Real-time Continuous Calibration of an EMG-Informed Neuromusculoskeletal Model for Assistive Exoskeleton Control

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BACKGROUND

Exoskeletons aid rehabilitation for neurological impairments, (e.g., spinal cord injury and stroke) [1], by integrating user intent into control for optimal outcomes [2]. Exoskeleton control can be informed by electromyography (EMG) via neuromusculoskeletal (NMS) models that capture complex neuromuscular dynamics to predict personalized muscle forces and joint moments [3]. These models are limited in real-time use as they require a lengthy calibration process.

AIMS

Reduce calibration time using an auto-differentiable NMS model [4] and enable real-time, continuous calibration for adaptive and personalized exoskeleton control.

METHODS

Participants performed a reaching task on an ArmeoPower exoskeleton, with EMG and exoskeleton data processed to drive an NMS model [4], predicting moments for proportional torque control (Fig. 1). Four calibration and control configurations were tested: 1) **Unassisted:** no assistive torque; 2) **Uncalibrated:** NMS model with no calibration; 3) **Offline Calibrated:** pre-calibrated to user offline; and 4) **Continuous Calibration:** model calibrated online. Muscle synergies were used post-hoc to synthesize missing EMGs to assess improved moment tracking.

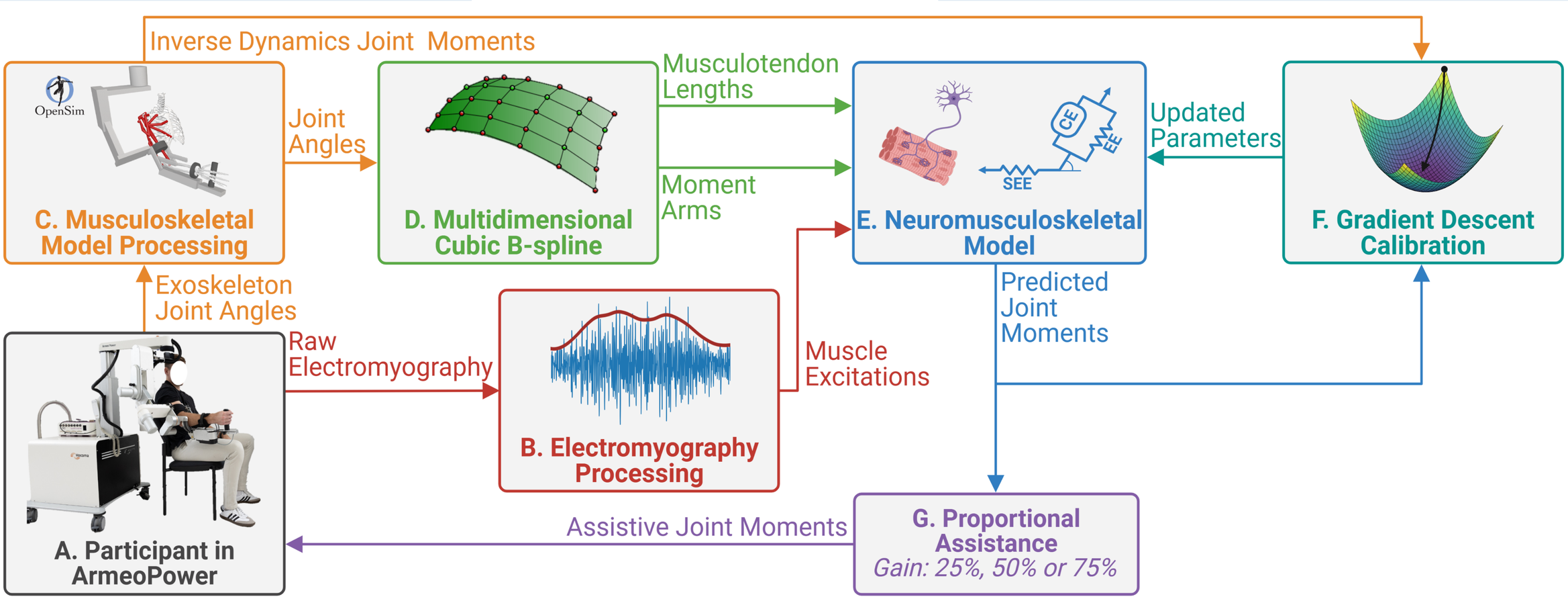


Figure 1: Overview of experimental setup for NMS model calibration and assistive control of an upper limb exoskeleton (ArmeoPower, Hocoma)

RESULTS & CONCLUSIONS

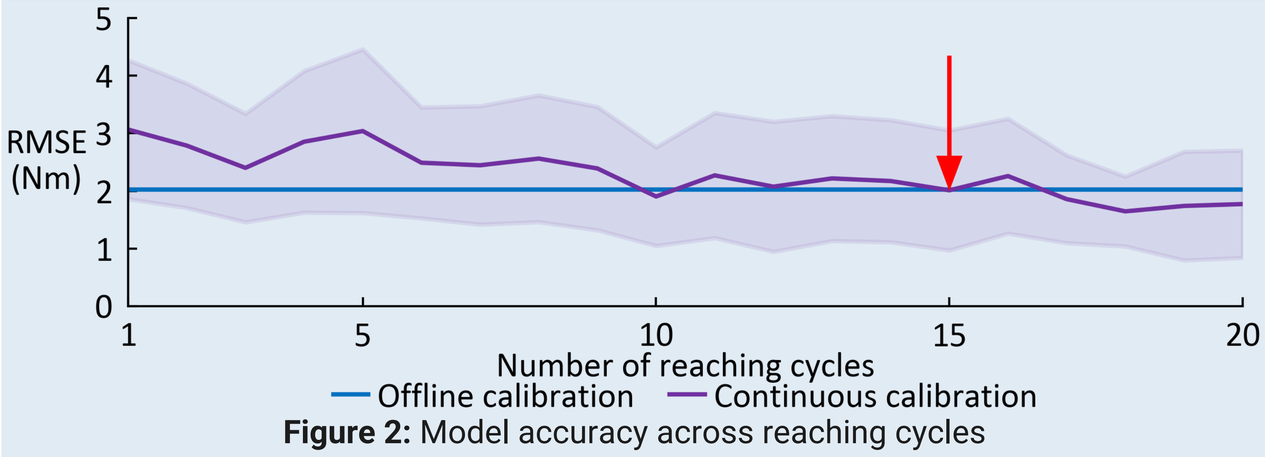


Figure 2: Model accuracy across reaching cycles

Removes need for slow offline calibration

The continuously calibrated model has the same accuracy to offline calibration in ~15 movement cycles (Fig. 2 see red arrow), which is less than 110 seconds, much faster than traditional offline calibration which can take hours

NMS models enhance exoskeleton control

Calibrated models provided torque assistance, decreasing time taken to perform each reaching task (Fig 3a), leading to more completed tasks in each 120 second trial (Fig 3b), while maintaining smooth hand movements—zero being more smooth and -16 less smooth (Fig 3c).

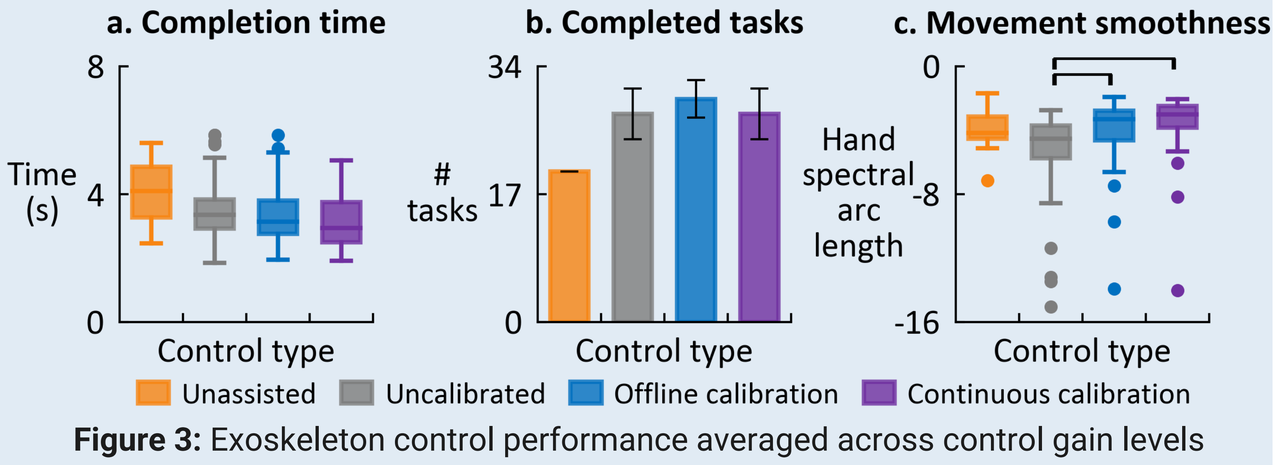


Figure 3: Exoskeleton control performance averaged across control gain levels

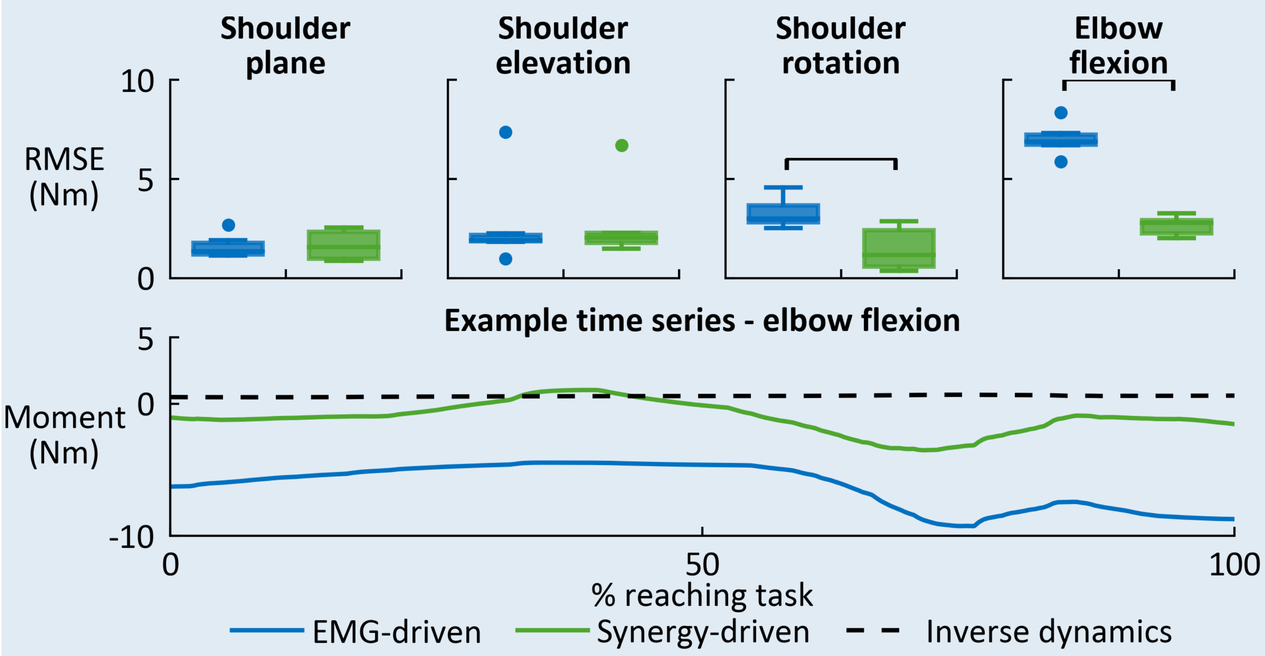


Figure 4: Moment tracking using offline EMG- and synergy-driven models

Need to include unrecorded excitations

Muscle synergies can be used to synthesize excitations for improved predictions of inverse dynamics moments (Fig. 4)

References

1. Mekki et al., Neurotherapeutics, 15(3) 604-617, 2018
2. Volpe et al., Curr Atheroscler Rep, 6(4) 314-319, 2004
3. Lloyd & Besier, J Biomech, 36(6) 765-776, 2003
4. Hambly et al., DOI:10.36227/techrxiv.173203595.54398588/v1, 2024

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