Estimating lumbar spine loading when using a passive back-support exoskeleton with adjustable support during Dungeness crab fishing tasks

Mina Salehi Sedeh [1] , Jeong Ho Kim[1,2]

October 2024

(1) Oregon State University

(2) Texas A&M University

Background

Existing epidemiologic evidence consistently shows that **commercial fishers suffer from a high rate of non-fatal injuries**, especially work-related musculoskeletal disorders (MSDs).

- MSDs prevalence rate: 15% in England to 93% in Egypt. [(1)]
- Most frequently affected body parts among fishermen: Low back, shoulders, and knees. [(1)]

The **US West Coast Dungeness crab fleet** is one of the most hazardous commercial fishing fleets in the US.

- Fatality rate: ~22 times greater than the rate among all US workers. [(2)]
- Non-fatal injuries: One in five crab fishers reported an injury incidence in the past year. [(3)]

1. (Remmen et al., 2021): Work-related musculoskeletal disorders among occupational fishermen: a systematic literature review.
2. (Case et al., 2015): Reported traumatic injuries among West Coast.
3. (Bovbjerg et al., 2019): Non-Fatal Injuries and Injury Treatment in the West Coast Dungeness Crab Fishery.

Crab fishing activities with a high MSDs risk

Activities such as **handling the gear (e.g., crab pot) and the catch** are related to the most injuries among Dungeness crab fishers. **(1)**

Crab pot handling

Guiding the pots lifted from the ocean using a mechanized winch crane and emptying the catch onto a sorting table.

Fishers adopt awkward postures to reach out and grab the pots and exert a high level of force to rotate and empty the pot (crab pot weight: up to 100 kg).

Crab sorting

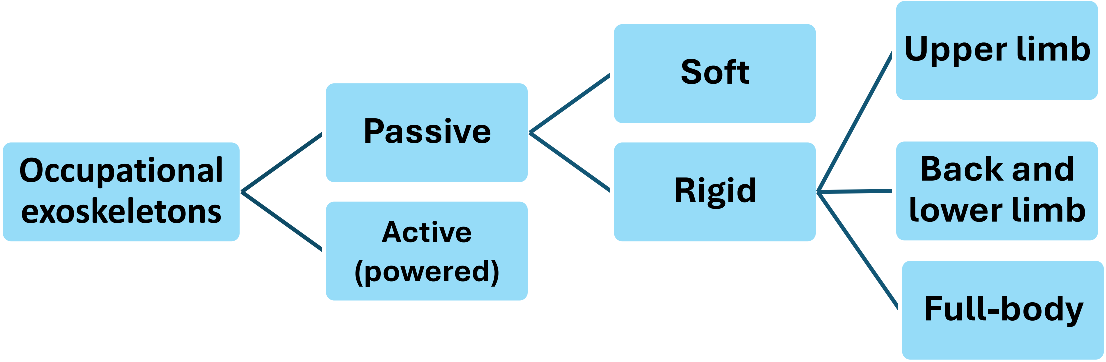
Sorting crab by gender and size.

Fishers bend over the table for prolonged periods, resulting in extensive trunk flexion and spinal biomechanical load.

1. (Kincl et al., 2023): Relationship of personal, situational, and environmental factors to injury experience in commercial fishing.

Occupational exoskeletons

Aim to reduce physical demands during occupational tasks by offering physical support, ultimately preventing work-related musculoskeletal disorders. [1]



Previous studies have extensively demonstrated the effectiveness of passive back-support exoskeletons in reducing muscle activity during occupational tasks, such as manual lifting and static forward bending. [2]

However, the effectiveness of occupational exoskeletons depends on their design, support level, and the specific tasks they are used for. [3]

1. (Reimeir et al., 2023): Effects of back-support exoskeletons with different functional mechanisms on trunk muscle activity and kinematics.
2. (Golabchi et al., 2022): A Systematic Review of Industrial Exoskeletons for Injury Prevention: Efficacy Evaluation Metrics, Target Tasks, and Supported Body Postures.
3. (Mohamed Refai et al., 2024): Benchmarking commercially available soft and rigid passive back exoskeletons for an industrial workplace.

Research questions

Are back-support exoskeletons effective in reducing spine biomechanical load during high-risk crab fishing tasks?

- Limited studies have focused on quantifying critical joint stress measurement (lumbar spine compression and shear forces) when using back-support exoskeletons, with no study targeting crab fishing tasks.

What support level is appropriate for these specific tasks?

- Back support exoskeletons are often offered by manufacturers with different support levels (varying actuator strength).
- However, selecting the appropriate support level is typically performed subjectively (e.g., based on user preference), rather than by considering objective injury risk metrics.

Objectives

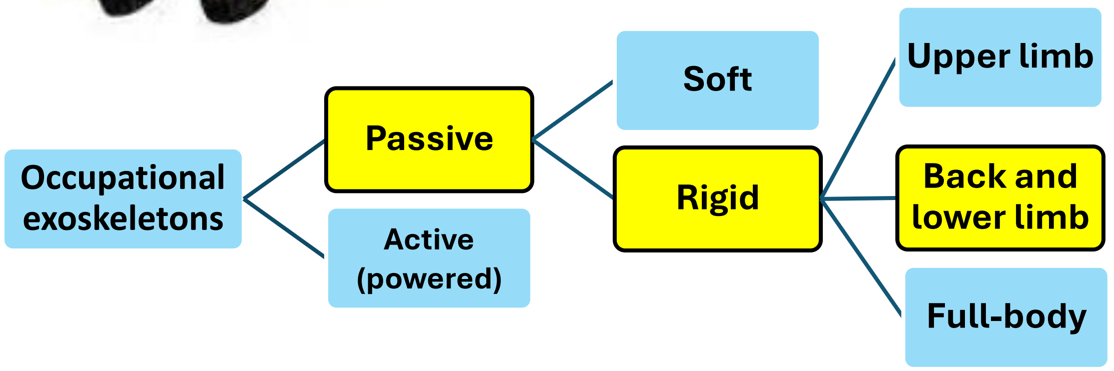
1) Quantify lower back biomechanical loads during crab sorting and crab pot handling when using a passive back exoskeleton.

2) Determine the effect of different support levels of the exoskeleton (ultra-light, light, medium, strong, and ultra-strong) on lower back biomechanical load.

1. (Kranenborg et al., 2023): Side-effects and adverse events of a shoulder- and back-support exoskeleton in workers: A systematic review.

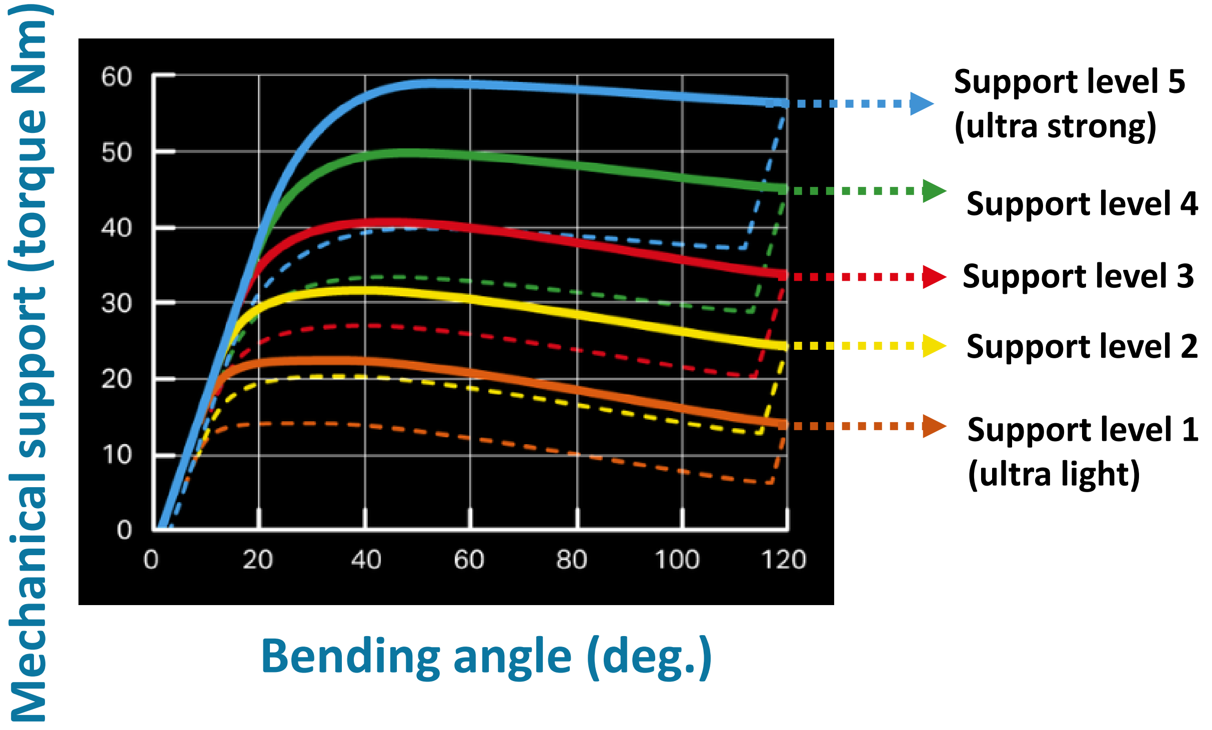
Exoskeleton used in this study:

A passive rigid back exoskeleton with
5 different support levels.



What is exoskeleton support level (torque level)?

The level of assistance (force) provided by exoskeletons as specified by manufacturers.



Methods

Participants

- ✓ 12 healthy males

Age (Mean ± SD): 33 ± 10.25 years old
Weight (Mean ± SD): 89 ± 26.8 kg
Height (Mean ± SD): 180 ± 7.5 cm

Motion data used in this study is from a previous study, but the experimental procedure will be explained briefly.

Study Setup and Apparatus

- Three-dimensional (3D) optical motion capture system

3D kinematic (motion) data at a sample rate of 200 Hz

- Two force platforms located under the participants' feet

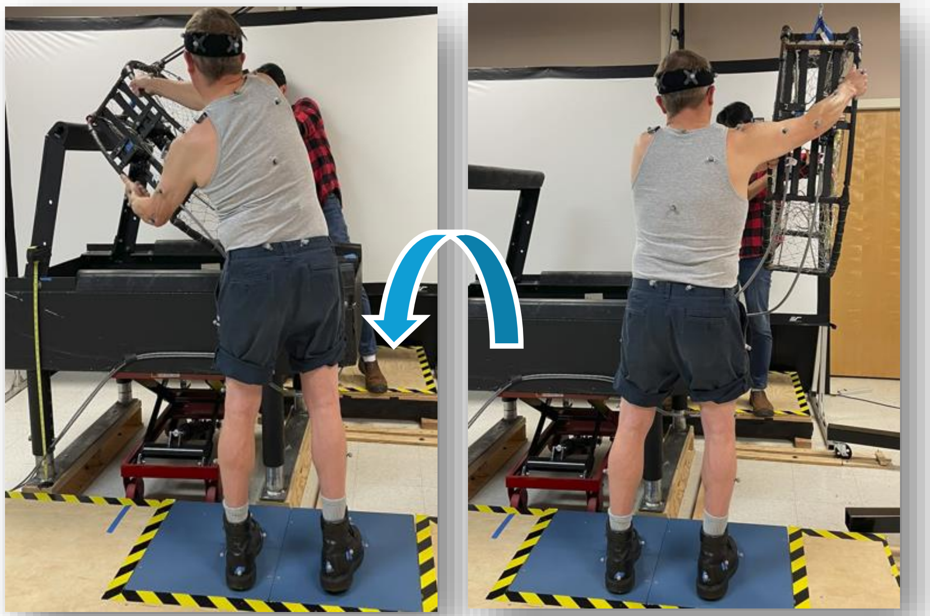
3D ground reaction forces and moments

Reflective markers were placed on 39 anatomical landmarks on participants' body

Force plated under participants' feet

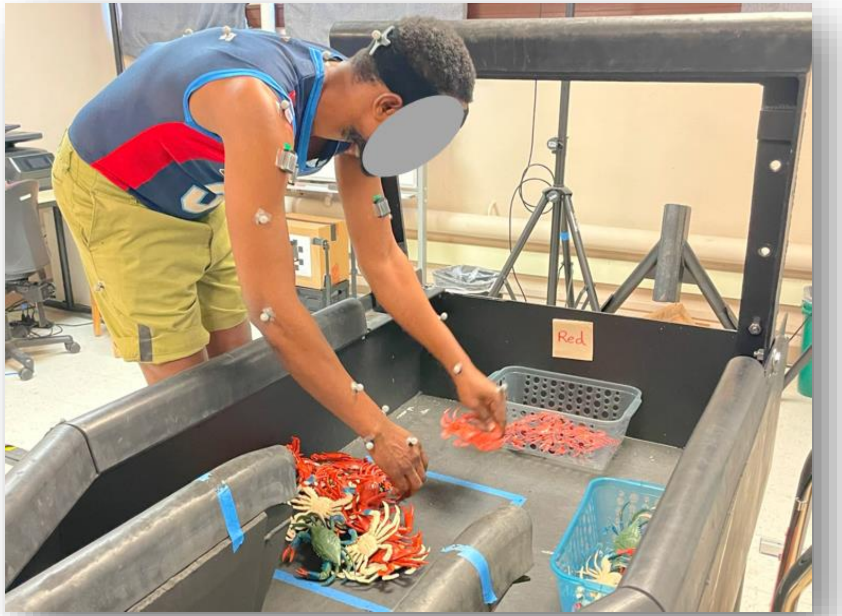
Methods: Experimental tasks

Crab pot handling



- ✓ A crab pot with a mass of 40 kg was used.
- ✓ The task involved grabbing the crab pot hanging from the block with both hands, placing it on the sorting table, tilting the pot from its vertical position (simulating crab pot emptying), and then tilting it back.

Crab sorting task



- ✓ A custom-built crab sorting table with a work surface height set at 16” (the average height of the sorting tables currently used by the West Coast Dungeness crab fishermen)
- ✓ Artificial plastic crab with a size of 14 × 17 cm and a mass of 150 gr, with two distinct colors (i.e., blue and red)
- ✓ The task involved sorting 40 crab by color.

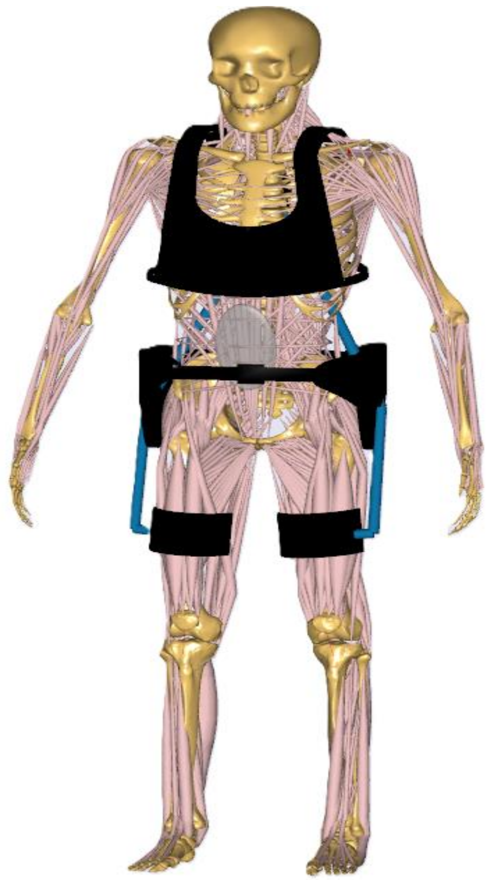
Methods:

Biomechanical Simulations

- **AnyBody Modeling system (AMS)[(1)]** was used for biomechanical analyses. Kinematic data (collected in the lab) were used to simulate participants' movements during each task.

- A simplified **CAD model of the exoskeleton** was created and imported into AnyBody software. The exoskeleton was connected to the human body model on specific contact points at the thorax, pelvis, and thighs, with two revolute joints located proximal to the human model hip joints, where the supportive torque was applied.

- Supportive torque was calculated based on the torque-angle graph provided by the manufacturer and trunk flexion angle at each step of the simulation.



Statistical Analyses

- **Generalized linear mixed models** were used to determine the effects of exoskeleton:

Fixed effect: Exoskeleton condition (Independent variable)
Random effect: Participants
Dependent variables: Lumbar compression and shear forces

- Shapiro–Wilk test was used to check for normality of distributions, with data transformation where required.

- Any statistical significance was followed-up with post-hoc Tukey tests.

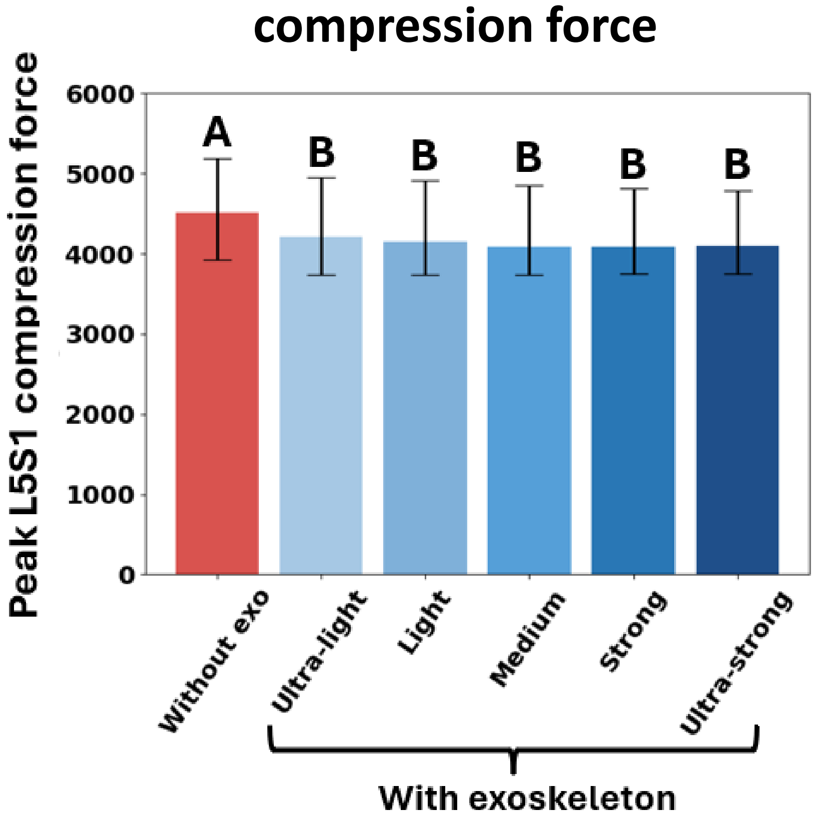
1. (Bassani et al., 2017): Validation of the AnyBody full body musculoskeletal model in computing lumbar spine loads at L4L5 level.

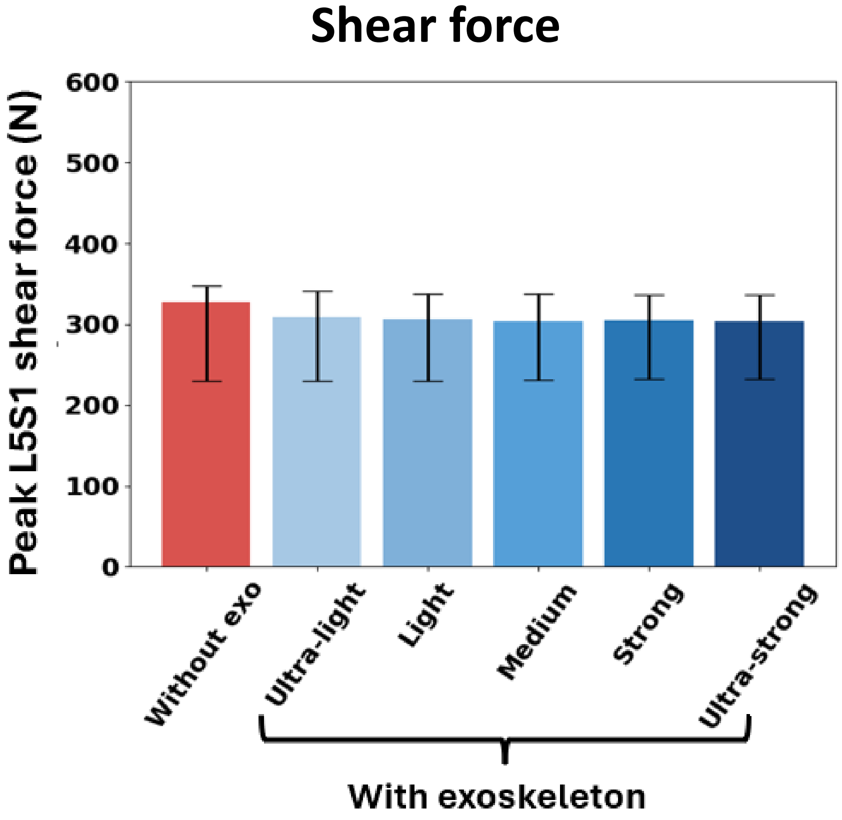
Results: Crab pot pulling task

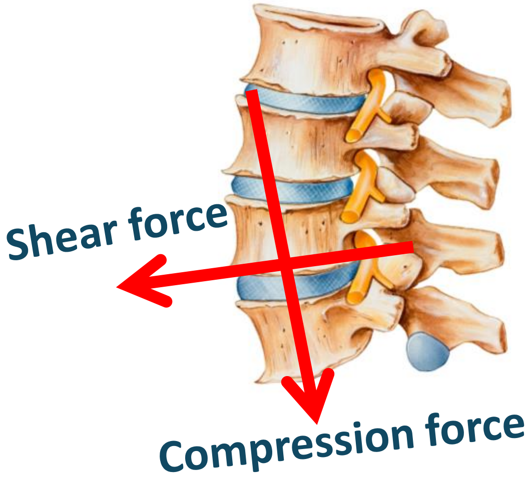
- Up to 9% reduction in L5S1 **compression force** with exoskeleton (p-value <0.05).

No statistical significance between different exoskeleton conditions.

- 5-7% reduction in L5S1 **shear force** with exoskeleton. However, the difference was not statistically significant.



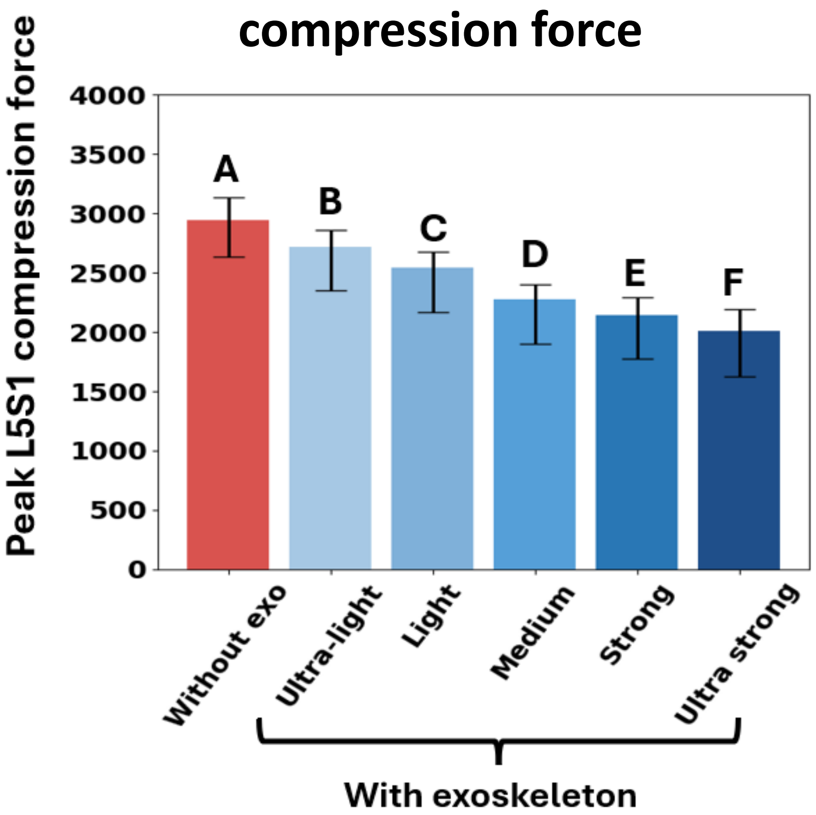


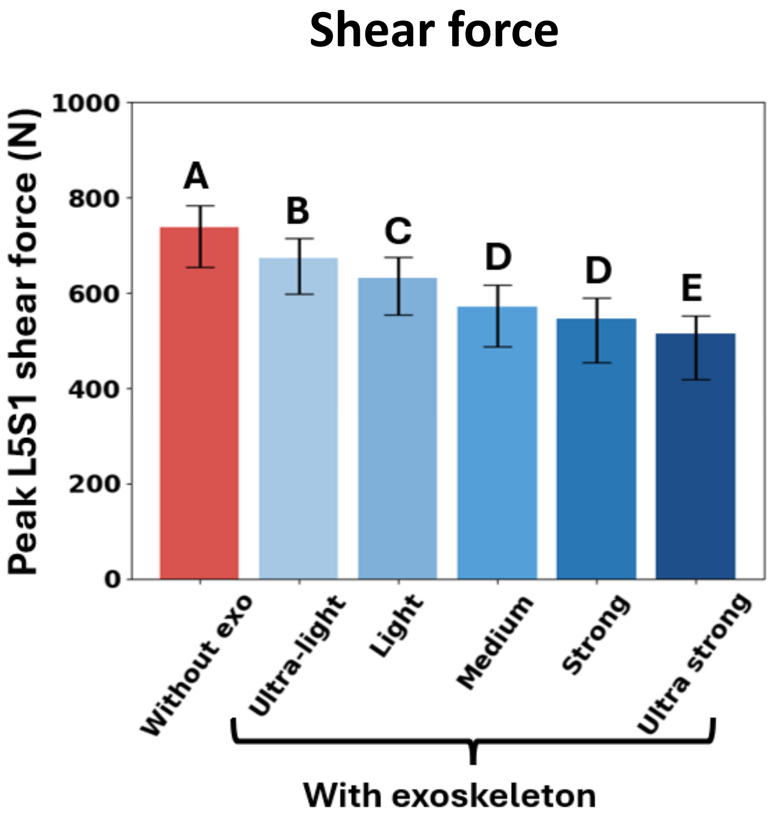


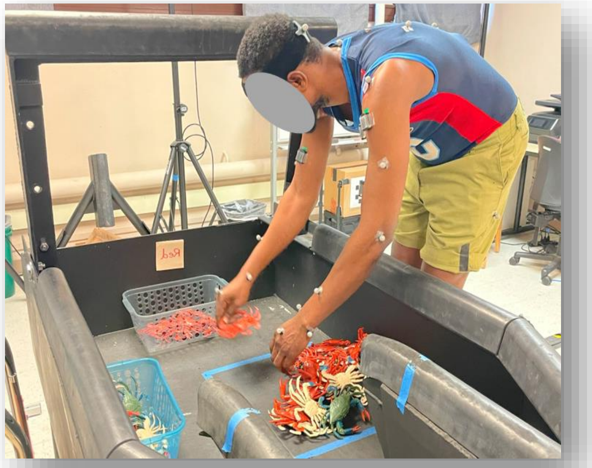
Results: Crab sorting task

- Up to 32% (ultra strong support level) reduction in **L5S1 compression force** with exoskeleton compared to no exoskeleton condition. (p-value <0.001)

- 4.6% to 26% reduction in **L5S1 shear force** with exoskeleton compared to no exoskeleton condition. (p-value <0.001)



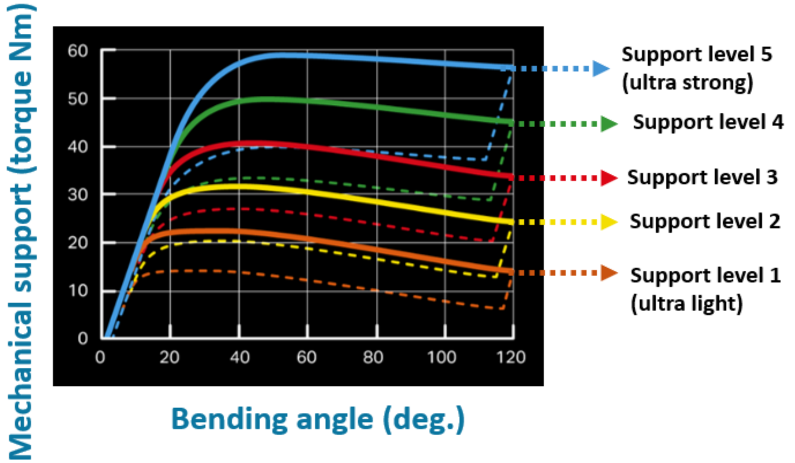


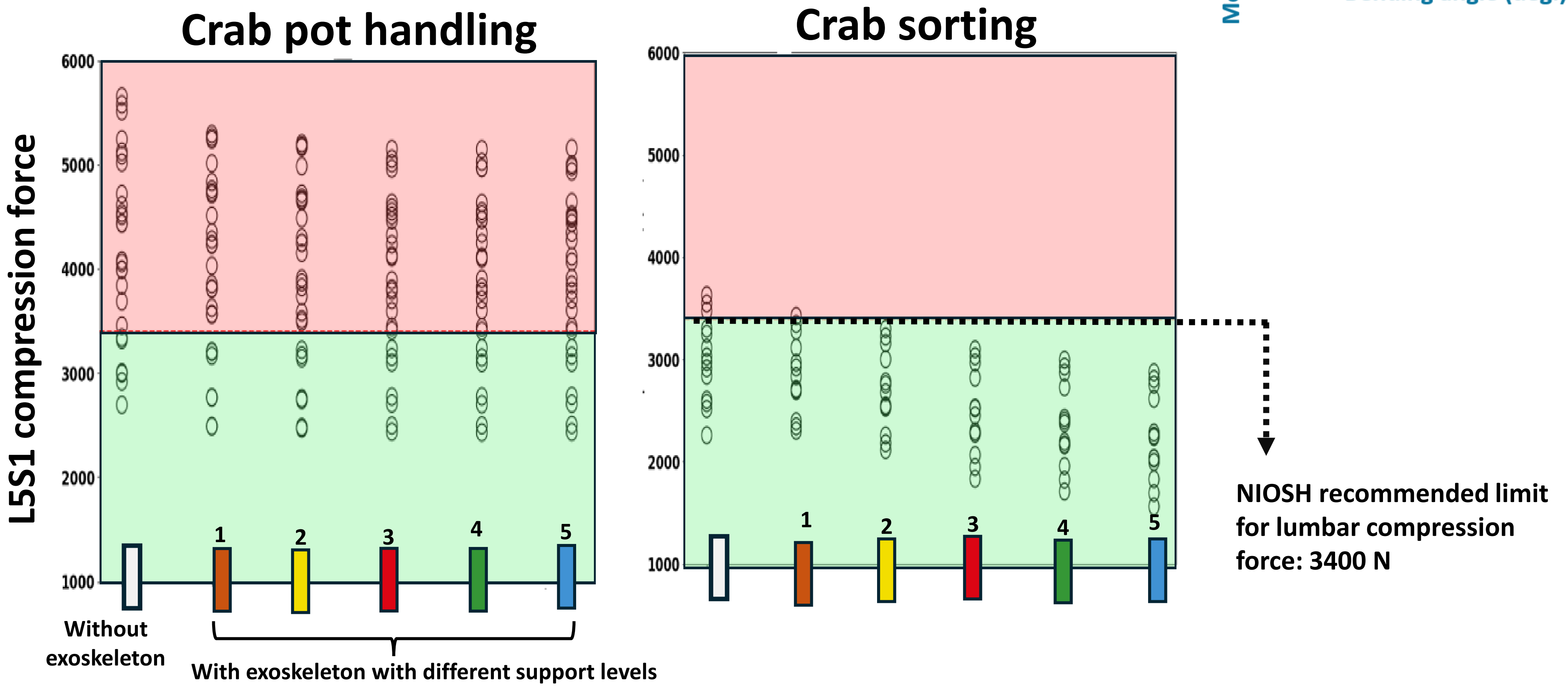


Results: Effects of different support (torque) levels

During crab pot handling, increasing the actuator level did not lead to further reductions in low back load.

During crab sorting, low back load gradually decreased as the exoskeleton assistive torque increased.





Discussion

- Crab pot handling and carb sorting both **are high-risk tasks that pose MSDs risk to Dungeness crab fishers**, particularly, crab pot handling poses substantial biomechanical loads and injury risk on the low back.

- Occupational back-support exoskeletons have the potential to reduce this risk, however, the **effectiveness is task-specific**. Similar results regarding exoskeleton effectiveness were reported in previous literature**. (1,2)**

Crab pot handling:

For this task, the exoskeleton had minimal impact on low back compression force and no significant effect on shear force, even with stronger actuators. This is likely due to the task's specific kinematics, which involves limited trunk flexion (mainly includes lateral bending), while the exoskeleton's support is primarily designed to assist with trunk flexion.

Crab sorting:

During the crab sorting task, which involves high trunk flexion, the exoskeleton provided significant assistive torque. Actuator levels 2 and 3 (low to medium) successfully reduced compression forces for all participants to below the NIOSH recommended limit. Therefore, stronger actuators (levels 4 and 5) may be unnecessary for this task (except for people with a high BMI), as excessive assistive force may lead to undesirable side effects like chest and thigh contact pressure and discomfort. **(3)**

(Alemi et al., 2020): Effects of two passive Back-support exoskeletons on muscle activity, energy expenditure, and subjective assessments during repetitive lifting

(Tröster et al., 2022): Biomechanical Analysis of Stoop and Free-Style Squat Lifting and Lowering with a Generic Back-Support Exoskeleton Model.

(Kozinc 2021 et al., 2021): Human pressure tolerance and effects of different padding materials with implications for development of exoskeletons and similar devices

Limitations and future direction

This study was the first to:
evaluate the biomechanical impacts of a passive exoskeleton for crab fishing activities and investigate the effects of different actuator (support) levels. However, several limitations must be acknowledged:

- This was a simulation-based study, with the effects of the exoskeleton assessed solely through biomechanical simulation and human-exoskeleton modeling.
  - **Future studies involving participants actually wearing the exoskeleton could evaluate additional factors, such as subjective measures and comfort levels.**
- The study's small sample size may limit its statistical power as well as the generalizability of the results.
  - **Future research should include a larger, more diverse population with varying anthropometrics.**
- The motion data for biomechanical simulations were captured without the exoskeleton, assuming minimal kinematic changes when wearing it. While evidence on exoskeletons' effects on human kinematics is mixed **(1)**, there is potential for limiting the trunk range of motion and consequently altering the exoskeleton provided support.
  - **Future studies should gather motion data during crab activities with participants wearing the exoskeleton to better understand these effects.**

1. (Golabchi et al., 2022): A Systematic Review of Industrial Exoskeletons for Injury Prevention: Efficacy Evaluation Metrics, Target Tasks, and Supported Body Postures

Acknowledgements

Research reported in this presentation was supported by the National Institute for Occupational Safety and Health (NIOSH) under Federal Training Grant T42OH008433.

The content is solely the responsibility of the authors and does not necessarily represent the official views of NIOSH.

NORTHWEST CENTER FOR OCCUPATIONAL HEALTH AND SAFETY
UNIVERSITY of WASHINGTON

Thank you!

Do you have any questions?

Salehim@oregonstate.edu
jay.kim@tamu.edu