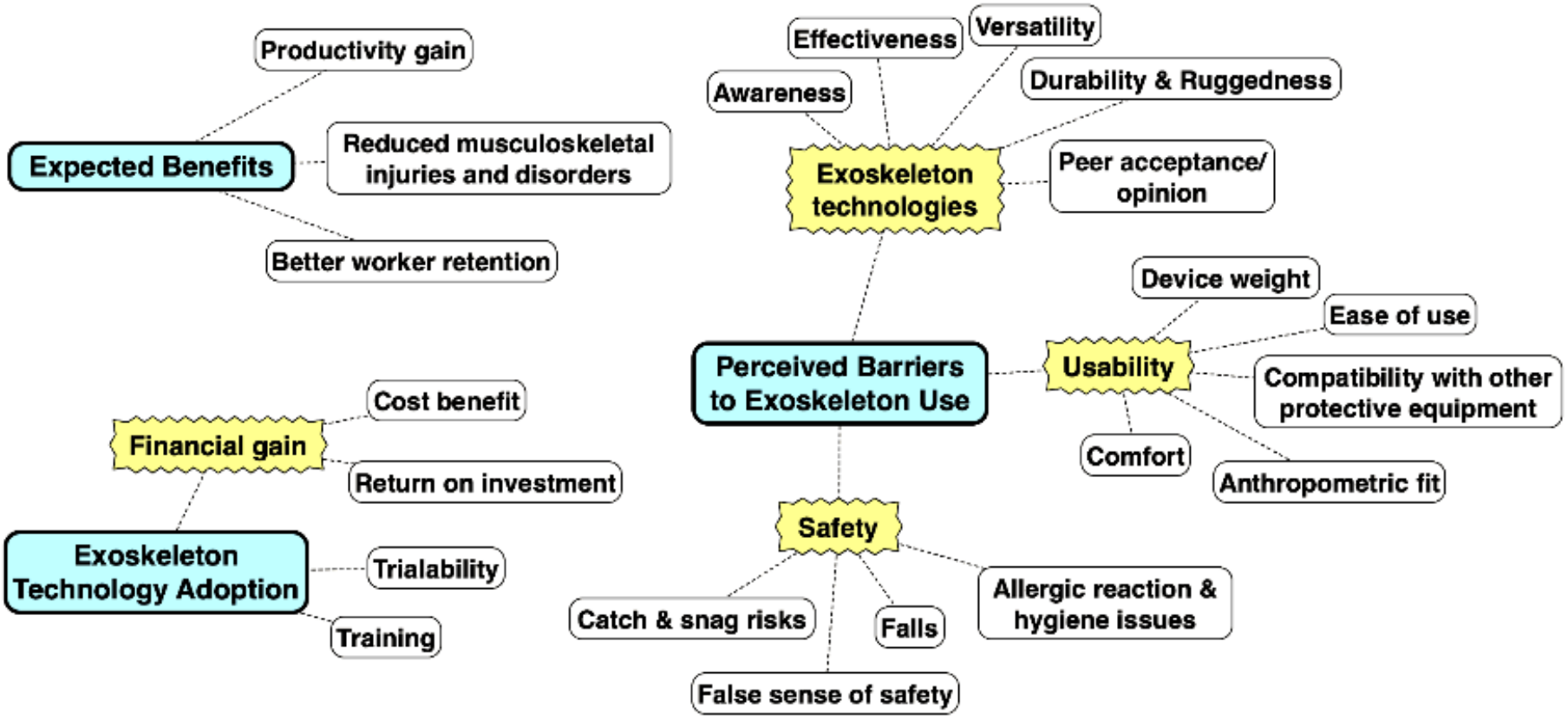
Evaluation of Exoskeletons in Construction

Understand	Relevant stakeholders' opinions on applications and promotors/barriers
Assess	Effectiveness, efficacy, and safety of different EXOs for tasks with high exposures, while considering task variability and unique demands in construction
Implement	Provide evidence-based information on the effectiveness, efficacy, and safety of exoskeletons in construction; guidelines for how they should be selected, adopted, and used.

Aim 1: Obtain input from construction industry stakeholders

Surveys (N=120) / Focus Group Interviews (N=30) will explore:

- Awareness and opinions of EXO use, including available technologies, usability, and safety
- Promoters of and barriers to EXO adoption
- Opinions regarding tasks or task characteristics (precision, complexity, dynamicity, worker posture, tool weight) that may benefit the most from EXOs
- Common measures for assessing productivity and work quality
- Information sources that are trusted for new construction technologies



Sunwook Kim, Albert Moore, Divya Srinivasan, Abiola Akanmu, Alan Barr, Carisa Harris-Adamson, David M. Rempel & Maury A. Nussbaum (2019) Potential of Exoskeleton Technologies to Enhance Safety, Health, and Performance in Construction: Industry Perspectives and Future Research Directions, IISE Transactions on Occupational Ergonomics and Human Factors, 7:3-4, 185-191, DOI: 10.1080/24725838.2018.1561557

Aim 1 Outcomes

Explore differences by:

- Trade
- Region
- Company Size
- Type of EXO
- Employers versus Workers
- Age
- Experience Level

Aim 2:
Determine the efficacy of commercially-available EXOs (ASEs and BSEs)

The effects of EXOs during simulations of targeted work tasks that vary load, precision, and posture to determine the effects on:

- work performance,
- physical demands, and
- usability

Outcome Measures	
Usability & Safety	Donning & Doffing
	Maneuverability in constricted space
Postural Control & Balance	Single-leg jump landing
	Figure-eight walking (F8W)
	Stair/Ladder climbing & Other Physical Demand Activities

	Concrete Grinding	Tuck Point Grinding	Drywall Hanging (Drilling)
Posture	Overhead vs Forward Reach	Forward Reach	Overhead vs Forward Reach
Load/Tool	Heavy (4.1 kg/9 lbs)	Medium (2.9 kg/6.4 lbs)	Light (1.4 kg/3 lbs)
Precision	Low	High	Medium
Movement Speed	Low	Medium	High

Figure 4. Adjustable height ceiling and wall apparatus (at UCSF) that holds different materials (concrete, brick wall, dry wall) for tasks requiring forward reach and overhead postures.

	Floor tile installation	Roof tile installation
Working Posture	Kneeling	Kneeling and Stooped (2 inclinations)
Load	Light (6”x6” tile), Medium (12”x12”)	Light (0.9 kg/2 lb) Heavy (3.4 kg/7 lb)
Precision	Medium and High	Low
Movement Speed	Low	Medium and High

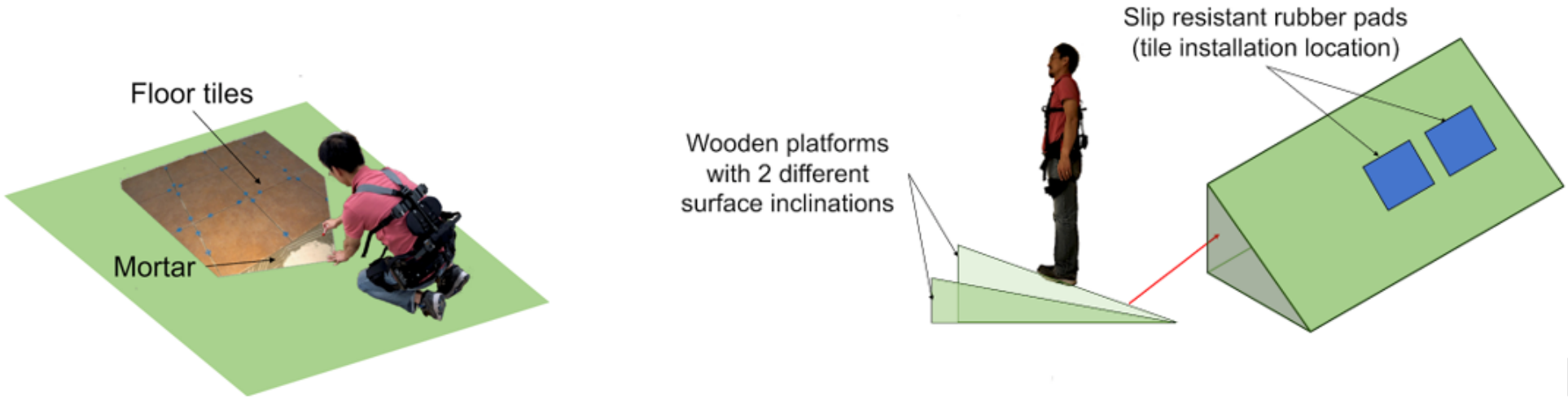
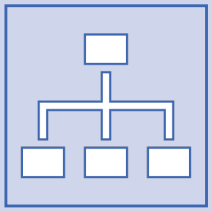


Figure 5. Task setup for simulating floor tile installation (left) and roof tile installation (right).

Outcomes	
Physical Demands	Metabolic demands
	Normalized muscle activity
	3D joint kinematics
Usability	Skin temperature
	User perception
Performance	Productivity
	Quality of Work
	Perceived Work Performance

Aim 3. Assess the perceived safety, effectiveness, and acceptability of EXO use by construction workers in a realistic context. (YRs 3-4)

Develop EXO Implementation Guidelines



Type-Benefit

considering task characteristics and safety considerations

Subjective assessment of effectiveness on work performance, physical demand and usability

Aim 4. Disseminate study findings nationwide (YRs 3-5)

construction contractors

trades

health and safety professionals

Next Steps

Please contact us at:
ucergonomics@gmail.com
nussbaum@vt.edu
If you are interested in participating.

1/29/20

- Looking for construction companies of all sizes with workers from different trades to respond to a 30-45 minute survey
  - Via interview with researchers
  - Via smartphone link (English/Spanish)

- Looking for construction companies or trade unions to facilitate a 2-hour focus group where researchers can meet with 3-5 workers at a time
  - Roofing
  - Flooring
  - Concrete grinding
  - Tuckpoint grinding
  - Drywall installation

THANK YOU!

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