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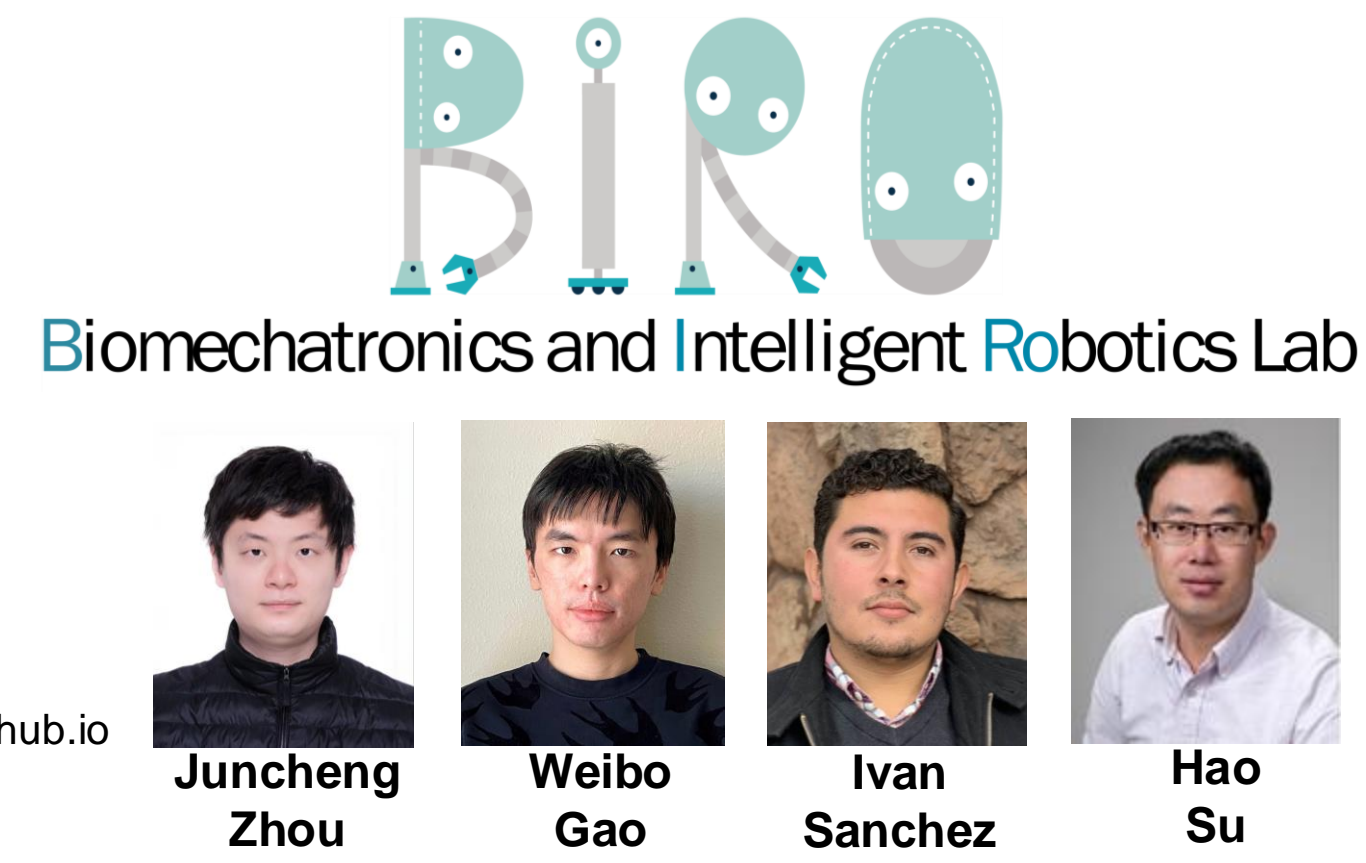
Experiment-Free Assistance of a Portable, Unobtrusive and Compact Hip Exoskeleton via Learning in Simulation

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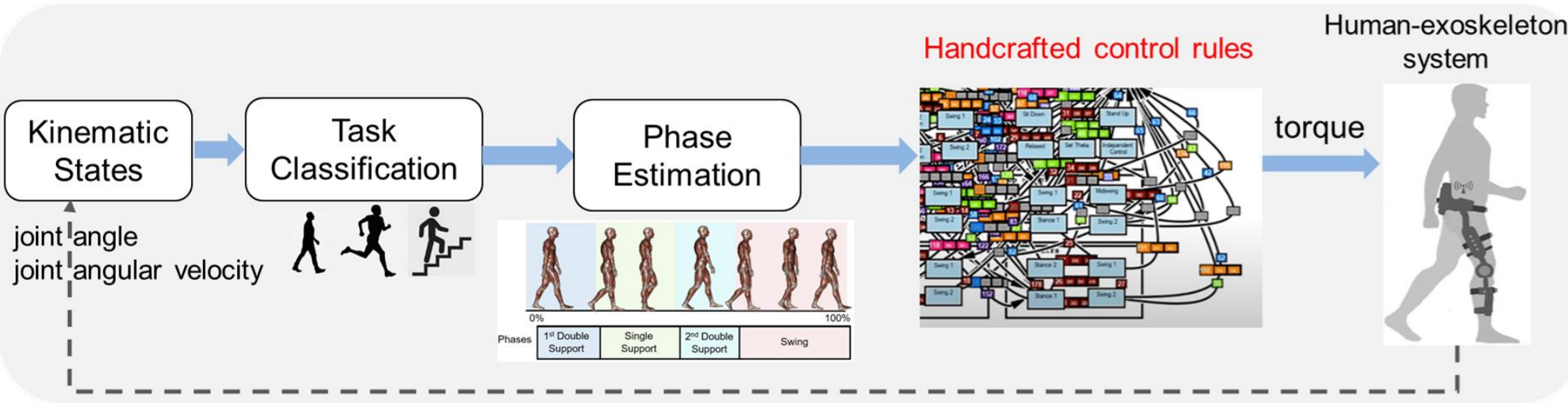


Website: <http://haosu-robotics.github.io>



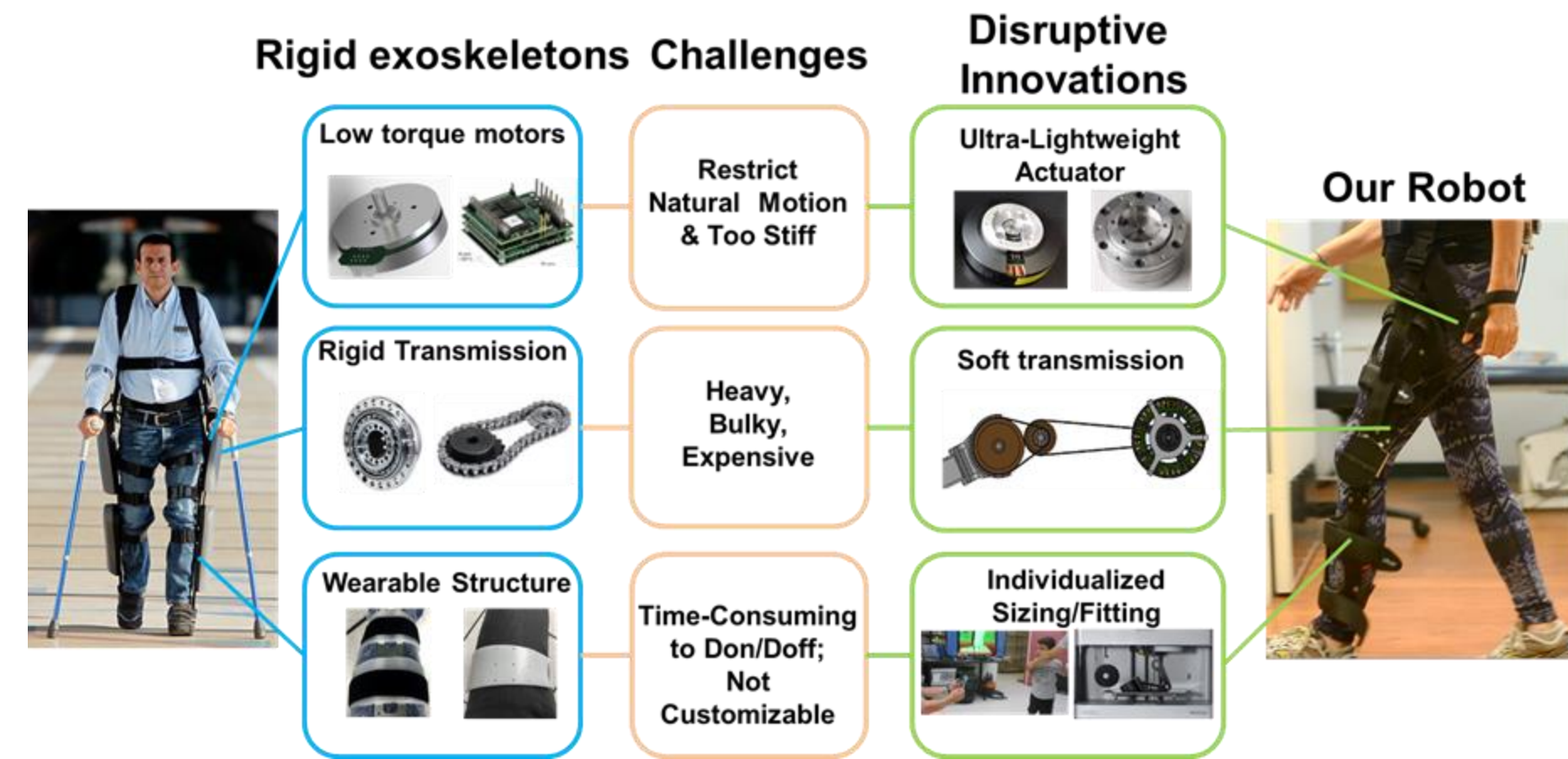
Objectives and Challenges

- Wearable robots like lower-limb exoskeletons have great potential for mobility restoration and human augmentation
- Challenge 1:** Required intensive human testing
- Challenge 2:** Required handcrafted control laws



Our Lightweight and High Torque Soft Exoskeleton

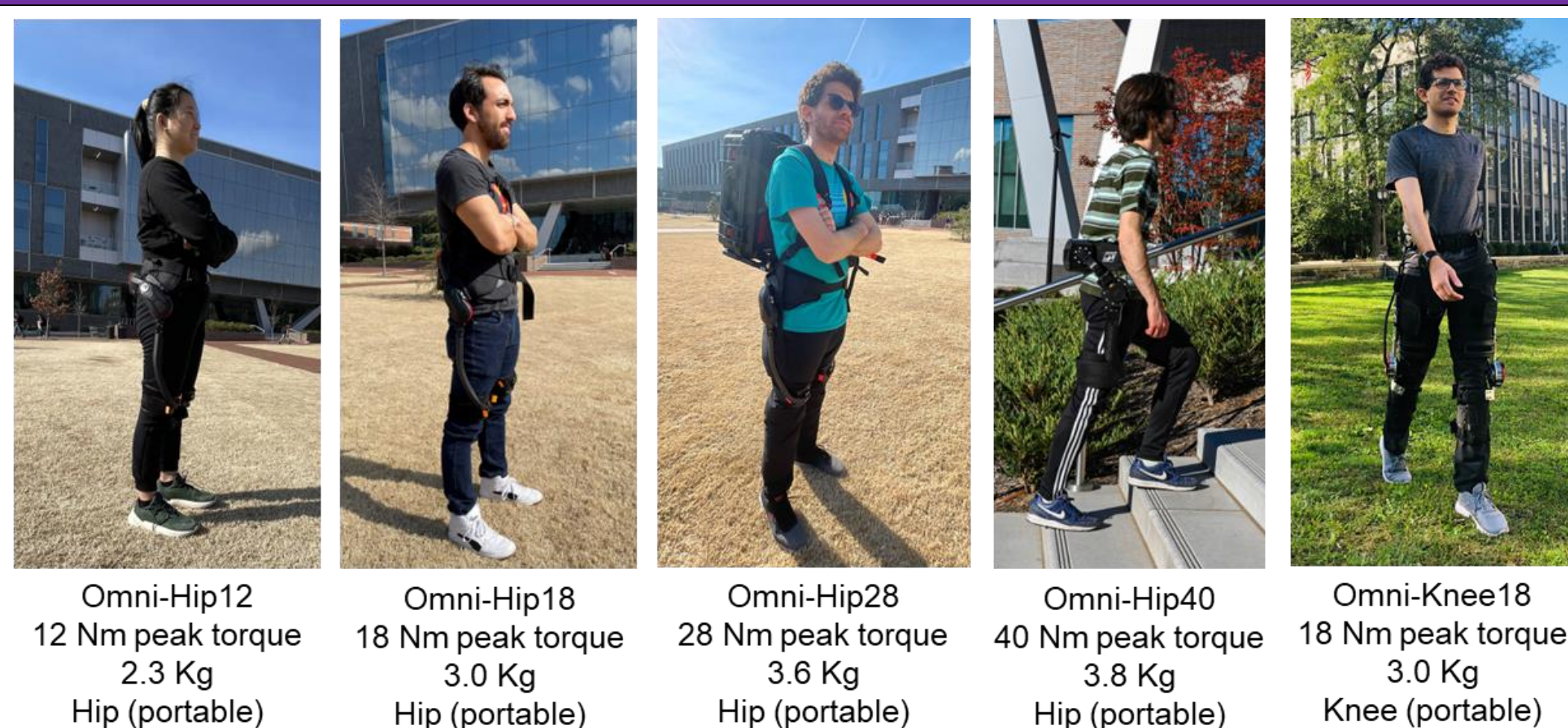
Paradigm Shift of Wearable Robots



Advantages of Our Soft Exoskeleton



Our Portable and Tethered Soft Exoskeleton Systems

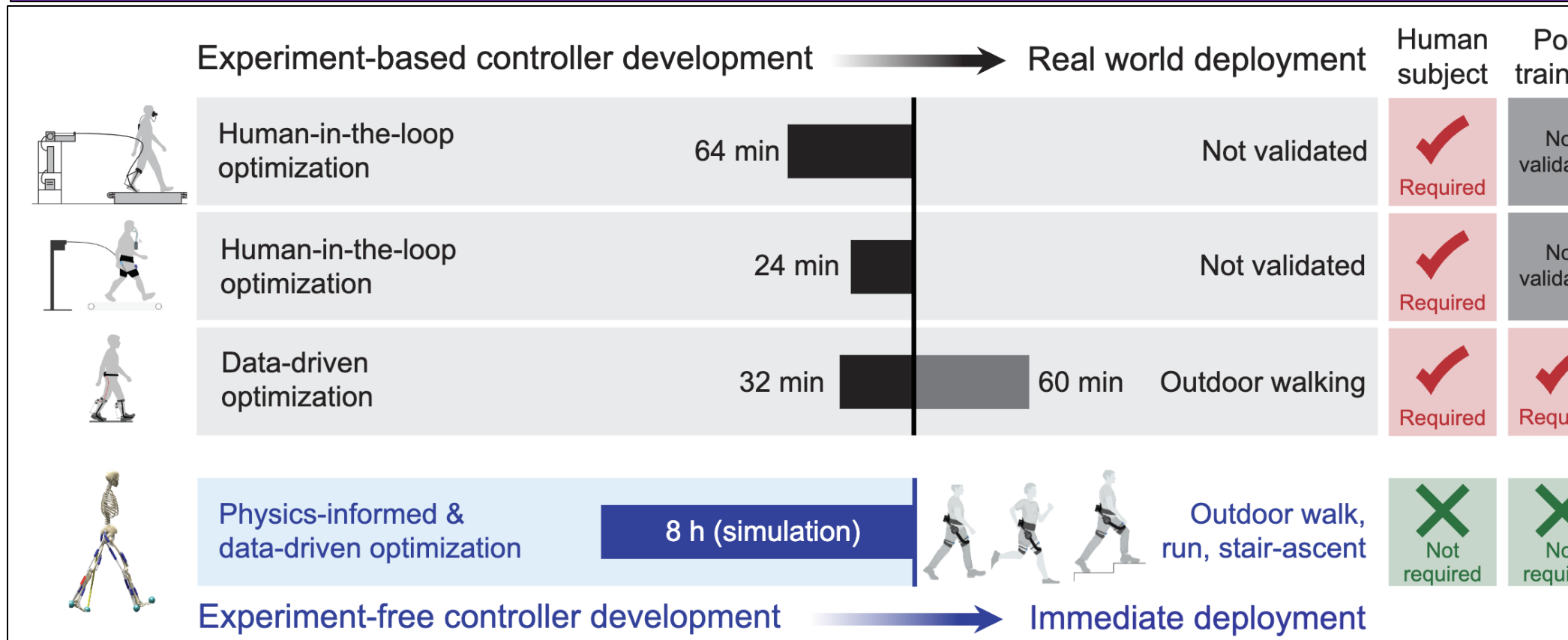


QDD Actuation Paradigm for Exoskeleton

New Actuation Paradigm for Co-Robots

	Geared Motor with Force/Torque Sensor	Series Elastic Actuator	Quasi Direct Drive Actuator [Ours] ^[7]
Compliance	Low ❌	Medium ⚠️	High ✅
Bandwidth	High ✅	Low ❌	High ✅
Efficiency	Low ❌	Medium ⚠️	High ✅
Actuation Paradigm	High ratio gear Conventional motor → Load	Conventional motor → Spring → Load	High torque density motor Low ratio gear → Load

Experiment-free Learning of Exoskeleton Controller In Simulation

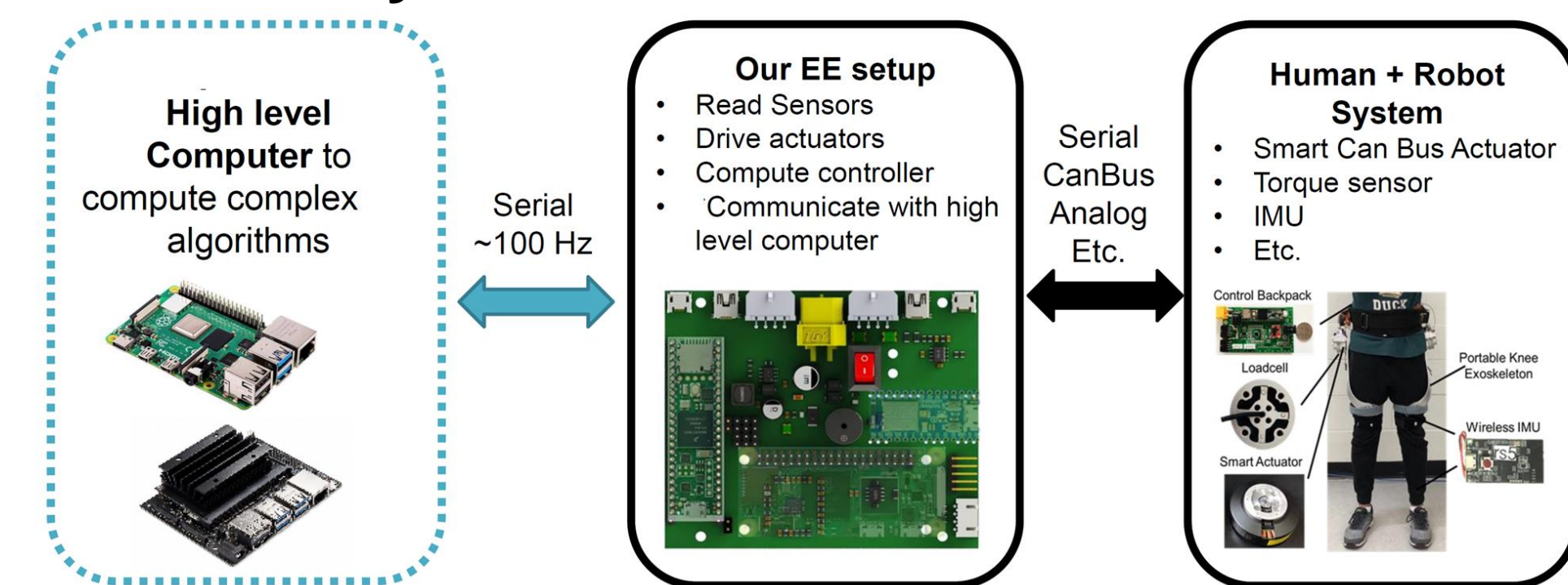


- Drawbacks of state-of-the-art methods to get exoskeleton controllers:
 - Requires intensive human experiments for training → This adds formidable cost when applied to another activity or participant
 - Typically for a single activity with steady-state motion → It cannot handle versatile activities or transitions between different activities
- Learning controllers entirely in simulation eliminates the need for human experiments. However, it is still unavailable for wearable robotics community. Key challenges are:
 - Incorporating controller design in the simulation
 - Incorporating human-robot interaction in the simulation
- Our Solution:**
 - Eliminates the need for human experiments, learns the exoskeleton controller purely from simulation, and provides immediate energetic benefit to humans
 - Provides synergistic assistance to different subjects for walking, running and stair-climbing

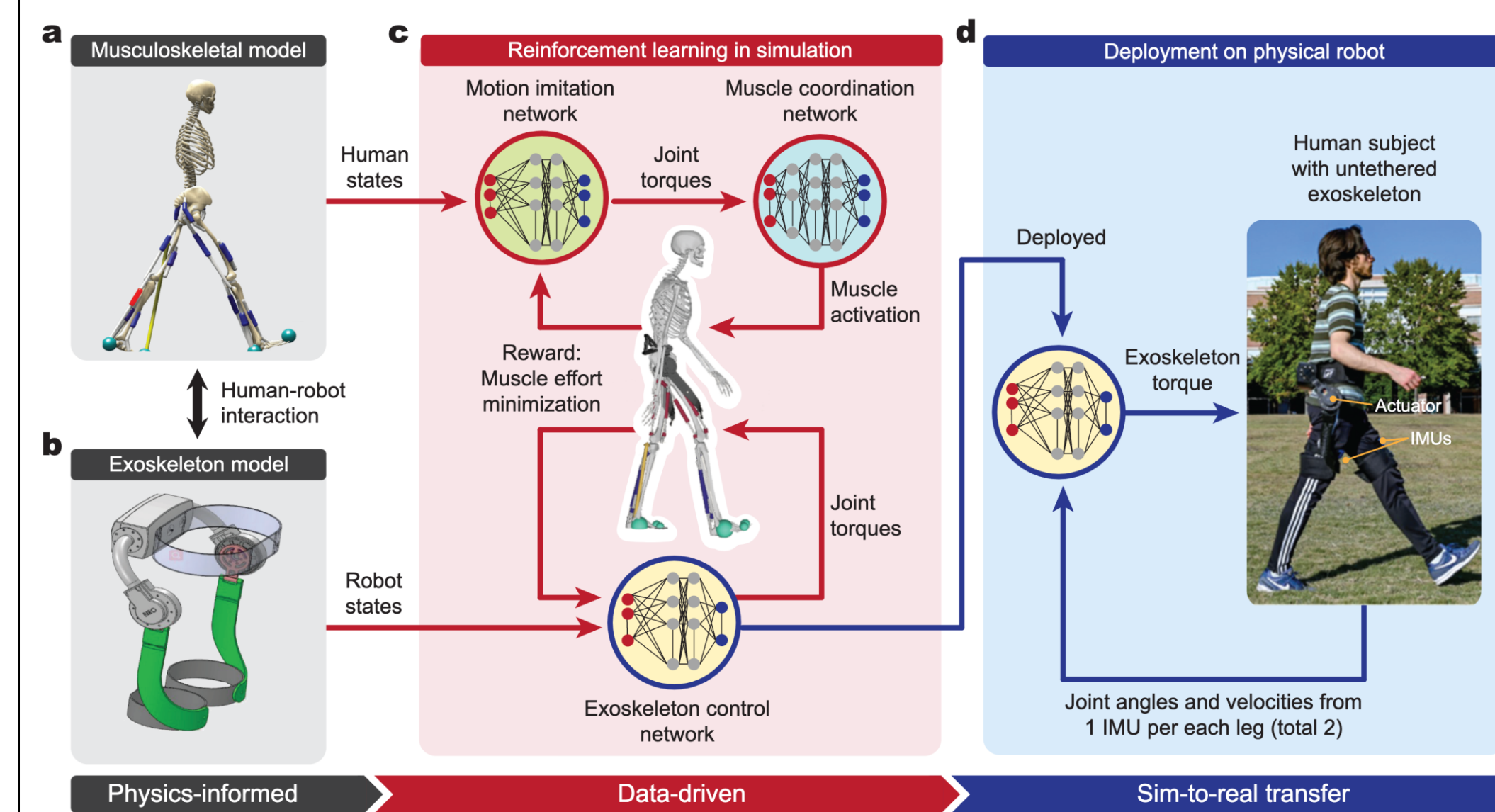
Portable Mechatronics Architecture

- We proposed a powerful electronics architecture using a hierarchical structure with a high-level computer and a low-level microcontroller.

System Control Architecture



Physics-informed And Data-driven Reinforcement Learning

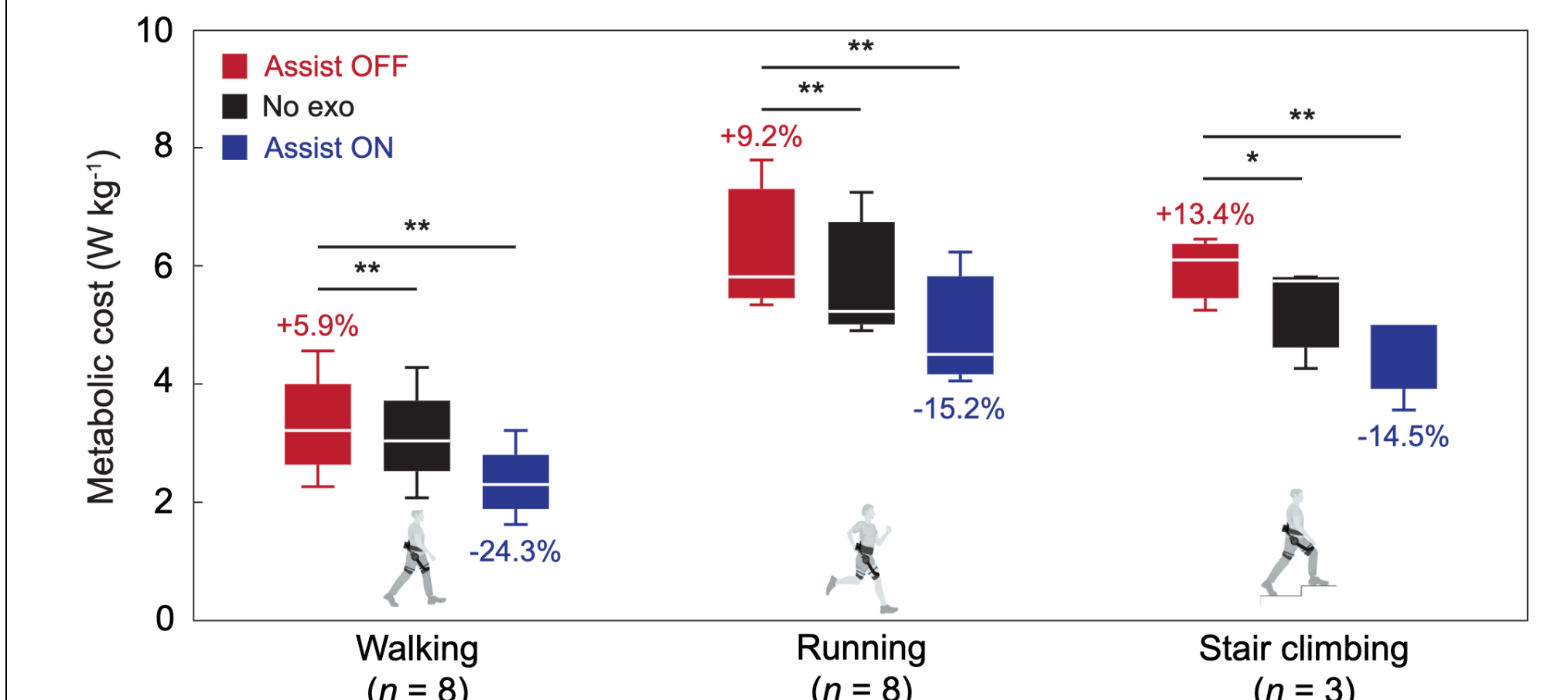


[1] S. Luo, M. Jiang, S. Zhang, J. Zhu, S. Yu, I. Dominguez Silva, T. Wang, E. Rouse, B. Zhou, H. Yuk, X. Zhou, and H. Su, "Experiment-free exoskeleton assistance via learning in simulation," *Nature*, vol. 630, no. 8016, pp. 353-359, Jun. 2024

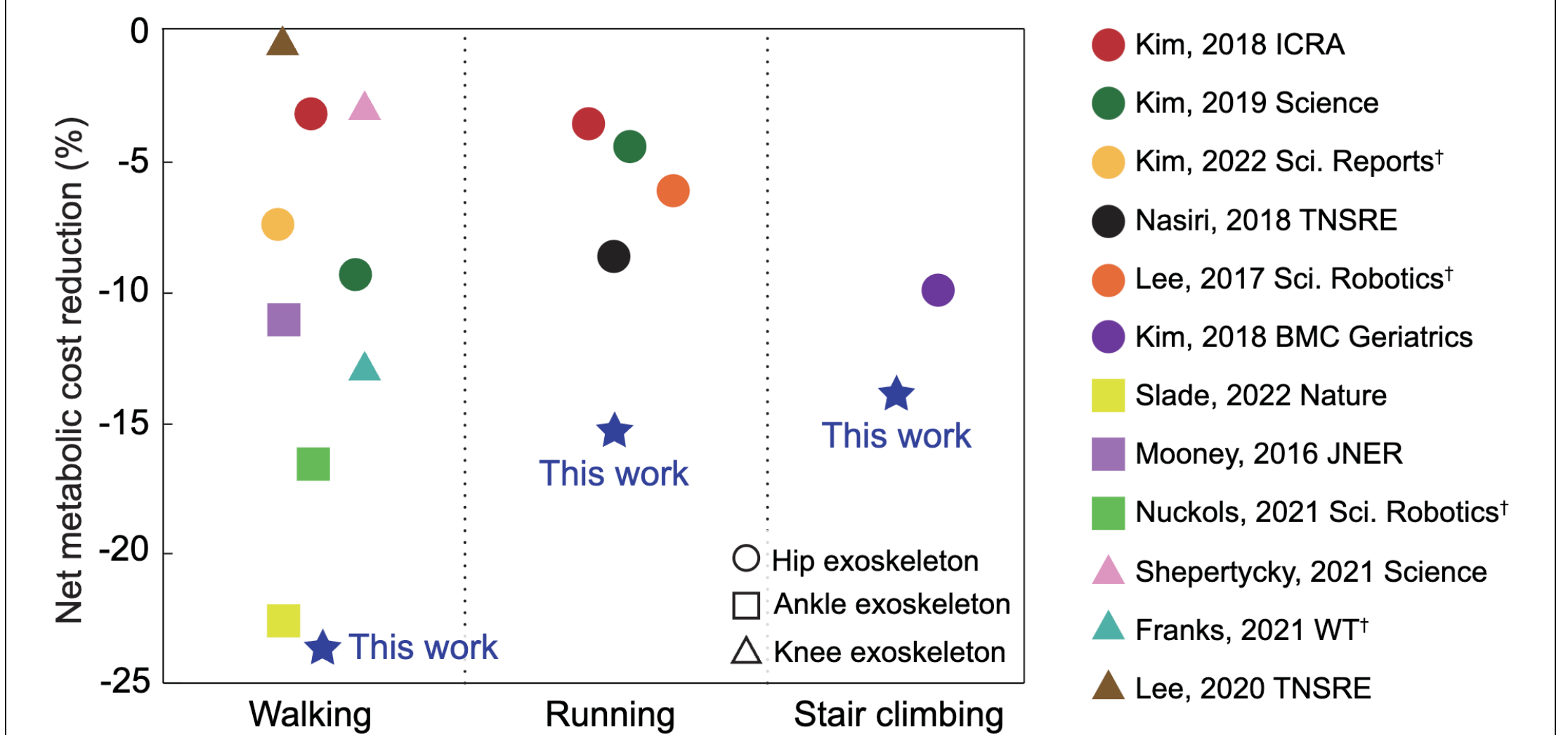
- Our learning method incorporates both physics-informed modeling and data-driven learning:
 - Physics-informed modeling of human musculoskeletal dynamics, exoskeleton, and human-robot interaction
 - Data-driven learning through publicly available human kinematic motion capture dataset
- Our learning method consists of three neural networks that are trained simultaneously for co-evolution:
 - Motion imitation network
 - Muscle coordination network
 - Exoskeleton control network
- Dynamics randomization was used to facilitate Sim-to-real transfer of the trained control policy

Significant Energetic Cost Reductions on Versatile Activities

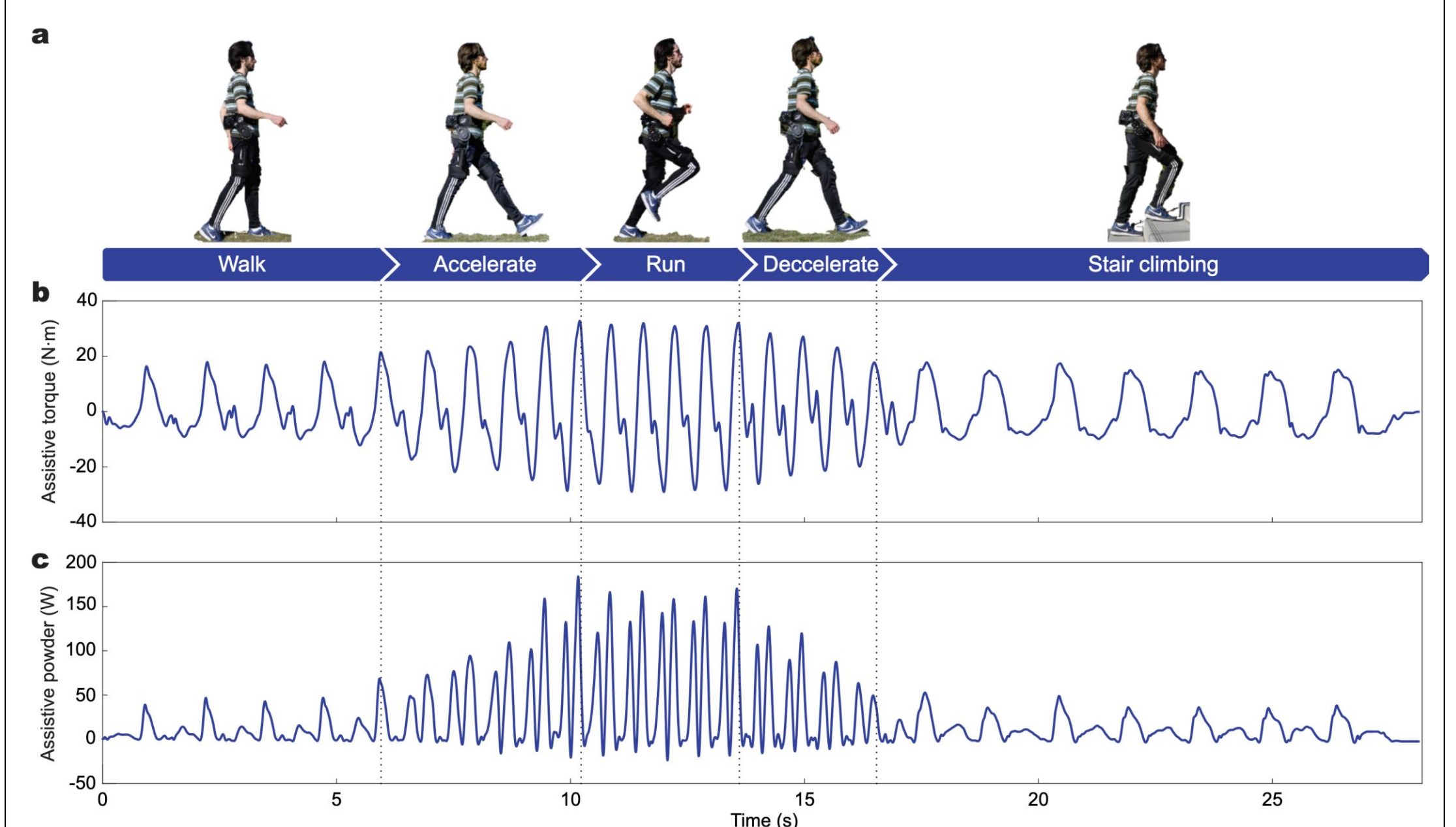
- 8 human subject (5 males, 3 females) experiments utilizing a lightweight, untethered and compliant hip exoskeleton
- Reduced significant metabolic cost by 24.3% for walking, 15.2% for running, and 14.5% for stair climbing



- More metabolic cost reduction than state-of-the-art robots



- Provides smooth transitions between different activities



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