BIOMECHANICAL ANALYSIS OF THE SHOULDER UNDERGOING INDUSTRY RELEVANT TASKS

Carlo Canezo[1], Dustin Crouch[2], Gregory Sawicki[1]

[1]Physiology of Wearable Robots Lab, School of Mechanical Engineering, Georgia Tech, Atlanta, Georgia

[2]Upper Limb Assist Lab, University of Tennessee, Knoxville, Tennessee

*Corresponding author's email: ccanezo3@gatech.edu

Motivation

Upper Body Exoskeleton (EXO) Technologies have seen developmental progress, but not widespread in industry. Challenges are:

- EXOs must **account for user and task (Multi DOF and Workspace)** or issues will arise (poor ergonomics, improper assistance, non-acceptance) [1]
- EXO development lacks a "formal roadmap" to inform designs [2]

To aid in developing Upper Body EXOs:

- Develop a **Biomechanical Model Data Set** of the Relevant Tasks
  - Gather instrumented data (EMG, MOCAP, GRF) to drive computational models (OpenSim)
  - Calculate **Upper Body Joint Level Outcome Measures** to determine injury "hotspots"
  - Utilize data as ground truth for training ML models for eventual EXO controller design [4]

Central Hypothesis

A) Increased interaction load leads to increased **Shoulder Joint** biomechanical demand*

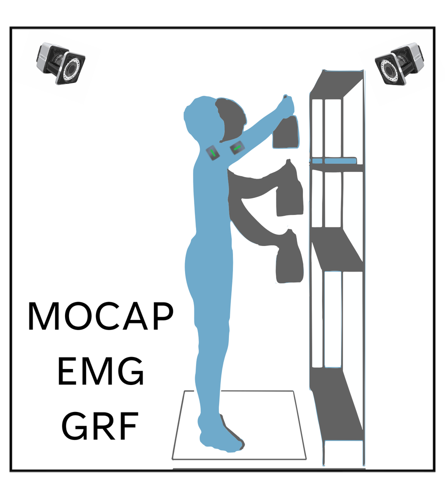
B) Demand* is further exacerbated by increased proximity in workspace extremes

Demand = Shoulder Joint Moments, Powers, Work, Impulse

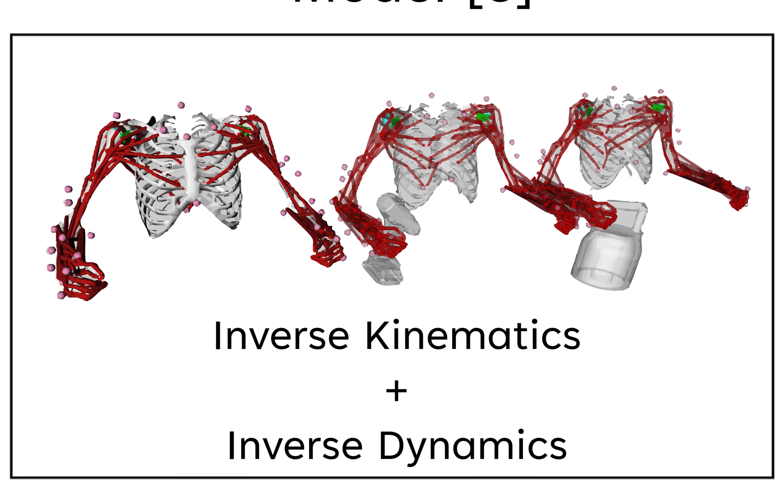
Methods

Analysis Pipeline

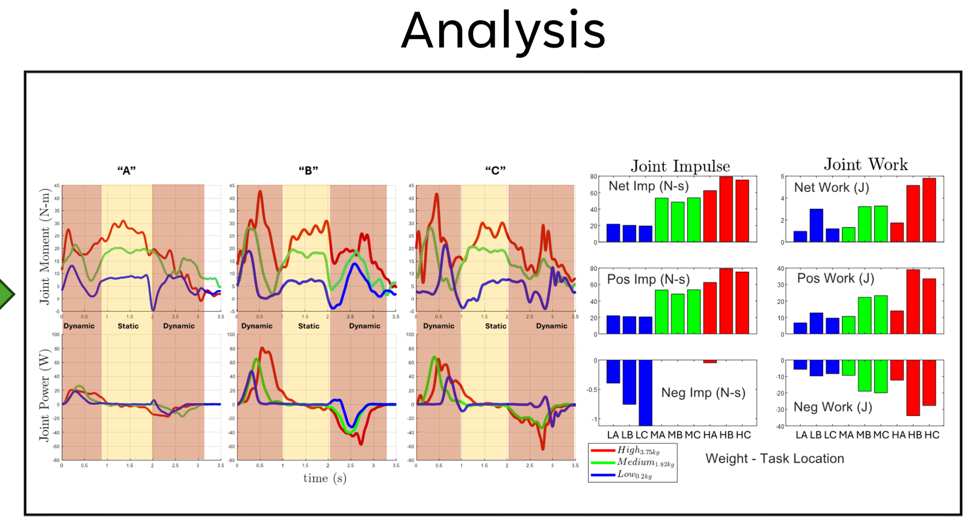
Data Collection



OpenSim with Upper Body Model [3]



Shoulder Joint Level Demand Analysis



Key Details

Shelf stacking/holding task

Dynamic and static motion of load for 1x arm

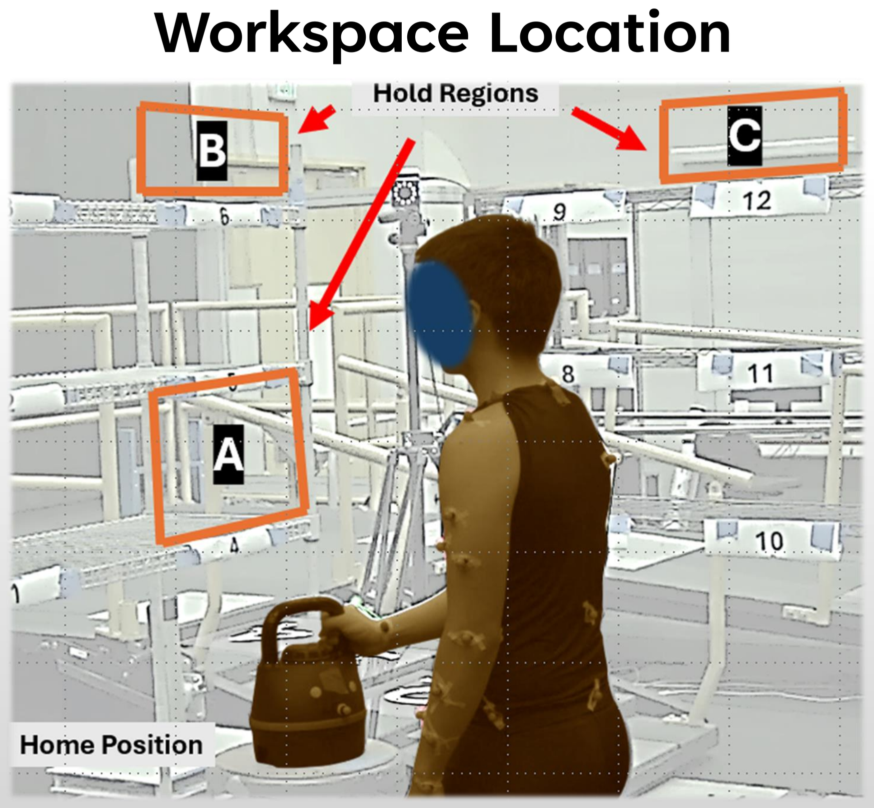
3x Regions of interest

- **A – Close Sagittal**
- **B – Extreme Sagittal**
- **C – Extreme Frontal**

3x Interaction loads

- **High – 3.75 kg (1 gallon jug)**
- **Medium – 1.78 kg (drill)**
- **Low – 0.2 kg (small object)**

Workspace Location



Interaction Loads

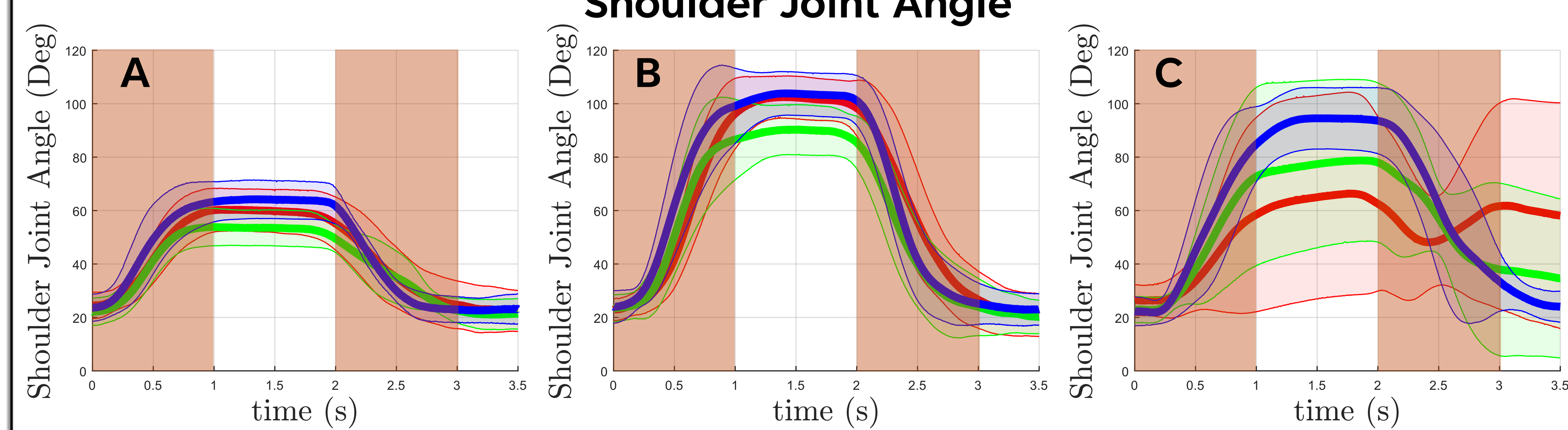
Motion Videos

SCAN ME

SCAN ME

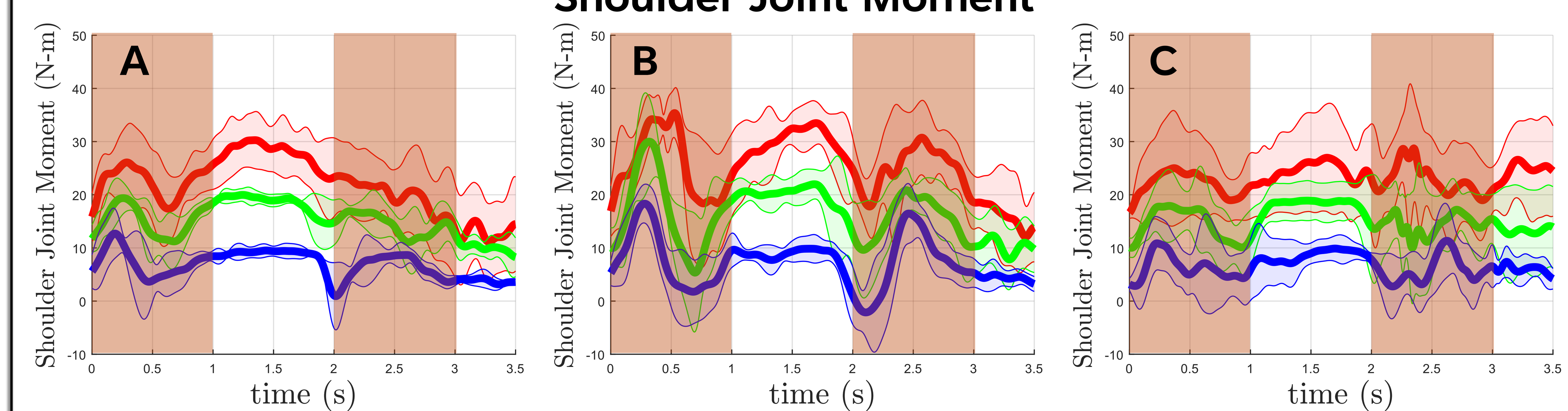
Kinematic Results N=5

Shoulder Joint Angle

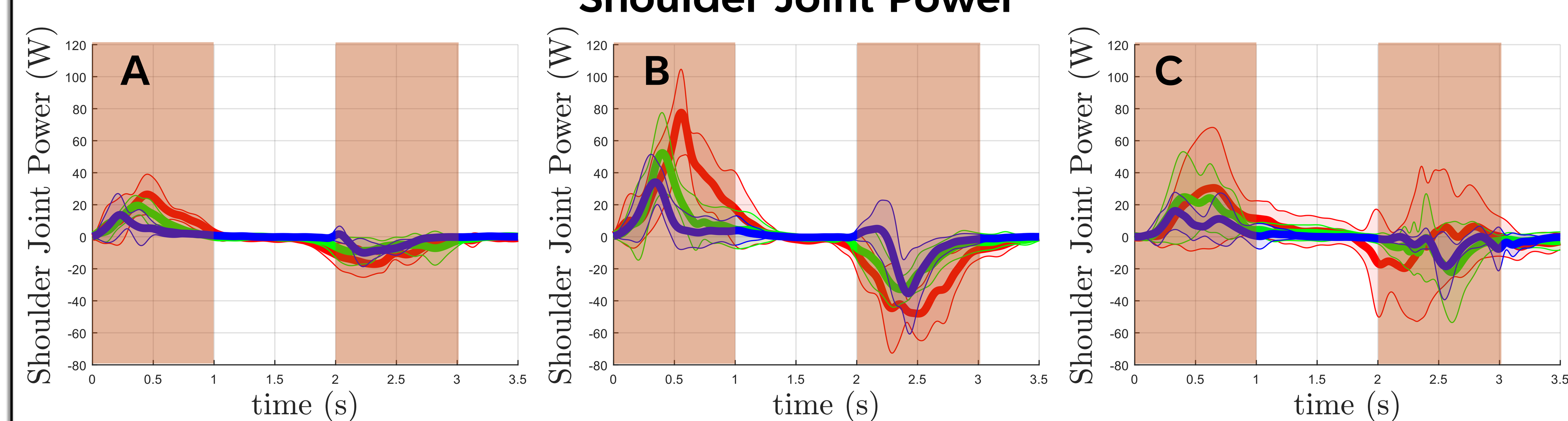


Kinetic Results N=5

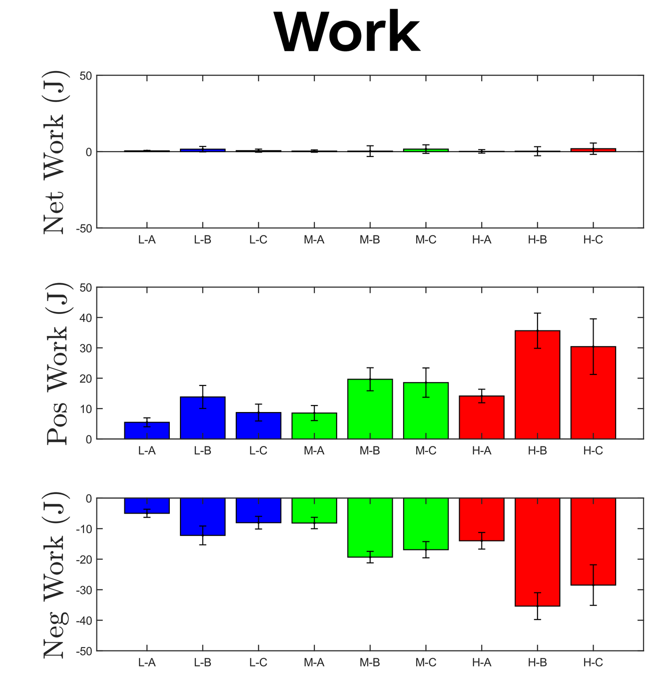
Shoulder Joint Moment



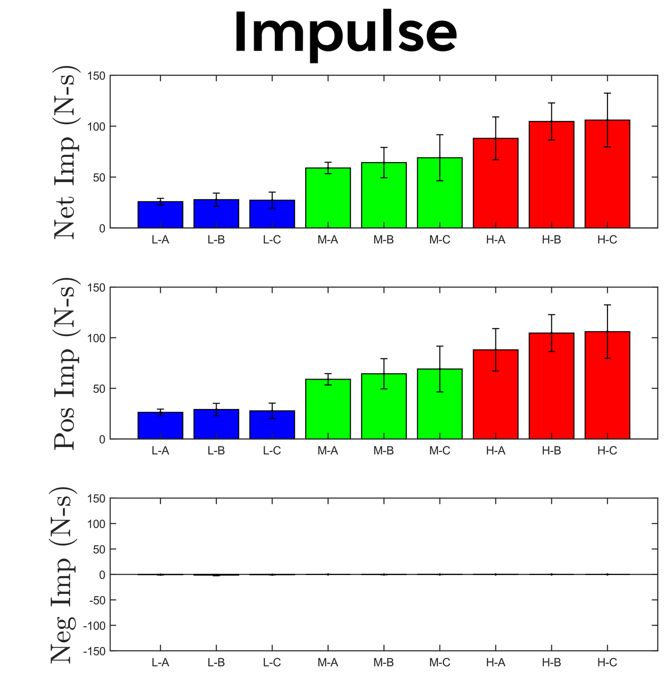
Shoulder Joint Power



Shoulder Joint Work



Shoulder Joint Impulse



Discussion

- Demand shows an increasing trend with higher interaction load
- Large Moment and Power peaks during the dynamic (brown region) phase
- Static phase has no power, but persistent torque to compensate gravity
- Net Work of the Shoulder Joint should be at/close to zero for a full return motion
- Work tied to the overall potential energy of load

Acknowledgements

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References

[1] Crouch et al. (2020), J. App Biomech. 36(2); [2] Nuckols et al. (2020), PLOS ONE 15(8); [3] Saul et al (2015), Comp. Methods in Biomech & BioEng 18(13); [4] Molinaro et al. (2024) Nature 635(8038).