The Relationship Between Assistance Torque And Muscle Activity During Lifting With Back-support Exoskeletons

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Introduction

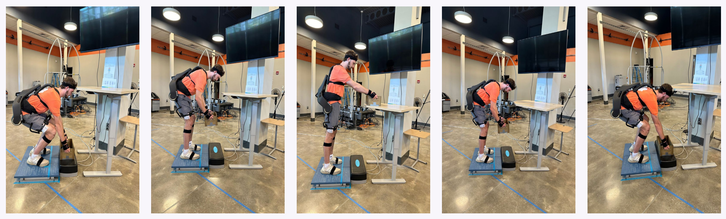
- Manual material handling: leading cause of work-related musculoskeletal disorders [1].
- Lower back: the most affected body region [2].
- Back-support exoskeletons (BSEs): aim to reduce occupational back injuries.
  - *Powered BSEs:* provide varying levels of hip-extension torque to reduce lumbar loading during lifting.
- **Current gap**: no evidence-based guidelines for user-specific selection of external assistive torque at different load levels.
- **Analogy to ankle exoskeletons**: Metabolic rate and peak assistance torque exhibited an exponential function, with decreasing returns at higher torque levels [3]; whether similar non-linearities exist in active BSEs is unknown.
- **Biomechanical concern**: Excessive assistance may foster over-reliance, antagonistic co-contraction, and altered movement and postures [4].

Study Aim & Hypotheses

- Apogee EXO (German Bionic Systems GmbH, Augsburg, Germany) is an active device with dual electric hip torque generators, with manually adjustable support level from 0 to 100%,
- Primary aim: Quantify back extensor and flexor muscles activity, including thoracic (TES) and lumbar (LES) erector spinae, rectus abdominis (RA), and external oblique (EO), across 8 EXO assistance levels during repetitive lifting.
  - Hypothesis 1: Muscle activation decreases with assistance up to a point, then plateaus or reverses (diminishing returns).
  - Hypothesis 2: The plateau occurs at a higher torque under heavier loads.

Method

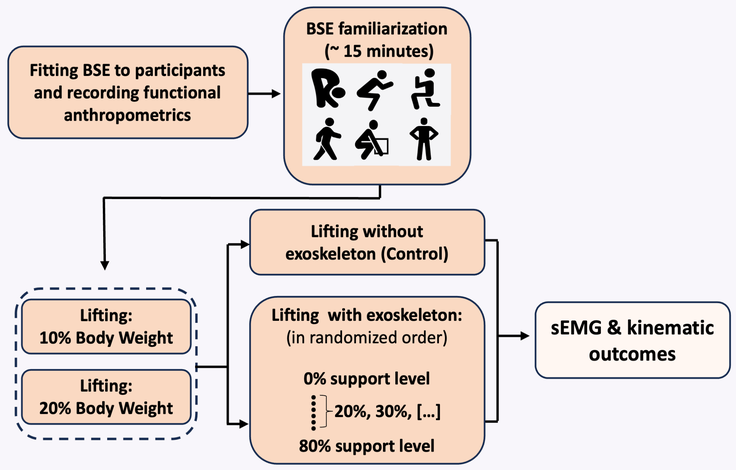
- Participants: 20 young & healthy participants (10M-10F).
- Experimental Design: Repetitive symmetric lifts at 4 lifts/min for 90 seconds, under 9 conditions.
  - Two levels of load in two separate session (10% vs 20% BW).
- Conditions: without EXO (control), wearing the EXO but without assistive support, and while using the EXO at seven different levels of assistance from 20 to 80%, randomized in two ways:
  - 50% decrease to 0%, then from 60% increase to 80%
  - 50% increase to 80%, then from 40% increase to 0%



Overview of the lifting task with a participant wearing the Apogee.

Instrumentation

- **Kinematic recording**: Xsens Awinda system with 17 IMUs recorded whole-body kinematics at 60 Hz.
- **Muscle activity recording**: Wireless surface-EMG (Ultium EMG system, Noraxon) — sensors placed bilaterally on trunk extensors (thoracic and lumbar erector spinae) and flexors (rectus abdominis and external oblique).



Overview of the experimental protocol.

Signal processing

- Kinematic data: low-pass 6 Hz bi-directional Butterworth.
- EMG data: band-pass 20–450Hz, 300ms RMS; normalized to 3s MVC trials.

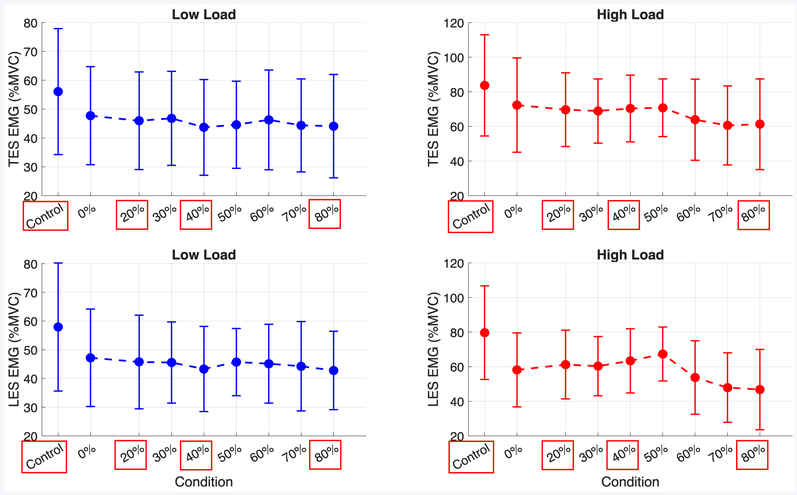
Outcome measures

- 90th percentiles of right-side activity for TES, LES, RA, EO.
- 90th percentile of trunk flexion angle.

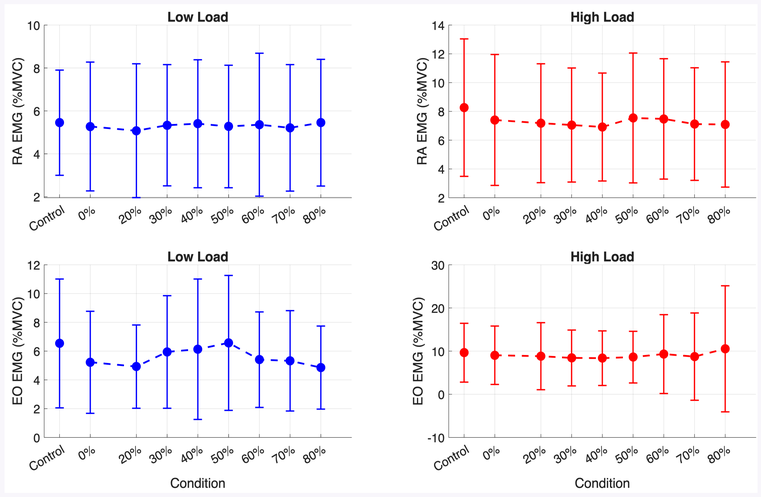
Statistical Analysis

- Repeated measure ANOVAs to assess the effects of support level (control, 20%, 40%, and 80% conditions) on EMG and postural measures in low-load and high-load conditions, with significance at $p < 0.05$.

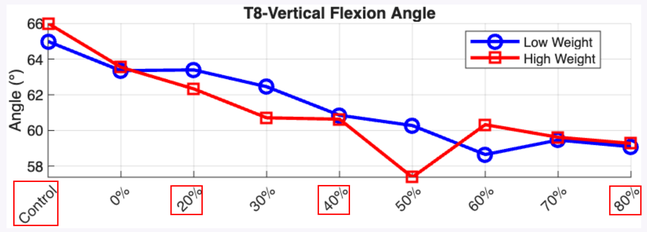
Results & Discussion



Peak trunk extensor muscles (thoracic and lumbar erector spinae) activity under different EXO assistance and Load conditions.



Peak trunk flexor muscles (rectus abdominis and external oblique) activity under different EXO assistance and Load conditions.



Peak trunk flexion angle under different EXO assistance and Load conditions.

- **EXO assistance** significantly affected peak extensor activity (TES & LES) for both loads ($p < 0.0001$) and trunk flexion angle for low ($p = 0.009$) and high loads ($p < 0.0001$).
- For both **low and high load**: Trunk flexion angle, TES, and LES activities in **20%, 40%, and 80% assist** were significantly lower compared to the **control** condition.
  - ➢ For the **high load** condition: LES and TES activity at **80%** was significantly lower than **20% and 40%** assist levels.
- Non-linear effect on extensor muscles: Under low-load, extensor activity reductions plateaued after 40%, whereas under high-load, activity decreased progressively up to 80%, indicating sustained benefits at higher assistance.
- Significant inter-individual variability was found for the assistance level at which trunk extensor muscle activity showed no further reduction.

Future Work

- We will investigate whether inter-individual differences in muscle activity benefits can be explained by subject-specific modeling.

Acknowledgments

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