Collaborative Research: NRI: INT: Customizable Lower-Limb Wearable Robot using Soft-Wearable Sensor to Assist Occupational Workers

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Goal: Personalization in lower-limb assistive wearable robots using human-in-the-loop (HIL) optimization to reduce the physical effort in intensive activities, thereby reducing injury.

Challenges

1) Inaccurate, slow physical effort estimation.

2) Error-prone, burdensome biofeedback sensors.

3) Evaluation for intensive activities.

Aim 1. Fast HIL optimization

- **The importance of personalized assistance for squatting was tested**
  - Developed fast model-free, phase-plane based metabolic cost estimation method (Fig. 1B) [1].
  - Implemented a squat assistance controller in a robotic ankle exoskeleton (Fig. 1 AD) [2].
  - Conducted human-in-the-loop optimization (Fig. 1)
  - The optimized assistance significantly reduced the metabolic cost of squatting (Fig. 2)
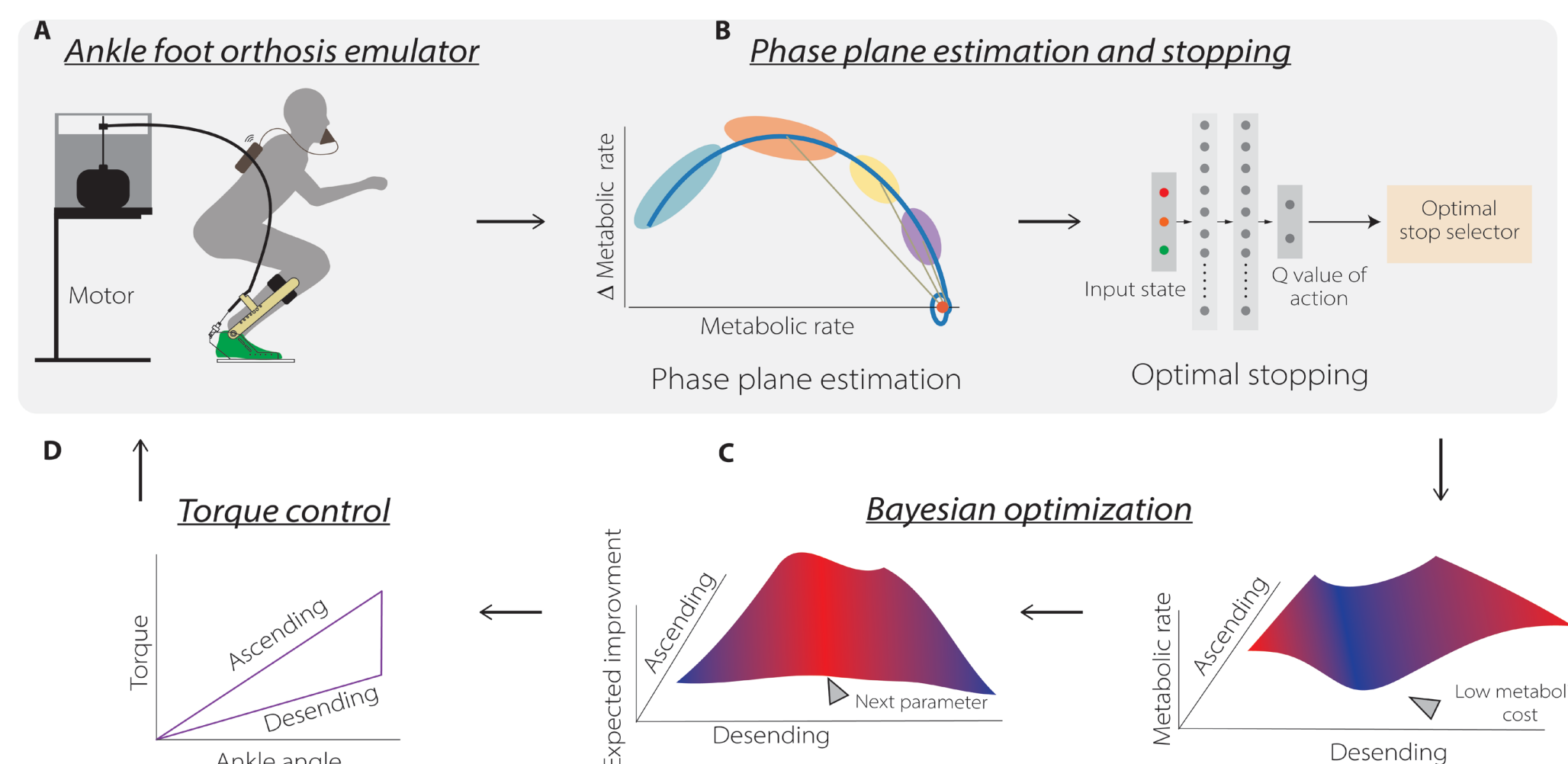

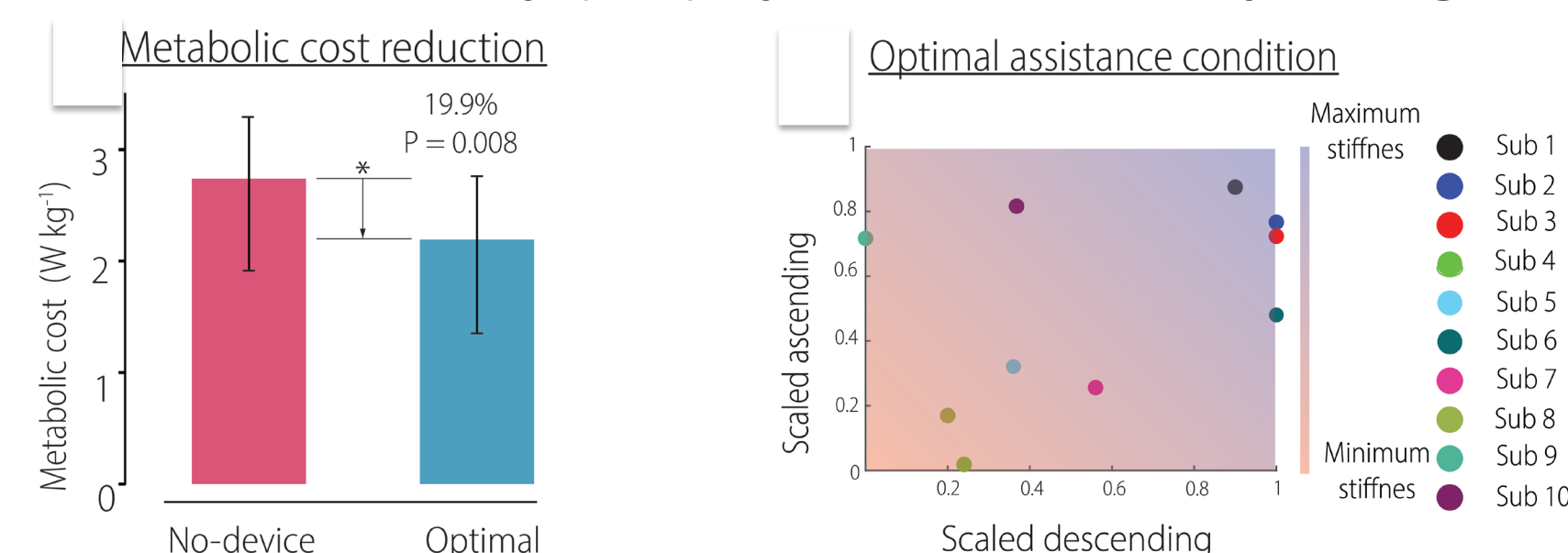Fig. 1 Human-in-the-loop (HIL) optimization for squatting.

Fig. 2 The optimized assistance reduced the metabolic cost of squatting (left). Each participant presented a different optimal assistance parameter set (right).

- **ECG metric can be an alternative measure**

$$RMSSD = \sqrt{mean[(RR\ Int._1 - RR\ Int._2)^2 + (RR\ Int._2 - RR\ Int._3)^2 + \dots + (RR\ Int._n - RR\ Int._{n+1})^2]}$$
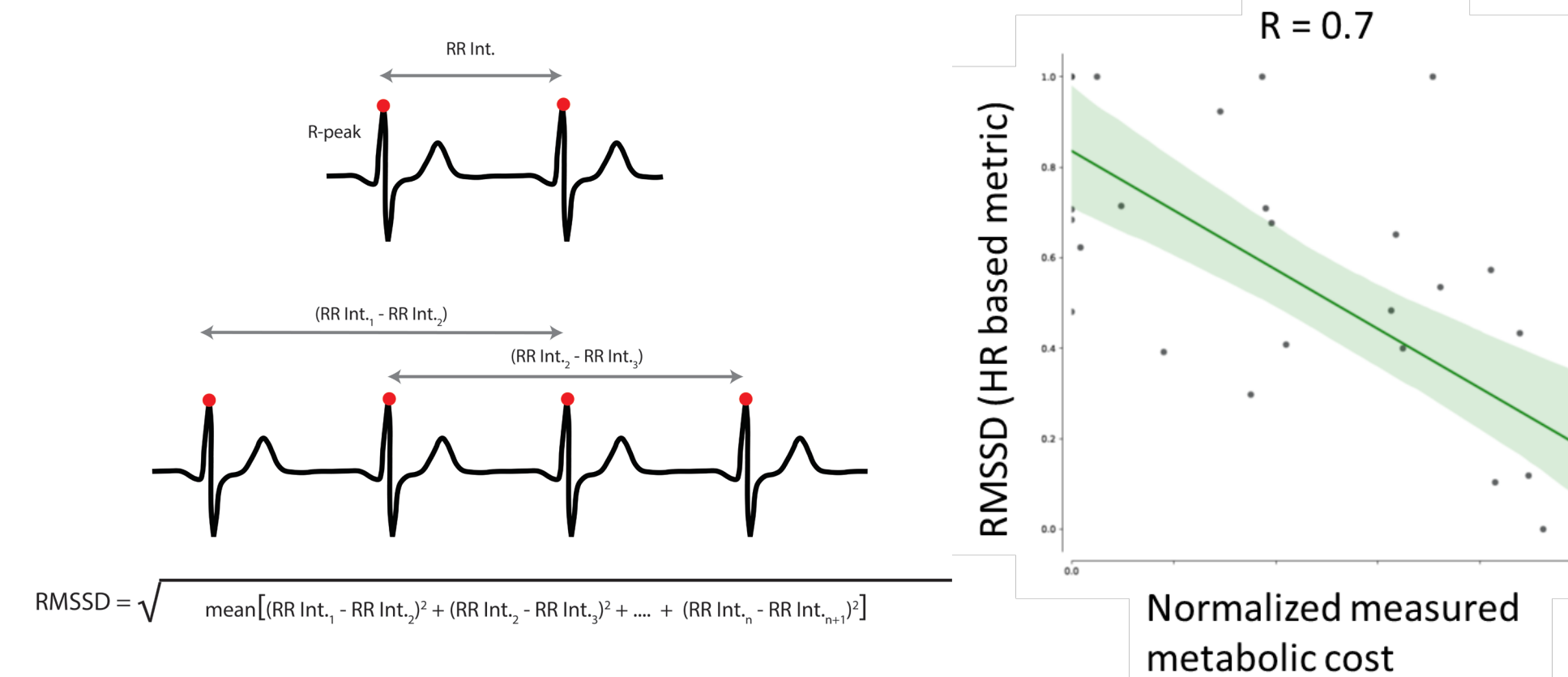
Fig. 3 RMSSD (left), an ECG measure, presented a high correlation to the metabolic cost of squatting (right).

- **Metric using EMG can be an alternative**
  - The optimized assistance reduced activities of muscle synergies (muscle coordination patterns) [3]
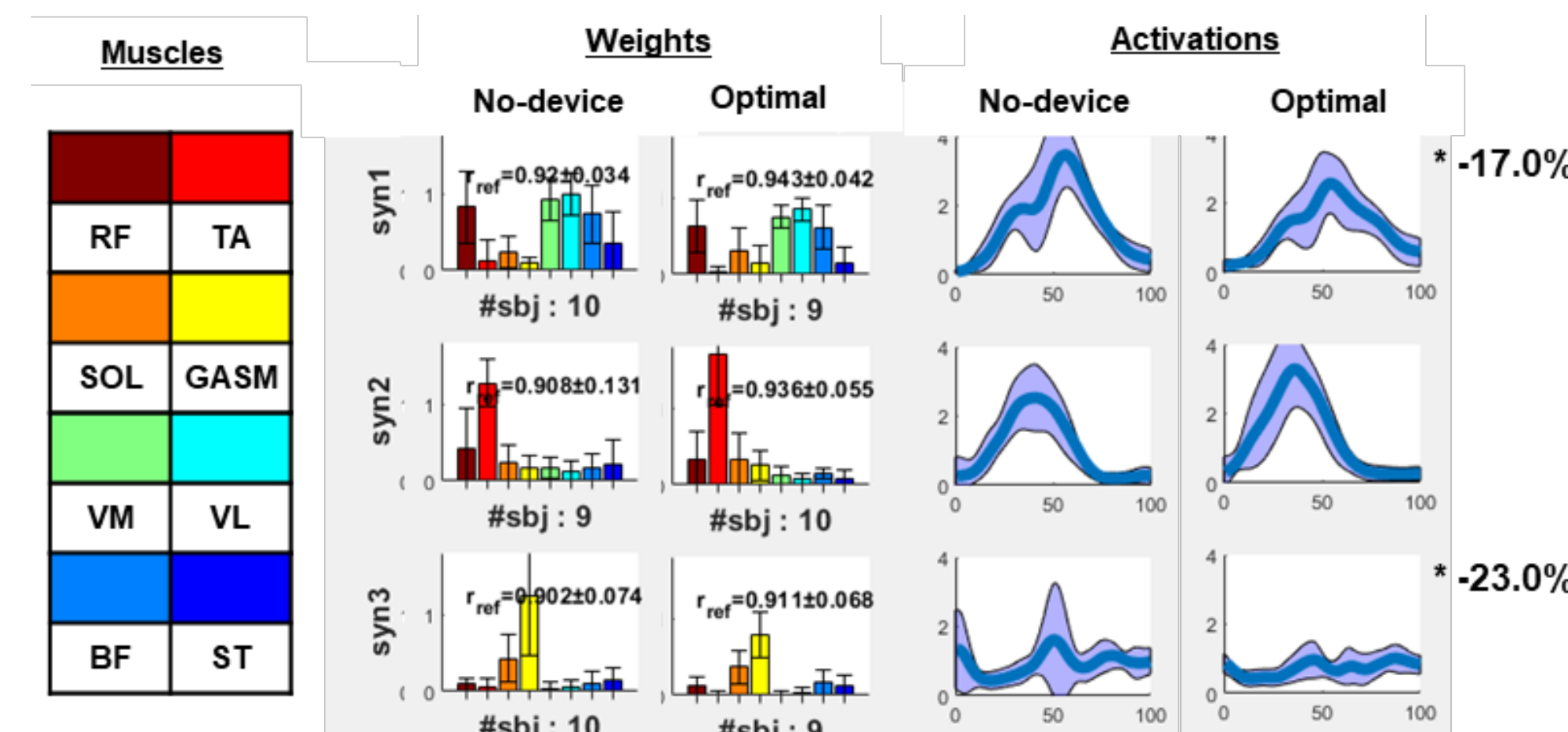

Fig. 4 Muscle coordination and activation patterns during squatting for the no-device and optimized assistance conditions.

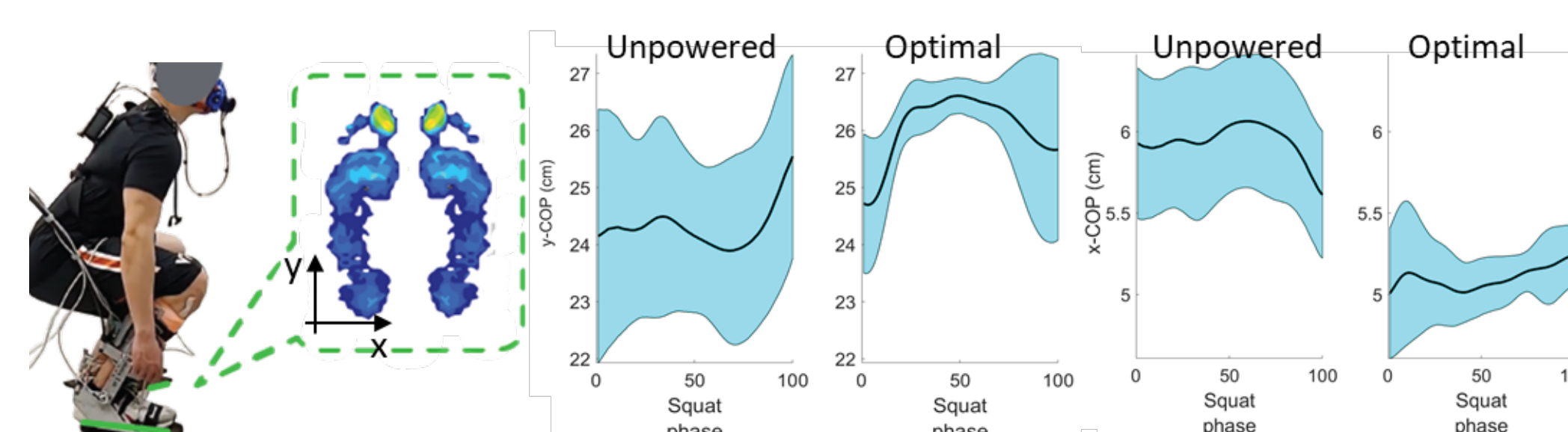- **A pressure sensor can be a potential measure**

Fig. 5 Personalized assistance appears to change CoP variability [4].

Aim 2: Soft wearable electronics

Fig. 5 Bulky Commercial calorimetric devices and soft wearable electronics (red circle). [5]
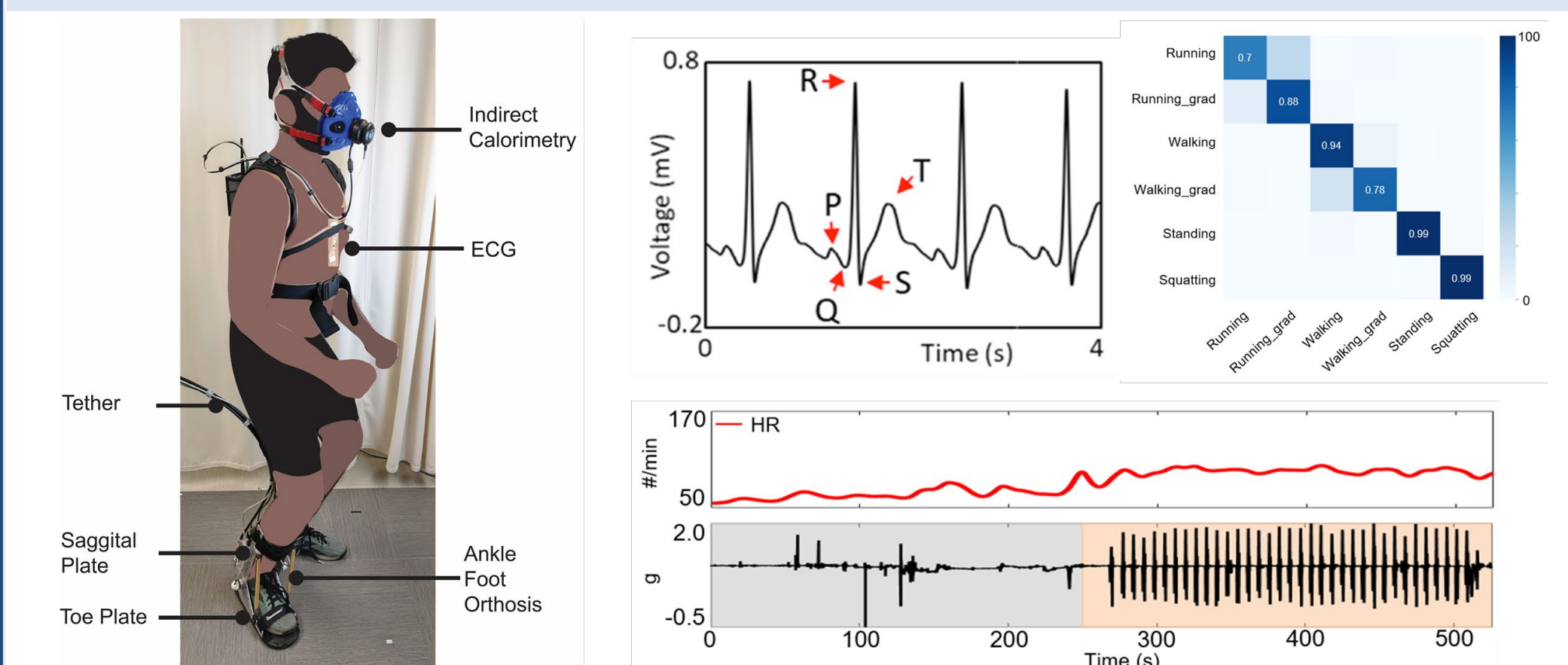
Aim 3: Seamless integration & evaluation

Fig. 6 AFO and biopatch with calorimetry mask (left) and bio-signal from soft wearable electronics (right) [5].

Impact: Science & Technology, Applications / Education

- Efficient physical effort estimation for customizing assistance to assist workers.
- Integrates research & education via projects with improved infrastructure
- Wireless, soft wearable electronics, applicable for diagnosis and monitoring.

References
[1] Kantharaju and Kim, in review
[2] Kantharaju et. al., in review
[3] Jeong et.al., in preparation
[4] Ramadurai et.al., in review
[5] Kim et. al, in preparation.