Analysis of Induced Muscle Activations by an Affordable, Reconfigurable Robot for Comprehensive Post-Stroke Rehabilitation

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TAKEAWAY: Our preliminary results indicate that the Rehab CARES TheraDrive reconfigurable robot induces different muscle activation patterns in its three positions but does not prevent the user from employing compensatory strategies, suggesting that **1-DoF robots are a promising platform for low-cost rehabilitation exercise and characterizing pathological movements**.

INTRODUCTION

- **Post-stroke upper-limb impairments** impact millions of people worldwide.
- **Low degree-of-freedom (DoF) robots** have the potential to provide more **affordable and accessible rehabilitation**, but there is concern that sacrificing complexity could reduce the efficacy of robotic rehabilitation.
- We introduce **the reconfigurable Rehab CARES system**, an expansion of the **Haptic TheraDrive robot**, and investigate if 3 different robot positions, which simulate activities of daily living (ADL), activate different muscles (as measured by surface electromyography, or sEMG) to provide comprehensive arm exercise.

METHODS

Rehab CARES System Design: The Rehab CARES project uses multiple **affordable, reconfigurable 1-DoF TheraDrive robots** to provide community-based, **post-stroke therapy in 3 distinct positions** (***Fig. 1***).



Pos. 1 (Reach-to-Grasp) *Pos. 2 (Wiping a Table)* *Pos. 3 (Turning a Door Handle)*

Fig. 1: *The TheraDrive robot in each of its 3 ADL-inspired configurations. In Pos. 1, the expected movement is shoulder and elbow flexion/extension. In Pos. 2, the expected movement is shoulder abduction/adduction. Pos. 3 expected movement is wrist pronation/supination.*

Participants: **11 individuals with hemiparesis** from stroke (age 60 ± 10 years, 4F/7M) were recruited to complete a preliminary feasibility study with the TheraDrive.

Experimental Protocol: Data were collected during a larger validation study consisting of 3–4 experimental days for each participant: 1 clinical assessment day; 1–2 days performing robot-based assessment tasks, **range-of-motion (ROM) movements**, and therapy games; and 1 day of qualitative interviews. In this paper, we only analyze **data from ROM trials**. All participants were outfitted with sEMG sensors on their impaired arm (***Fig. 2***, ***Table I***).

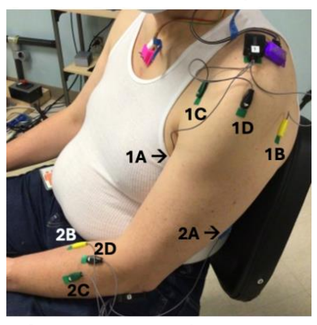


Fig. 2: *sEMG placement.*

Table I: *Sensor placement and activating motions.*

ID	Location	Expected Activating Motions
1A	biceps brachii	shoulder flex, elbow flex, wrist sup
1B	posterior deltoid	shoulder (ext, ex-rot)
1C	anterior deltoid	shoulder (flex, in-rot)
1D	middle deltoid	shoulder abd
2A	triceps brachii (long head)	shoulder (ext, add), elbow ext
2B	wrist flexor bundle	wrist flex
2C	wrist extensor bundle	wrist ext
2D	brachioradialis	elbow flax, wrist (pro, sup)

Data Analysis: Participants were split into two groups based on Fugl-Meyer Upper Extremity score (FM): moderate/severe impairment (n = 3, FM ≤ 50) and mild impairment (n = 8, FM > 50). sEMG data were processed according to a standard procedure (***Fig 3***). Area under the curve (AUC) was used to calculate overall muscle activations. Mann-Whitney U tests were used for statistical analysis.

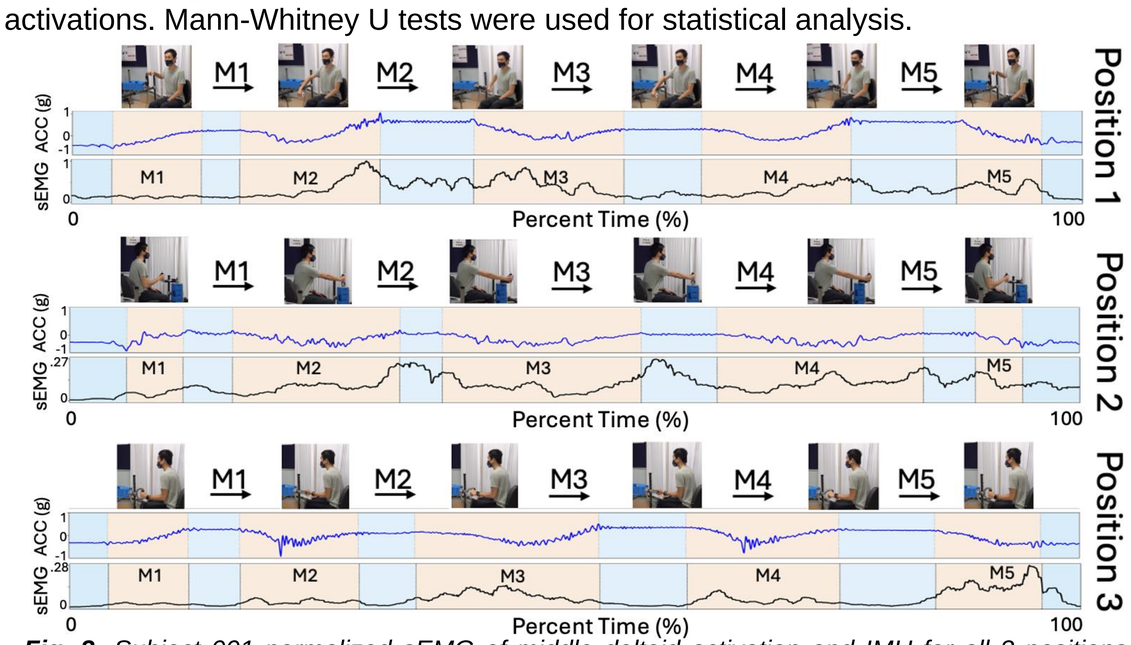


Fig. 3: *Subject 001 normalized sEMG of middle deltoid activation and IMU for all 3 positions.* sEMG data were clipped to relevant movements, as identified by IMU data. Raw sEMG data underwent a high pass filter at 10Hz, baseline offset removal, an envelope with a window size of 80 samples (320ms), and a rolling window outlier removal over 100 samples (3s). For each subject, each channel was normalized to its highest signal value across ROM trials.

RESULTS

Variation Across Impairment

- **ROM**: The moderate/severe impairment group had a **smaller ROM** than the mild impairment group, particularly in Pos. 2 and Pos. 3 (***Fig. 4***).

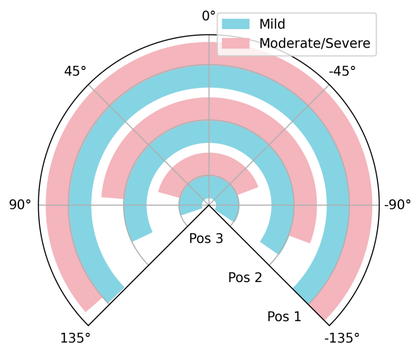
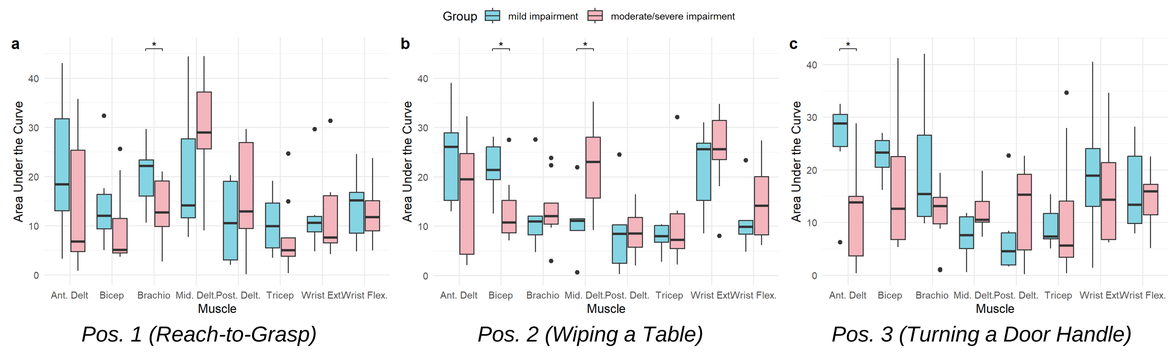


Fig. 4: *Average ROM in 3 positions.*

- **Position 1**: The mild impairment group had significantly **higher brachioradialis** AUC than the moderate/severe impairment group, z = 45, p = 0.036 (***Fig. 5a***).
- **Position 2**: The mild impairment group had significantly **higher biceps** AUC than the moderate/severe impairment group, z = 38, p = 0.042. The moderate/severe impairment group had significantly **higher middle deltoid** AUC than the mild impairment group, z = 6, p = 0.029 (***Fig. 5b***).
- **Position 3**: The mild impairment group had significantly **higher anterior deltoid** AUC than the moderate/severe impairment group, z = 56, p = 0.0202 (***Fig. 5c***).



Pos. 1 (Reach-to-Grasp) *Pos. 2 (Wiping a Table)* *Pos. 3 (Turning a Door Handle)*

Fig. 5: *AUC-quantified muscle activations for all three positions.* ***a:*** *Pos. 1;* ***b:*** *Pos. 2;* ***c:*** *Pos. 3*

Variation Across Position

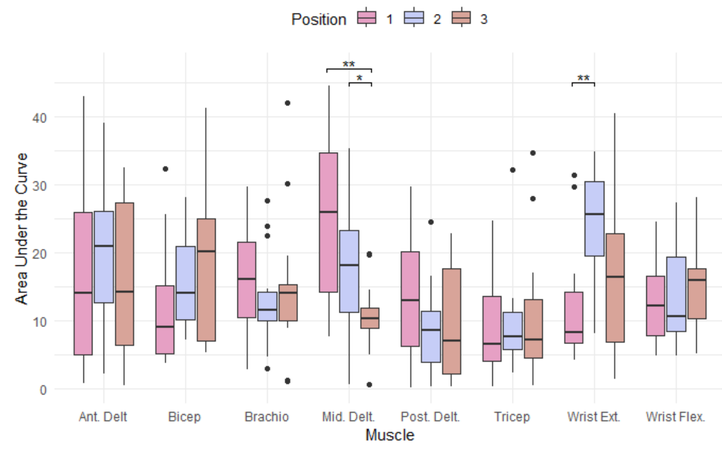


Fig. 6: *AUC-quantified muscle activations for each position.*

- **Middle Deltoid**: Middle deltoid AUC was significantly **higher in Pos. 1** than Pos. 3, z = 217, p = 0.001 (***Fig 6***). Middle deltoid AUC was also significantly **higher in Pos. 2** than Pos. 3, z = 180, p = 0.029 (***Fig 6***).
- **Wrist Extensor**: Wrist Extensor AUC was significantly **higher in Pos. 2** than Pos. 1, z = 35, p = 0.005 (***Fig 6***).

DISCUSSION

- **The Rehab CARES system effectively activates diverse muscle patterns across its three configurations.** Pos. 1 activated the middle deltoid, posterior deltoid, and brachioradialis. Pos. 2 primarily activated the anterior deltoid and wrist muscles. Pos. 3 showed the highest activation of the biceps and wrist flexors.
- **Muscle activation patterns suggest compensatory behaviors are employed in all positions, especially by more impaired participants.** In Pos. 1, the moderate/severe impairment group showed significantly lower brachioradialis activation and significantly higher middle deltoid activation. In Pos. 2, the mild impairment group exhibited higher activation in the biceps and the anterior deltoid, indicating that the shoulder flexed as the elbow bent—a common abnormal synergy. In Pos. 3, the moderate/severe impairment group showed greater activation of the middle deltoid and the posterior deltoid, possibly due to compensatory shoulder twisting.
- **This study represents a first attempt at understanding how a reconfigurable 1-DoF robot activate muscles in a post-stroke population.** Limitations include small sample size, low sampling frequency of the sEMG, and low task complexity. Future work should involve a more in-depth analysis of agonist–antagonist muscle pairings, more advanced analytical techniques, inclusion of healthy controls, and a longitudinal evaluation of the rehabilitation effectiveness of the robotic system.

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