Bio-inspired Shoulder Exosuit with Cable-Driven Quasi-Direct Drive Actuation

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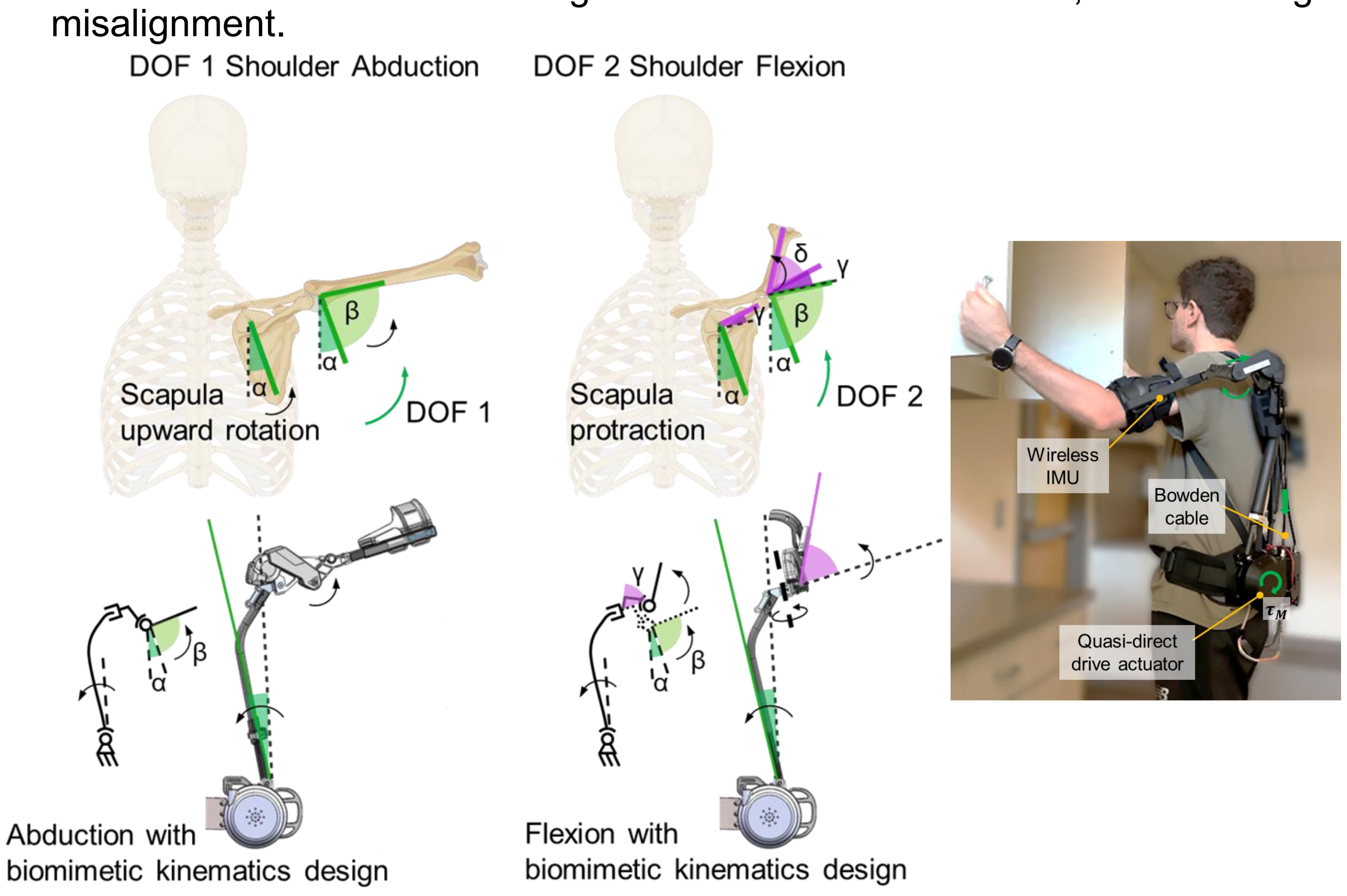
Motivation / Introduction

- State-of-the-art assistive shoulder exoskeleton can provide support to shoulder lifting, but they can cause misalignment issues and significantly impede natural shoulder movement.
- State-of-the-art assistive shoulder exoskeleton cannot be both lightweight and provide torque assistance >11.5 Nm* due to limitations in their actuation
- To overcome these limitations, we developed the most lightweight, powered shoulder exoskeleton with cable-driven quasi-direct drive actuation that can assist shoulder flexion and abduction without joint misalignment issue and not compromising natural shoulder movement.

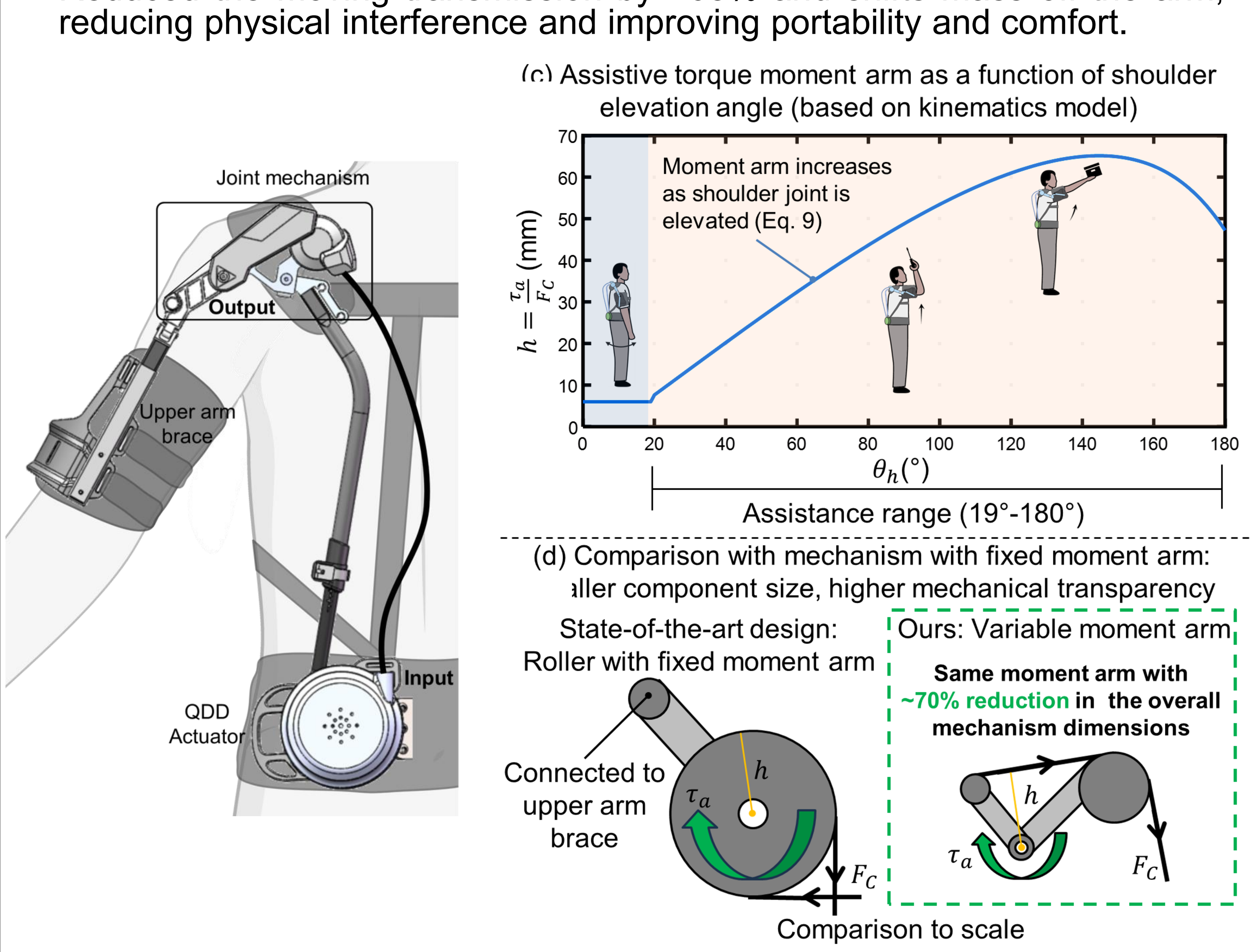
Bio-inspired Mechanism to Prevent Joint Misalignment

- Our design mimics scapulothoracic rhythm (upward rotation and protraction) so the device's instantaneous center of rotation follows the anatomical shoulder through elevation and reach, minimizing misalignment.



Variable Lever Arm Mechanism design

- Our design increased the cable moment arm with humeral elevation (≈71 mm at high angles), delivering higher shoulder torque where needed without raising motor current.
- Reduced the moving transmission by ~68% and shifts mass off the arm, reducing physical interference and improving portability and comfort.



Acknowledgment

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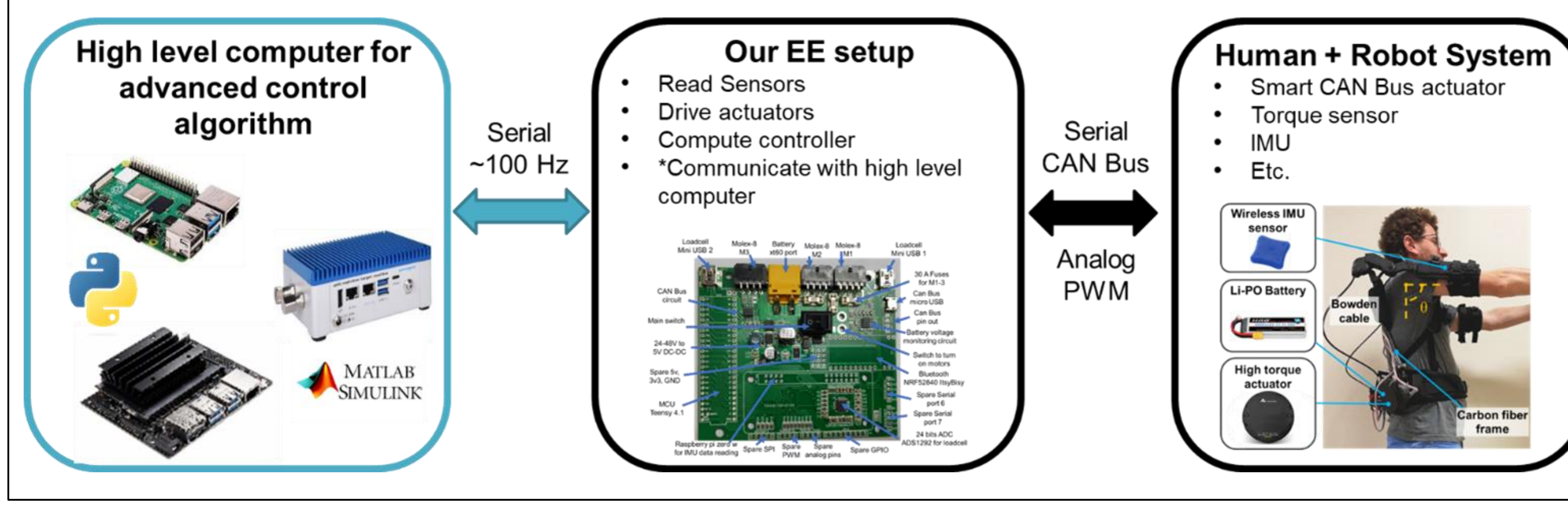
Reference

[1] J. Zhu, C. Jiao, I. Dominguez, S. Yu and H. Su, "Design and Backdrivability Modeling of a Portable High Torque Robotic Knee Prosthesis With Intrinsic Compliance for Agile Activities," in IEEE/ASME Transactions on Mechatronics, vol. 27, no. 4, pp. 1837-1845, Aug. 2022.
[2] S. Yu, T.H. Huang, D. Wang, B. Lynn, D. Sayd, V. Silivanov, Y.S. Park, Y. Tian, H. Su. "Design and Control of a High-Torque and Highly-Backdrivable Hybrid Soft Exoskeleton for Knee Injury Prevention during Squatting". IEEE Robotics and Automation Letters, Jul 26;4(4):4579-86., 2019.
[3] T. Huang, S. Zhang, S. Yu, M. MacLean, J. Zhu, A. Lallo, C. Jia, T. Bulea, M. Zheng and H. Su, "Modeling and Stiffness-Based Continuous Torque Control of Lightweight Quasi-Direct-Drive Knee Exoskeletons for Versatile Walking Assistance," in IEEE Transactions on Robotics (TRO), vol. 38, no. 3, pp. 1442-1459, Jun. 2022.

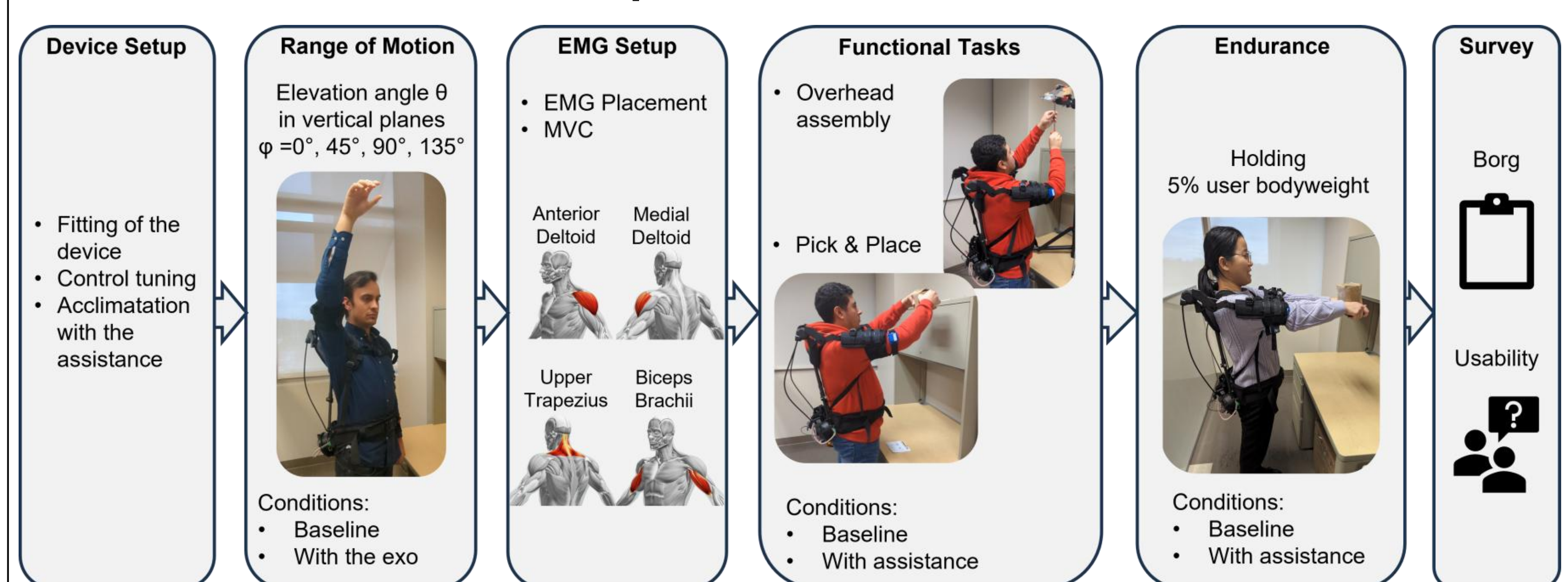
Portable and Expandable Electronics Architecture

- We proposed a powerful electronics architecture using a hierarchical structure with a high-level computer and a low-level microcontroller.
- Our customized high-torque density motor and compact customized electronics maximize the portability and can handle AI computation workloads with various interfaces for multi-sensor infusion.

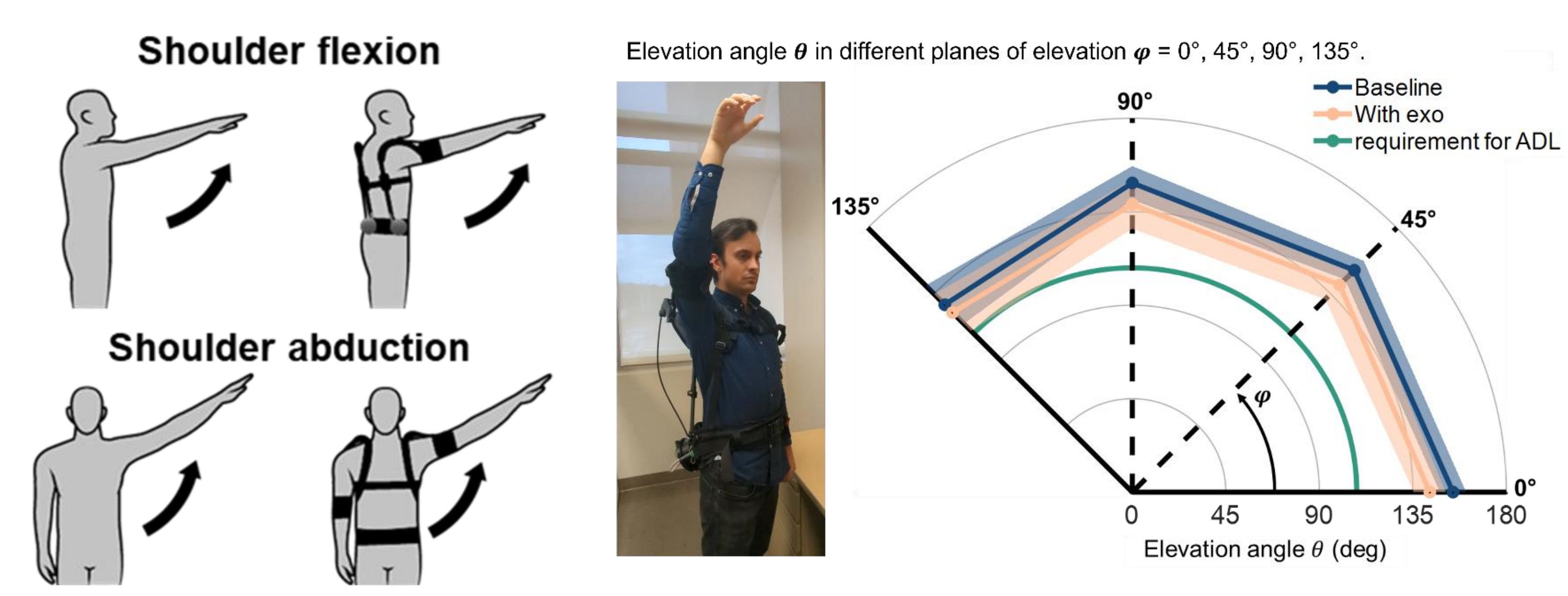


Experiment Results

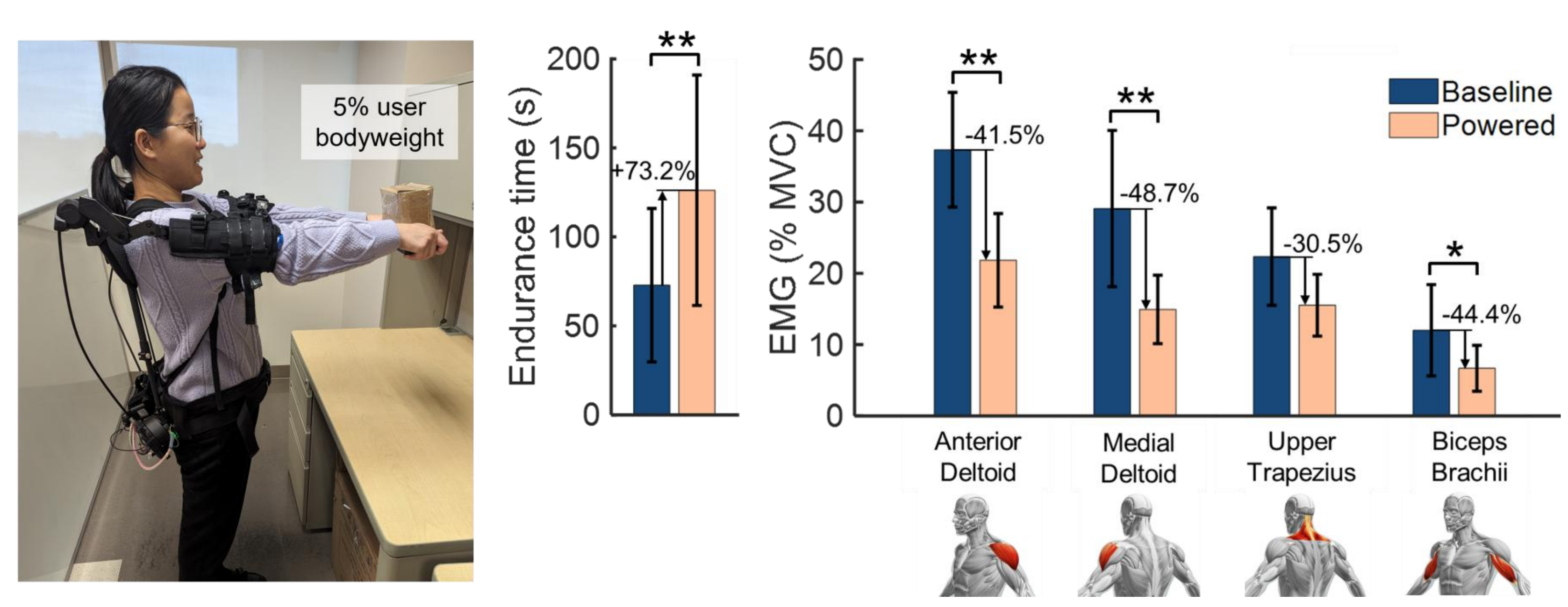
Experiment Protocol



- Our robot can assist both shoulder flexion, and abduction, with minimized reduction in range of motion (<8%) compared with no exoskeleton condition. Wearing the exoskeleton resulted in a slight reduction of the range of motion compared with the baseline condition (not wearing the device), but it did not compromise the possibility of performing most activities of daily living.



- The average endurance time increased from 73 s to 126 s (+73.2%) with assistance compared to not wearing the device. This result is supported by the fact that on average, the activity of recorded muscles significantly decrease



- For all the recorded muscles, muscle activity was reduced with exoskeleton assistance compared to the baseline condition without wearing the device. Average EMG reductions due to assistance were 52.8%, 65.2%, 26.4%, and 31.7% for anterior deltoid, medial deltoid, upper trapezius, and biceps brachii, respectively