Leg Isoinertial Measurement Brace (LIMB):
A Portable System for Quantifiable Musculoskeletal Assessment

Nathan D. Schilaty, Jacob Loufek, Aidan M. Foy, Benjamin Keister, David Botero

Background

- Objective assessment of lower extremity neuromotor control essential for: [1]
  - Musculoskeletal injury management
  - Rehabilitation
  - Return-to-duty decision making
- Existing assessment technologies are predominantly *isometric* or *isokinetic* dynamometers (**Fig. 1**)
  - Large (~64 ft^2)
  - Costly (>$50K)
  - Restricted to fixed environments
- Portable alternatives rely on clinician applied force
  - Measurement subjectivity
  - Limited reproducibility
- Leg Isoinertial Measurement Brace (**LIMB**) developed to (be):
  - Clinician independent
  - Wearable *isoinertial* assessment platform[2]
  - Deliver quantifiable and repeatable torque loading in austere and far forward environments

Objectives

- Describe functional limitations of existing isometric / isokinetic musculoskeletal assessment devices in austere environments.
- Analyze wearable, motor driven *isoinertial* torque delivery for objective and reproducible neuromotor assessment.
- Discuss the operational and clinical relevance of portable torque-measuring systems for rehabilitation and return-to-duty decisions.

Figure 1: On-Market Isokinetic / Isometric Muscle Measurement Devices. A variety of current options for measuring muscle force / torque. Footprints of the devices vary from small to large. Some devices require practitioner-dependent counterforce. (From left to right: *HumacNORM, VALD DynaMo, BTE Primus RS, Biodex 3, MicroFET2*.

Methods

Brace-Mounted System

- Brushless DC motors
- Dual *ODrive* S1 controllers (M8325 motor kits)
- (2) TRS-2K strain-gauge torque sensors

Programmable *Isoinertial* Torque

- Simultaneously record torque during active user resistance
- Enable real-time biomechanical stiffness assessment

Wearable Design

- Objective torque application without reliance on practitioner-dependent force

Device Footprint

- < 3 ft^2 (0.28 m^2)
- Capable of field / military theater setting

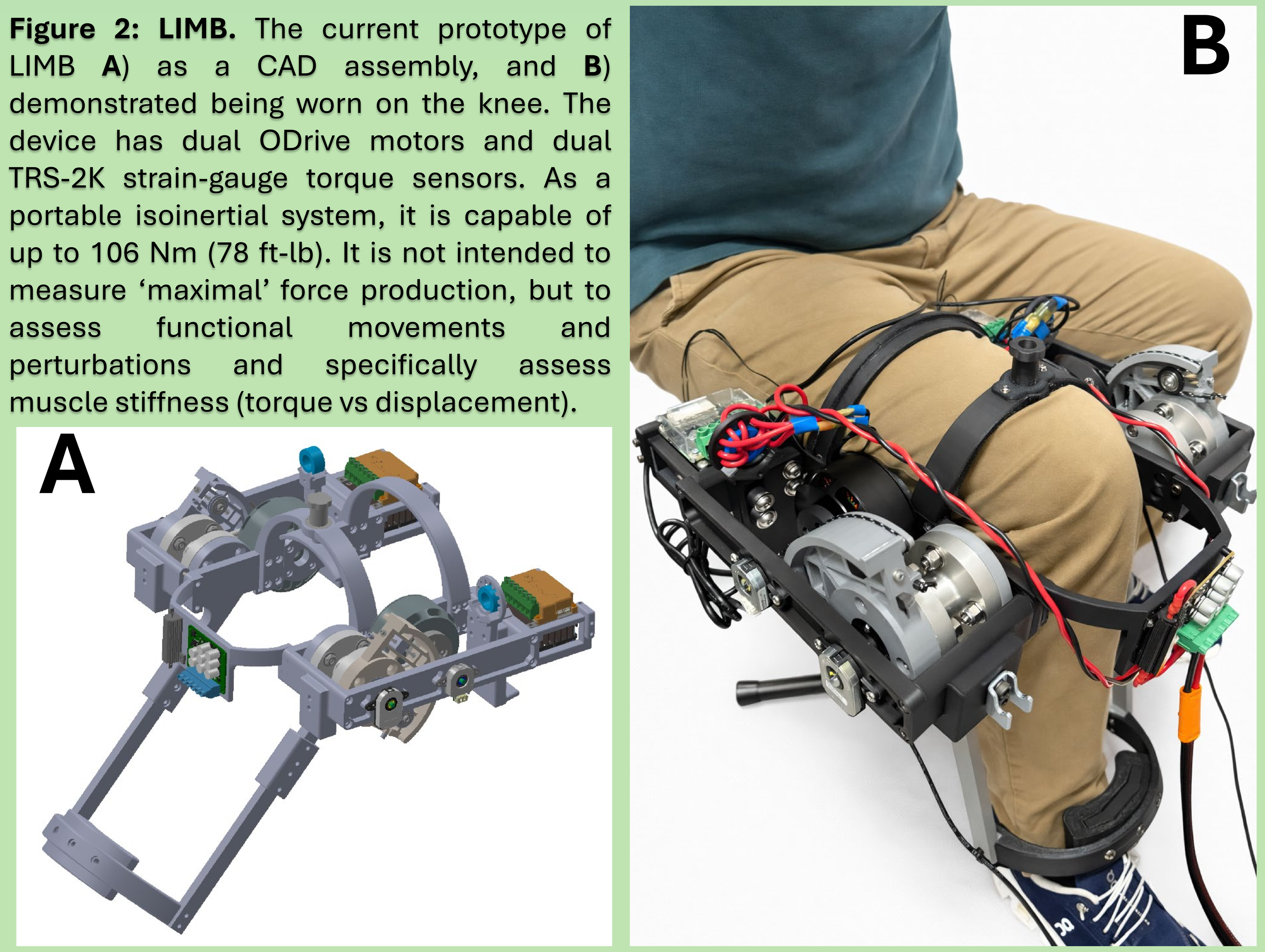
Operational Requirements

- Compare against existing commercial systems (**Fig. 1**)
  - *Biodex System 3 or 4*
  - *HumacNORM*
  - *Vald DynaMo*
  - MicroFET2

Reliability

- (5) output curves assessed in *SPSS v30*

Figure 2: LIMB. The current prototype of LIMB **A**) as a CAD assembly, and **B**) demonstrated being worn on the knee. The device has dual ODrive motors and dual TRS-2K strain-gauge torque sensors. As a portable isoinertial system, it is capable of up to 106 Nm (78 ft-lb). It is not intended to measure 'maximal' force production, but to assess functional movements and perturbations and specifically assess muscle stiffness (torque vs displacement).



Results

- LIMB delivered consistent and custom programmable torque profiles across alterable force configurations

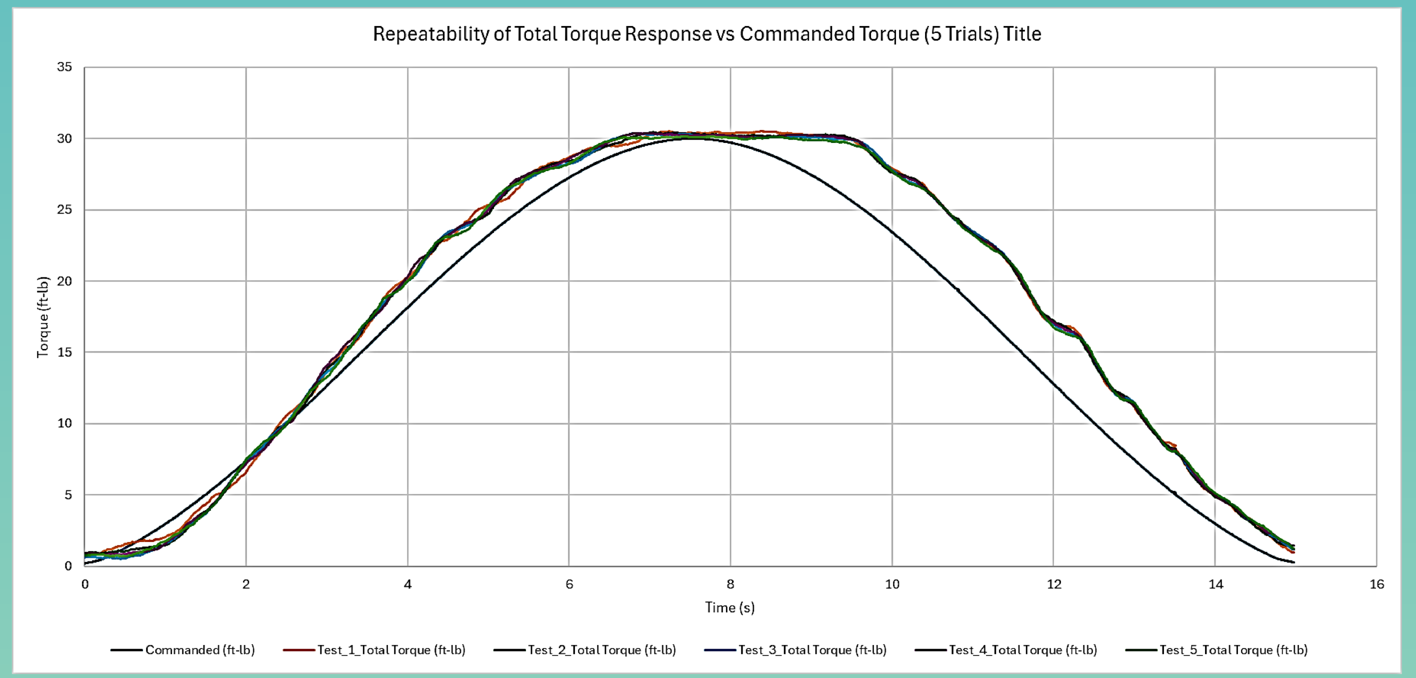


Figure 3: Command vs Delivered Torque. The dual LIMB motors deliver a consistent and reproducible torque curve.

- LIMB maintained real-time torque capture (n=5)
  - **Cronbach's α = 1.000** (p<0.001)
- Median error **2.4 [0.8, 4.8] Nm** command vs. delivered torque
- Compared with fixed dynamometry systems (~64 ft^2, 5.95 m^2), LIMB operates within ~3 ft^2
  - **95.3% reduction** in operational footprint

Conclusion

- LIMB → novel wearable *isoinertial* assessment system
  - Enables **objective and replicable evaluation** of lower extremity neuromotor control
  - Small footprint
  - Not reliant on clinician force (↑ reliability)
- Applied torque is quantifiable and repeatable across trials
- Ongoing clinical validation will further characterize:
  - Torque time behavior
  - Repeatability
  - Sensor fidelity under loading conditions representative of rehabilitation tasks
- LIMB's small footprint, portability, and quantitative torque control **support musculoskeletal monitoring in deployed, austere, and resource limited care environments**

Acknowledgements

Funding provided by the Florida Department of State Center for Neuromusculoskeletal Research and Florida High-Tech Corridor Early-Stage Innovation.

References

[1] Aerts et al. Reliability and Agreement of Hand-Held Dynamometry Using Three Standard Rater Test Positions. *Int J Sports Phys Ther*. 2025;20(2):253-262.

[2] Schilaty ND et al. Neuromotor control associates with muscle weakness observed with McArdle sign of multiple sclerosis. *Ann Clin Transl Neurol*. 2022;9(4):515-528.