Automatically Modulating Activation of the Paralyzed Trunk and Hip Muscles to Improve Manual Wheelchair Propulsion

Stephanie Nogan Bailey BSE[1], Kevin M. Foglyano BSE[1], Lisa M. Lombardo MPT[1], Ronald J. Triolo PhD[1,2]

[1] Advanced Platform Technology Center, Louis Stokes Cleveland Veterans Affairs Medical Center, Cleveland OH, [2] Departments of Orthopaedics & Biomedical Engineering, Case Western Reserve University, Cleveland OH

OBJECTIVE

- During manual wheelchair (MWC) propulsion, the trunk flexes and extends throughout the propulsion cycle [1] to help create mechanical power for movement**.**
- MWC users with paralysis of core muscles assist/resist excessive forward or backward lean and stabilize the torso with their arms.
- Inefficient propulsion mechanics lead to shoulder problems and difficulty navigating challenging terrains.

Figure 4: Propulsion data collected from wrist-worn sensor and instrumented pushrim from C7 AIS B SCI MWC user

- Constant activation of the paralyzed hip/trunk muscles with neural stimulation improves MWC propulsion efficiency on level terrain [2].
  - Stimulation stiffens the torso so the arms can more effectively transmit forces and moments to the pushrim.
  - Advantages disappear during sprints and up ramps.
- Appropriate timing of stimulation with the propulsion cycle may allow MWC users to better move or directionally stabilize their trunks **[Figure 1]** to increase efficiency and improve upper extremity mechanics.

Figure 1: MWC user with C5 AIS B SCI can more easily propel with a stable trunk due to stimulation (right), compared to without stimulation (left).

The purpose of this study was to determine a method to accurately detect transitions between contact and recovery phases of MWC propulsion with minimal instrumentation to appropriately modulate trunk stimulation for improved pushing mechanics during challenging conditions.

DESIGN / METHOD

MWC propulsion consists of 2 main phases: **contact** when leaning forward with hands on the pushrims and **recovery** when pulling trunks and arms back to prepare for the next push **[Figure 2].**

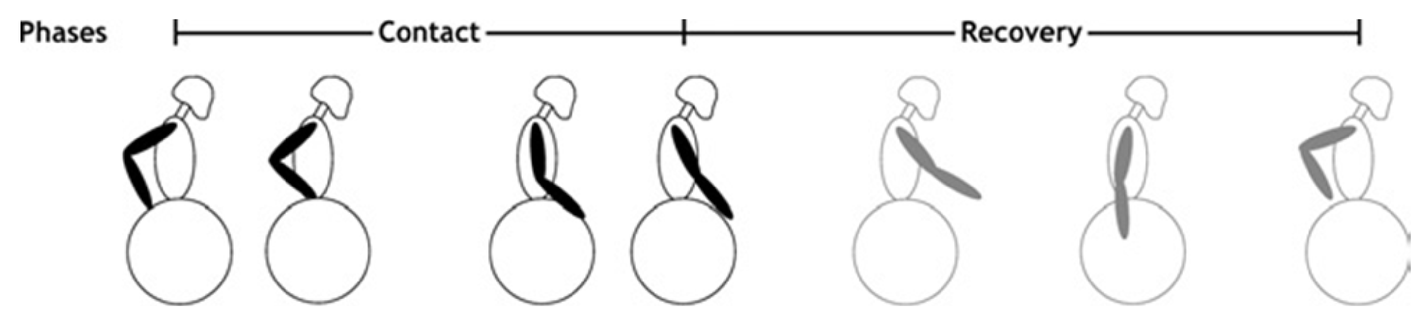

Figure 2: A propulsion cycle consists of the contact and recovery phases. (Kwarciak, Archives PM&R, 2009).

We can detect transition periods between each phase by mapping the sagittal and frontal plane components **[Figure 3]** (using a custom wrist accelerometer [3]) to the propulsion phases (determined by an instrumented pushrim) **[Figure 4]**.

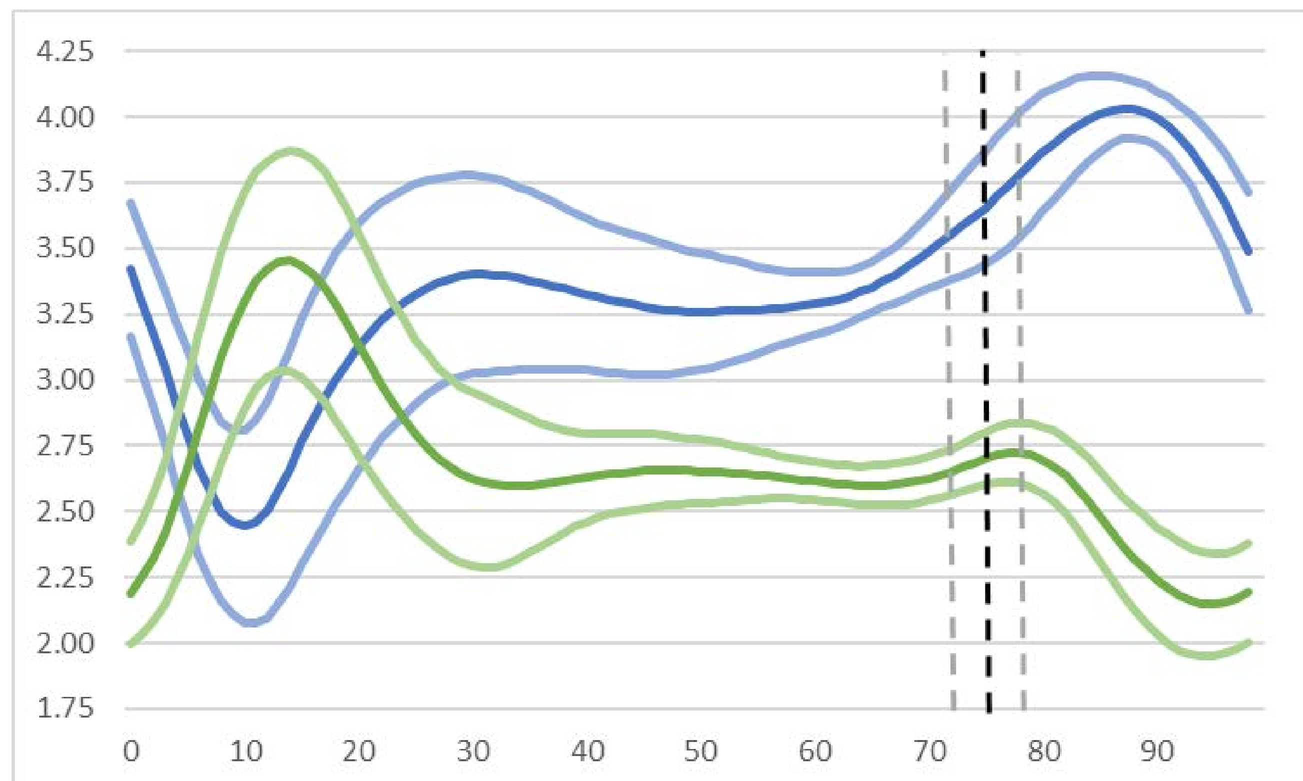

Figure 3: Sagittal and Frontal Plane Accelerations (V) vs % Propulsion Cycle.

- During contact, low-level stimulation was applied via intramuscular electrodes connected to an implanted pulse-generator to erector spinae, quadratus lumborum, posterior portion of adductor magnus, and gluteus maximus to stabilize trunk while allowing forward lean.
- Signal features that predict the transition to recovery activated higher level stimulation to stop excessive forward lean and assist return to upright position.
- Modulated stimulation was implemented during propulsion across a flat, smooth 10m walkway with 1 MWC user with a T4 AIS A SCI.
- Initial data with constant, low-level stimulation was collected from 4 additional MWC users during the same propulsion condition.

RESULTS

Pushing with modulated stimulation:

- Rated "**very easy**" compared to "very difficult" without stimulation (7-point User Ratability Scale).
- Modulated stimulation **increased propulsion speed** on level ground (1.42 m/s vs 1.37 m/s without stimulation).
- With **comparable pushing mechanics**:
  - Peak force of 97.92 $\pm$ 14.02 N
  - 66.98 $\pm$ 5.93% mean fraction effective force
- >95% of phase transitions were detected accurately by accelerometer ($\pm$2SD of those measured by instrumented pushrim).
- Initial data from 4 MWC users suggest a similar implementation is feasible and can be generalized **[Table 1]**.

Rate of Phase Transition Detection	S2: T6 AIS A	S3: T4 AIS B	S4: T3 AIS A	S5: T4 AIS A	Mean
Contact → Recovery	90%	75%	100%	100%	91%
Recovery → Contact	90%	81%	100%	93%	91%

Table 1: Rate of phase transition detection for an additional 4 subjects during propulsion with low-level, constant stimulation.

CONCLUSION

- Simple wireless wrist-worn accelerometers can:
  - Accurately, robustly detect phase transitions of MWC propulsion.
  - Provide effective command signals to control stimulation.
- Modulating trunk and hip activation to coincide with phases of the propulsion cycle can increased speed.

We are currently evaluating the potential of such systems to improve propulsion mechanics and efficiency during challenging activities such as sprinting and negotiating ramps.

REFERENCES

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