Evidence (and several personal opinions) regarding the benefits and potential limitations of **occupational exoskeletons**, as well as future research needs, and recommendations

Maury A. Nussbaum, PhD

Occupational Ergonomics & Biomechanics Labs

Department of Industrial & Systems Engineering

nussbaum@vt.edu

VIRGINIA TECH

Major Topics

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What Are (Occupational) Exoskeletons?

"A **wearable device** that augments, enables, assists, and/or enhances motion, posture, or physical activity, through **mechanical interaction** with the body."

Exoskeleton: consisting of hard and/or rigid structures

Exosuit: majority of the structure consists of soft and/or elastic structures

ASTM F48.91 Terminology

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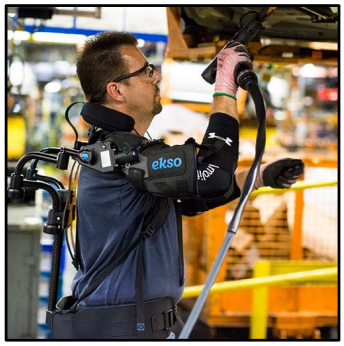
suitx.com



eksobionics.com

laevo-exoskeletons.com

paexo.com

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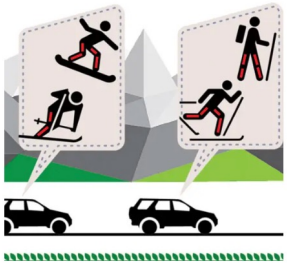
Cornell (1961)

GE Hardiman (1965-71)

Popular Science (Nov. 1965)

5

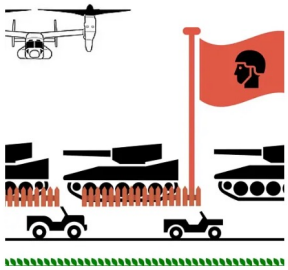
Current exoskeleton landscape



Consumer (7)

Industrial (48)

Medical (59)



Military (4)

exoskeletonreport.com

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Occupational Exoskeletons

Arm Support (18)

Back Support (24)

Leg Support (4)

Power Glove (2)

Tool Holding Exoskeleton (3)

exoskeletonreport.com

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Diverse technology is available

Energy Source(s)	Body Part(s)	Task(s)
Passive	**Upper extremity**	**Lifting**
Active	**Back/hips**	**Holding**
Mixed	Hand (grip)	**Overhead work**
	Lower extremity	Carrying
	Whole body	Tool use

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So, how do they work?

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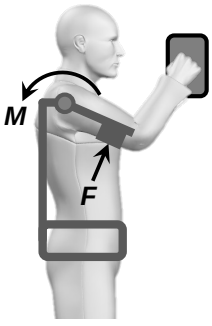
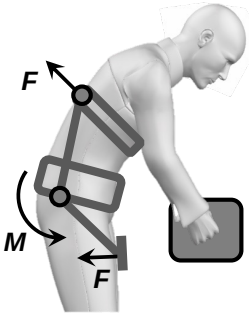
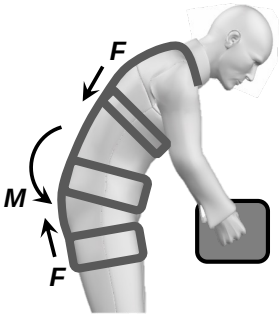
Exoskeleton support mechanisms



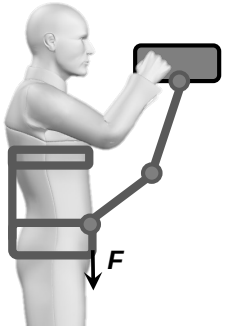
Arm Support



Back Support



Back Support
"Exosuit"



Tool Support

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What are the potential benefits and limitations of exoskeletons?

Opportunity:	Decrease physical demands; enhance performance
Risks:	Increase physical demands @other body regions; safety
Challenges:	No practical guidelines; limited evidence overall

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ASEs: Evidence from the **Lab**

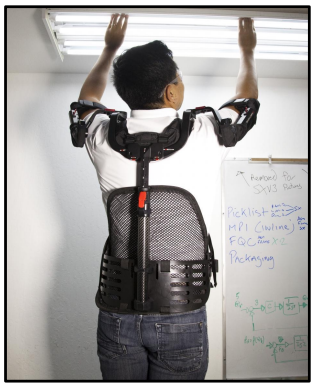
EksoBionics EksoVest™

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

Eksobionics.com

SuitX ShoulderX™[3]

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



Suitx.com

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

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ASEs: Evidence From the **Field**

airpower-usa.com

Levitate Airframe™

- Decreased shoulder muscle activity & fatigue in manufacturing[1,2]
- Decrease in shoulder pain among surgeons during/after an operation[3]
- Decrease in HR in wholesale and retail trade tasks; willingness to use[4]

[1]Gillette & Stephenson, 2019; [2]Gillette et al. 2022; [3]Liu et al. 2018; [4]Marino 2019

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BSEs: Evidence from the **Lab**

Laevo™[1,2,3,4]

- Decreased low-back muscle activity and discomfort, increased endurance, reduced energy expenditure
- In static and dynamic tasks

en.laevo.nl

SuitX BackX™[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. 2020; [4]Alemi et al. 2020

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BSEs: Evidence From the **Field**

SuitX BackX™

- Increased heart rate among wholesale and retail trade workers; perceived benefits and willingness to use; concerns about movement quality and comfort[1]

Laevo™

- 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]

[1]Marino 2019; [2]Hensel & Keil (2019); [3]Amandels et al. (2019); [4]Motmans et al. (2019)

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Efficacy vs. Effectiveness

MOST EXISTING EVIDENCE IS FROM LAB-BASED (SHORT-TERM EFFICACY)

FIELD STUDIES (OF LONG-TERM EFFECTIVENESS) ARE HARD!

RELATIVELY FEW REPORTS OF EFFECTS *IN SITU*

LAB-BASED RESULTS MAY NOT ALWAYS TRANSFER

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Similar tasks completed in controlled & field settings

- **Differences found:**
  - ASEs decreased upper TRP activity (up to 46%) and HR in isolated tasks
  - Smaller effects in the field (<26%)
  - Relative effects of the two ASEs differed between testing scenarios

De Bock et al. (2021)

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Key Points:

ASEs & BSEs reduce exposure to injury risk factors, but:

- Benefits of an ASE or BSE depend on the design and task demands
- Potential for minor-moderate adverse effects (discomfort, safety)
- Fitting diverse workers is critical
- Very limited evidence on long-term effects

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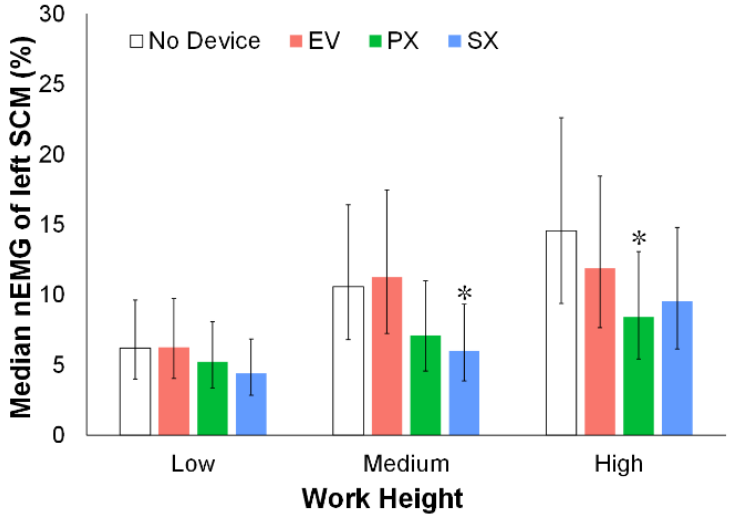
Task-specific & device-specific effects: **Overhead work**



Ojelade et al. (In Preparation)

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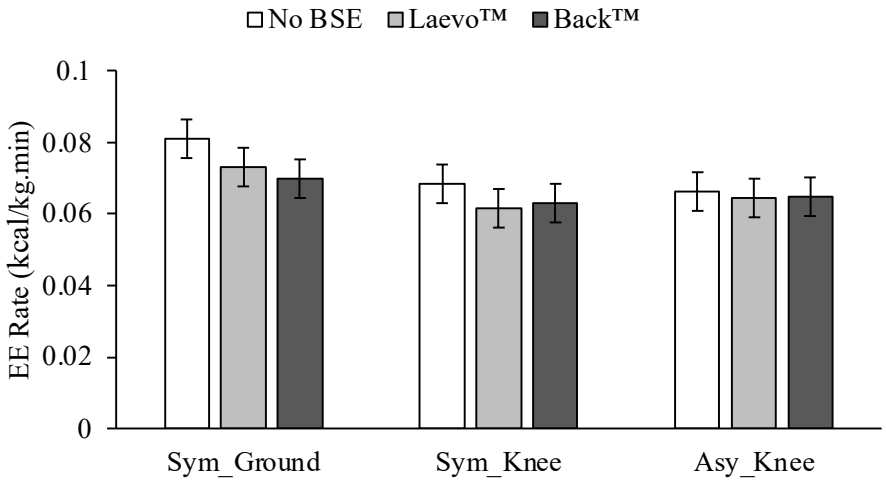
Task-specific & device-specific effects: **Lifting**



Madinei et al. (2020)

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Potential Problems with EXO Use

- Muscle “deconditioning”?
- Excessive interface pressure and discomfort[1,2]
- Challenge to maintain balance; decreased ability to react to a postural perturbation[3,4]
- Physical demands at “other” body regions
- Safety concerns (snags, product damage, etc.)

[1]Madinei et al. 2020; [2]Kozinc et al. 2021; [3]Park et al. 2021; [4]Steinhilber et al. 2022

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Can passive EXOs increase fall risks?

- **Research Focus:**
  - Recovery from out-of-balance situations
- **Two Approaches:**
  - “Tether release” with a passive **BSE**
  - Simulated slips and trips with a passive **lower-extremity EXO**

info.ergoscience.com

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Tether Release: Effects of a BSE

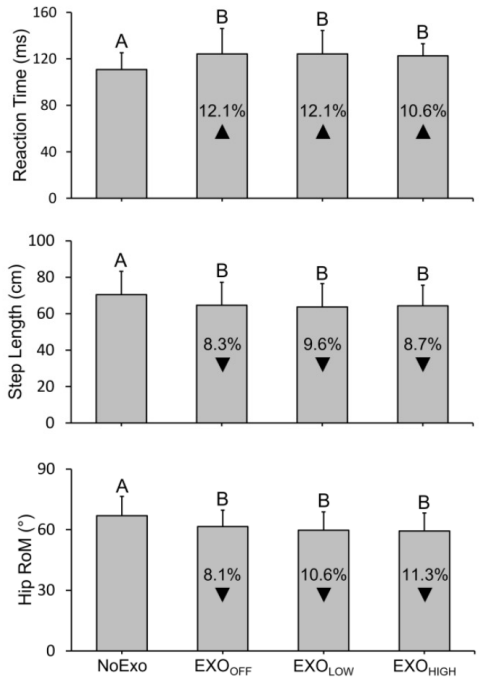
- **Subjects:**
  - 16 young volunteers
- **Task:**
  - Recover balance after release
  - BSE conditions: 1) none; 2) off; 3) low; 4) high
- **Measures:**
  - Maximum lean angle
  - Recovery kinematics

Park, J.-H. et al. (Accepted with minor revisions) Wearing a back-support exoskeleton impairs single-step balance recovery performance following a forward loss of balance, *J. Biomechanics*

23

BSE use **did not** affect recovery ability

- **No significant difference in maximum lean angle**
- **Evidence for an increased postural challenge and potential fall risks**
  - Increased reaction time
  - Smaller step lengths
  - Reduced hip flexion



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Recovery from slip- & trip-like perturbations

- **Subjects:**
  - 6 young volunteers
- **Overview:**
  - Leg-support EXO conditions: 1) none; 2) “low seat”; 3) “high seat”
  - Range of forward and backward perturbation speeds
  - Measures: recovery; harness loads; step kinematics

Dooley et al. (in preparation)

25

- **Recovery from slip-like perturbations was more compromised**
- **High-seat configuration was worse than low**

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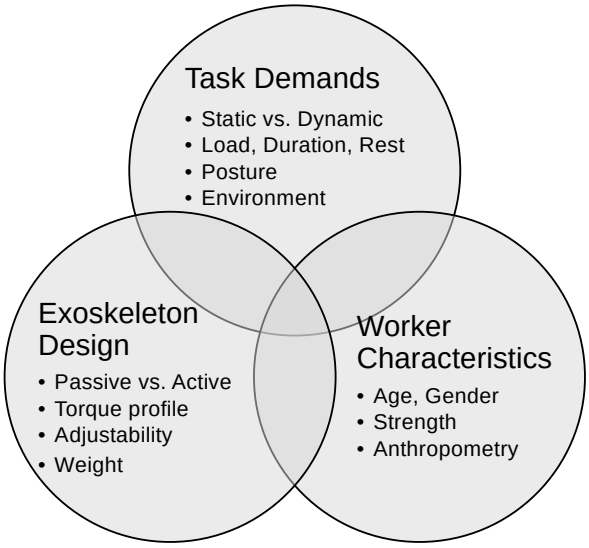
- Becoming clear that the effects (beneficial and otherwise) are complex.
- How should we think of EXOs? (PPE, Engineering Control, …)
- **EXO = Tool**



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ford.com

Is the Future of Work Augmentation?

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Active Exoskeletons are Emerging

CrayX

Lockheed ONYX

Sarcos Guardian XO

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Using a complex, whole-body, active EXO

Research Questions:

- Potential benefits for common occupational tasks?
- Hard to learn to use?

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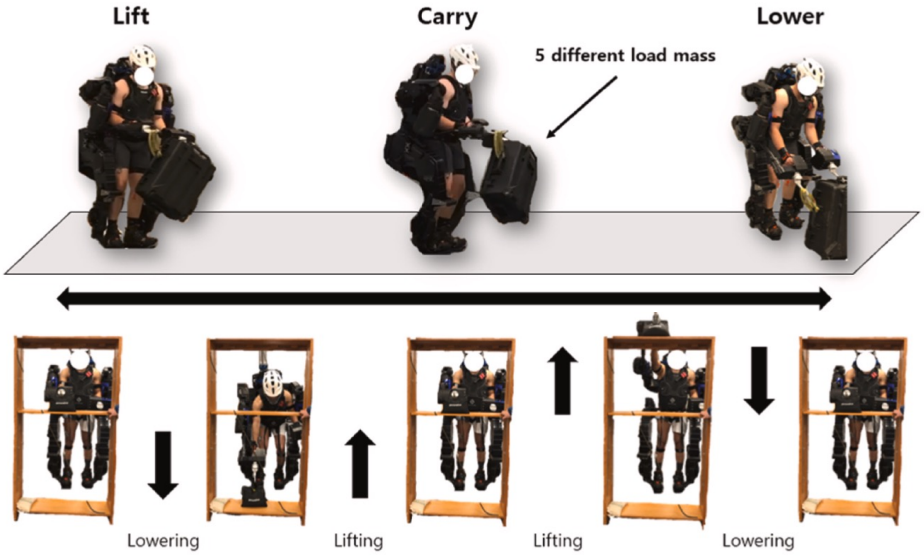
Load handling with a WB-EXO

- **Subjects**
  - Six volunteers
  - Extensive training (>8 hours)
- **Tasks**
  - Load carriage: 5 masses (4.5 – 26 kg)
  - Load transfers: 7 masses (0 – 47 kg)



Park, H. et al. (2022)

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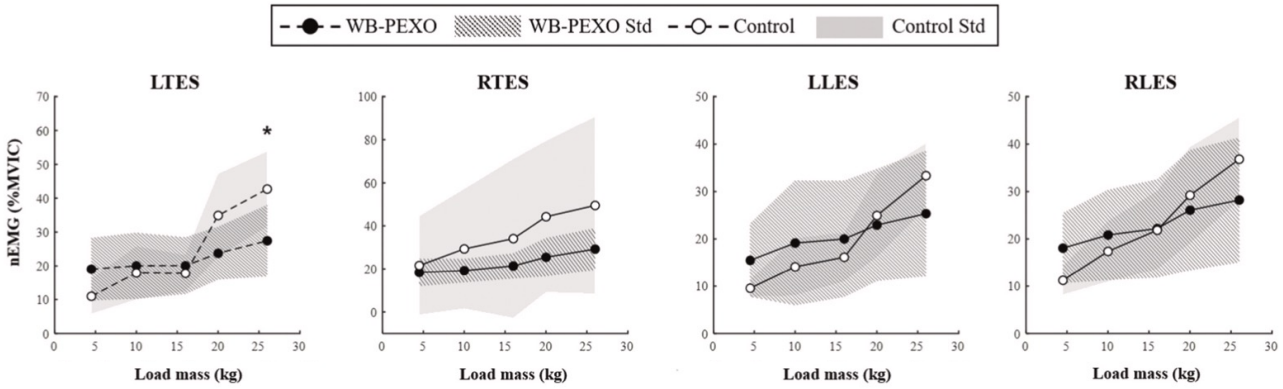
During **load carriage**, the WB-EXO reduced muscle activity for higher masses



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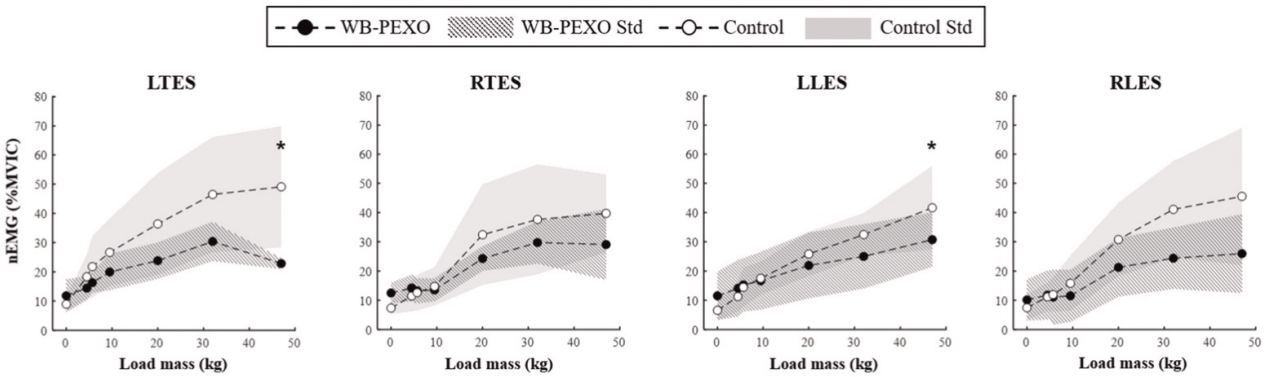
During **load transfers**, the WB-EXO reduced muscle activity for all but the lowest masses



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Learning to use a WB-EXO

- **Subjects**
  - Five experts (extensive experience)
  - Six novices
- **Tasks**
  - Walking on a linear track; load transfers
  - Experts completed one testing session
  - Novices completed 3 sessions over 4 days

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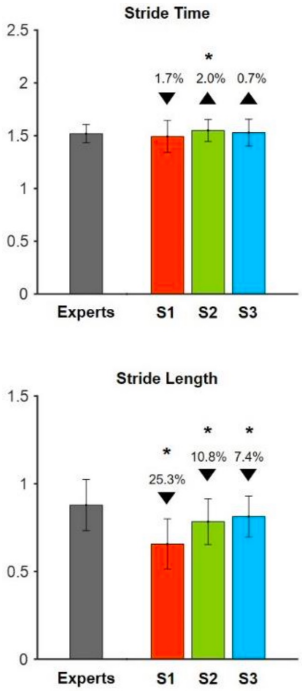
Novices had not yet adopted expert gait strategies

- **Shorter steps, though converging**
- **Distinct behaviors remained in:**
  - Joint kinematics (hip range-of-motion)
  - Joint torques (hip & knee)
  - Muscle activation (quadriceps)



Park, H. et al. (Revision in process) Motor adaptations when learning to walk with a whole-body powered exoskeleton

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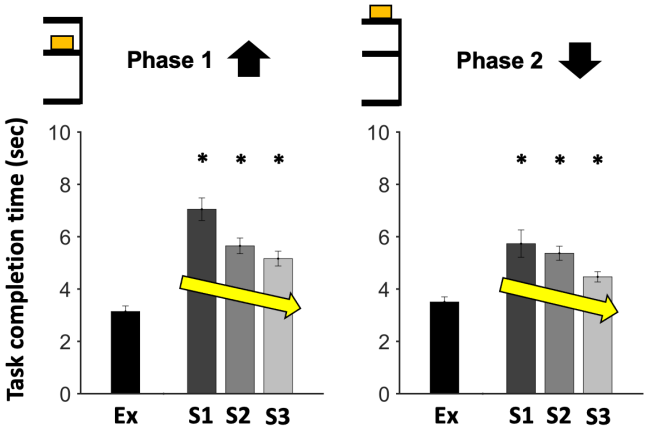
Novices had lower performance & behavioral differences in completing load transfers

- **Longer task completion times**
- **Less shoulder flexion**
- **More muscle activity**
- **Converging to experts**



Park, H. et al. (2022) *HFES Conference*

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More Information is Needed

Understand	Optimizing designs; effective use of active/passive elements; predicting benefits & risks (models)
Assess	System-level "fit"; training needs; health benefits or limitations; useful for injured workers or RTW?
Implement	Provide guidelines for safe & effective selection, adoption, and use

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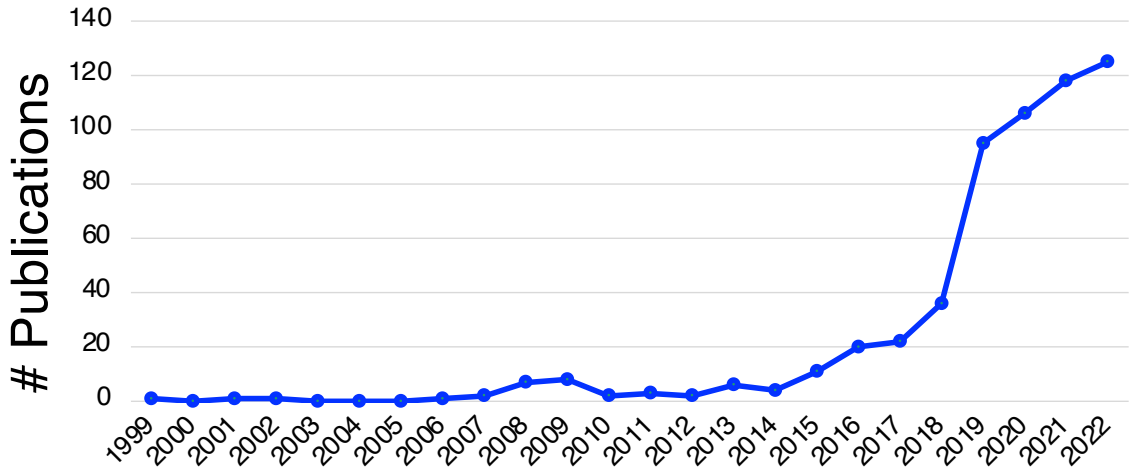
Evidence on Occupational Exoskeletons is Emerging Rapidly



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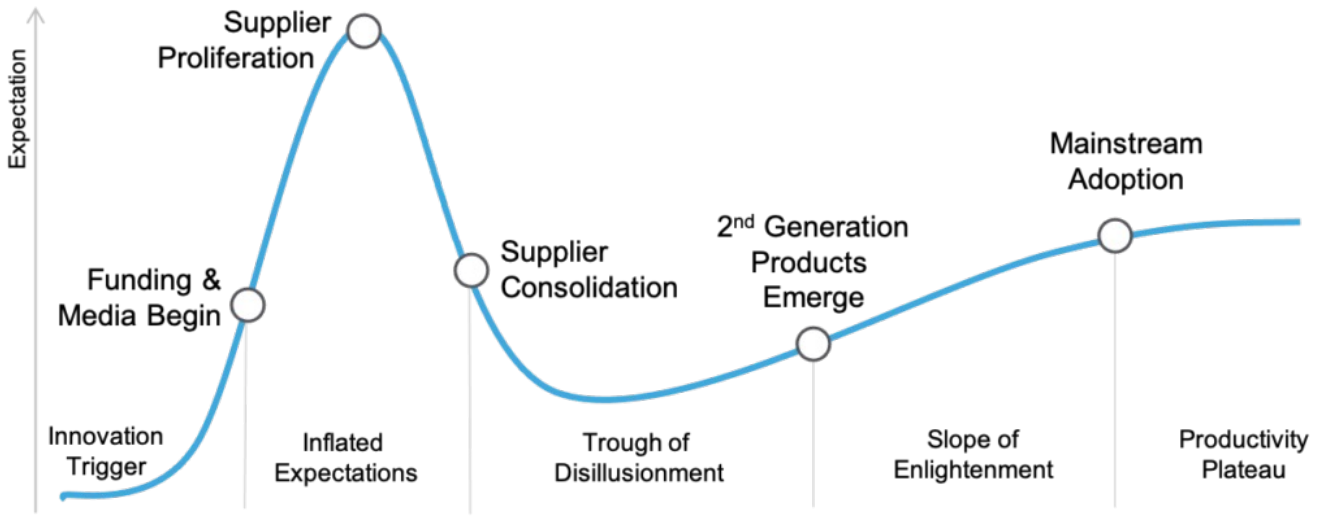
The Gartner Hype Cycle



productfolio.com

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The Future of Occupational Exoskeletons

The future is active, smart, and soft

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Recommendations

1. Challenges in finding a good match between a worker, a task, and an EXO design
2. Be aware of potential adverse effects
3. Consider exploring initially on a small scale
4. EXO companies may suggest good use cases
5. Benefits may or may not be found, and may take time to realize
6. The technology continues to change & improve

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- Any opinions expressed do not necessarily represent those of the noted sponsors

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