Less Strain, More Boxes: The Exoskeleton Effect on Port Warehouse Workers

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Methodology

Research Design and Data Collection

Research Objectives

To determine whether wearing an exoskeleton during manual box handling reduces warehouse workers' physiological fatigue and muscle load and increases their productivity.

Participants

20 warehouse workers handling cargo boxes in a port logistics warehouse at PT. Samudera Indonesia.
Height 148–175 cm, body weight 48.6–91 kg.

Study design

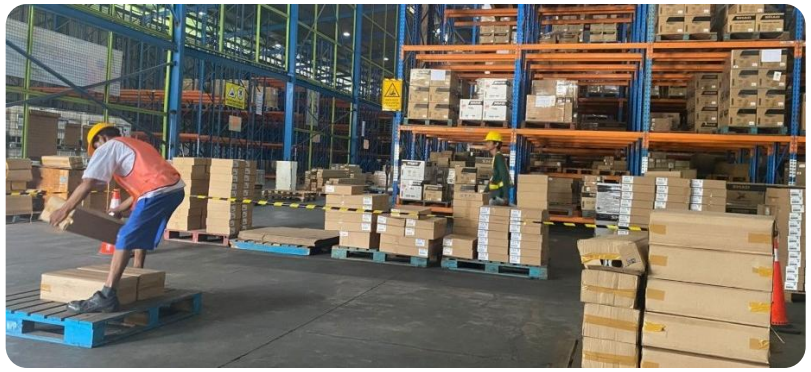
Within-subject comparison: each worker did the same box-handling task **without** the exoskeleton and **with** it, counterbalanced.
Pilot study on 20 Jan; data collected 22 Jan – 6 Feb 2026.

Measures

HRV: Mean HR, RMSSD, LF, HF
EMG: Biceps femoris (L/R), thoracolumbar fascia, erector spinae
Borg RPE before and after the task
Productivity: number of boxes moved
HRV and EMG: 40 min, in eight 5-minute segments

Analysis

One-way repeated-measures ANOVA, $\alpha = 0.05$.







Task, exoskeleton fitting and HRV/EMG setup

Results

Key Findings

Productivity

Average boxes moved per worker rose from **177** without the exoskeleton to **186** with it, a significant increase (p = .024).

+5.1%

HRV · all changes significant (p ≤ .031)

Mean heart rate (bpm) decreased	135.2 → 125.0
RMSSD (ms), recovery capacity increased	9.02 → 10.08
LF, stress response decreased	159.3 → 114.2
HF, relaxation increased	53.6 → 110.1

EMG muscle activity · all significant (p < .01)

Erector spinae (right lower back) decreased by	35.78%
Thoracolumbar fascia (left lower back) decreased by	32.62%
Biceps femoris (right thigh) decreased by	19.77%
Biceps femoris (left thigh) decreased by	18.38%

Perceived exertion (Borg RPE): the average rise during the task fell from 3.3 to 1.7 points (about −48.5%), but this was not significant (p = .328). Overall, the exoskeleton eased physiological strain and lower-back load most.

Conclusion

Key Takeaways

Lower back load drops by about a third

−33% to −36%

The exoskeleton reduced activity in the erector spinae and thoracolumbar fascia, and reduced thigh muscle activity by about 19%.

Less physiological strain

4 of 4 HRV markers

Heart rate and LF fell while RMSSD and HF rose, all significantly: workers' bodies stayed closer to a relaxed, recovering state.

Productivity improves, not just comfort

+5.1% boxes moved

Output rose from 177 to 186 boxes ($p = .024$), so wearing the device did not slow workers down.

Perceived fatigue: a trend, not yet proven

−48.5%, p = .328

Borg RPE rose less with the exoskeleton, but the difference was not significant; workers may need longer use to feel the benefit.

Implication: exoskeletons are a promising ergonomic intervention for manual cargo handling at the port.

Future research: longer, counterbalanced trials with more workers to confirm the effects on perceived fatigue.