Automatic Application Of Neural Stimulation During Wheelchair Propulsion Enances Recovery Of Upright Sitting From Destabilizing Events

HYATT REGENCY DENVER & COLORADO CONVENTION CENTER · SEPTEMBER 3-6, 2017

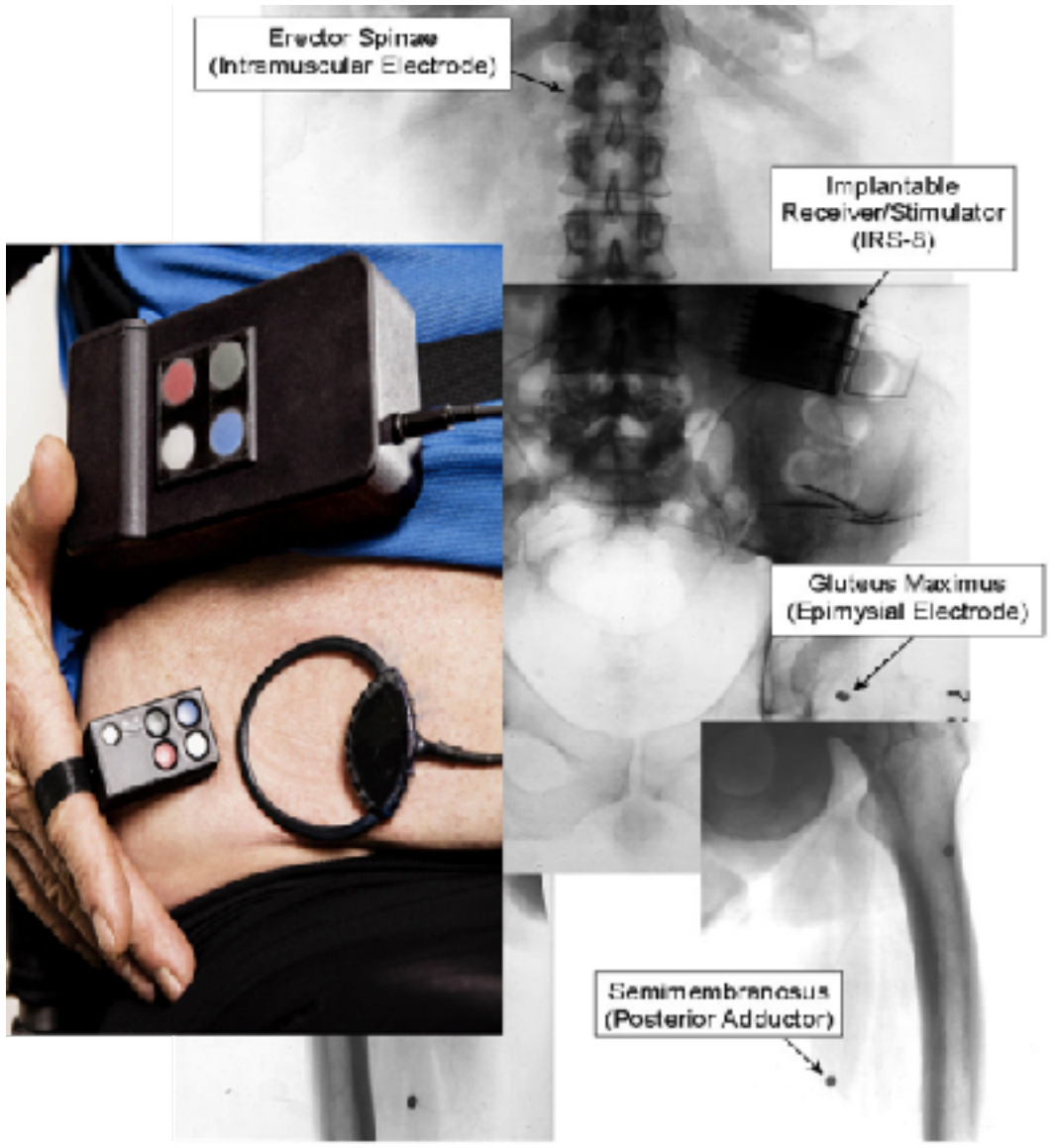
Background

- **Clinical Problem**
  - Tips and falls are leading causes of injury for wheelchair users
  - Riding surface and environmental factors contribute to wheelchair instability, and ultimately, falls
    - Collisions with obstacles, sharp turns, uneven or inclined surfaces, and curb drops
- **Conventional Approaches**
  - Seat belts, cushions, and supports
    - Restrict desired motions in daily activities
    - Cause pressure ulcers, skin tears, lowered self-esteem, and even asphyxiation

Gavin-Dreschnack D, et. al. Jou Nursing Care Qual, 20, 2005
Chaves ES, et. al. Assist Tech, 19, 2007
Kamper D, et. al. Spinal Cord, 37, 1999
Minkel JL. Physical Therapy, 80, 2000

Neural Stimulation

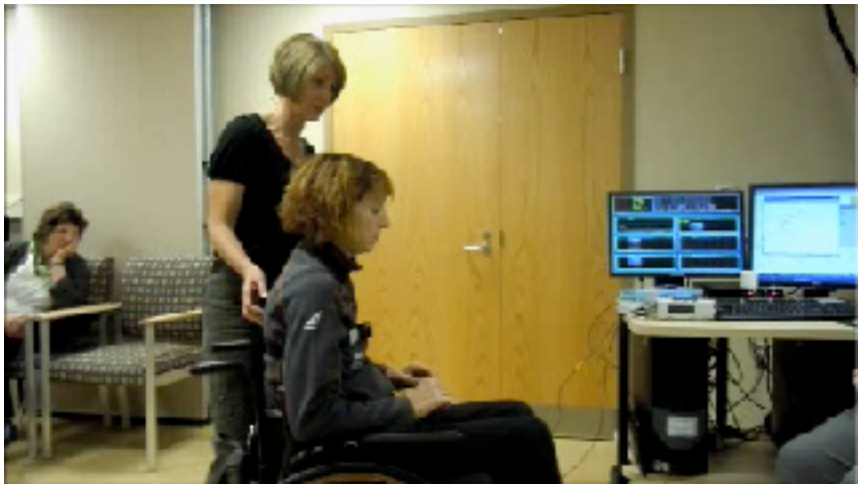
- Small currents applied to peripheral nerves cause otherwise paralyzed muscles to contract
- Intramuscular electrodes at T12-L-3 spinal nerves activate Erector Spinae (ES), Quadratus Lumborum (QL) & Iliopsoas (IL) to control lumbar spine & pelvis
- Electrodes inserted at gluteal & sciatic nerves extend & adduct the hip



Previous Work

Neural Stimulation can:

- Normalize vertebral alignment & restore anterior pelvic tilt
- Expand bimanual work volume & sagittal reach
- Stabilize sitting against perturbations by up to 45%
- Automatically return to erect for full forward flexion
- Enable retrieval of objects from the floor



WITHOUT Neural Stimulation

WITH Tilt-Triggered Stimulation

C7 AIS C

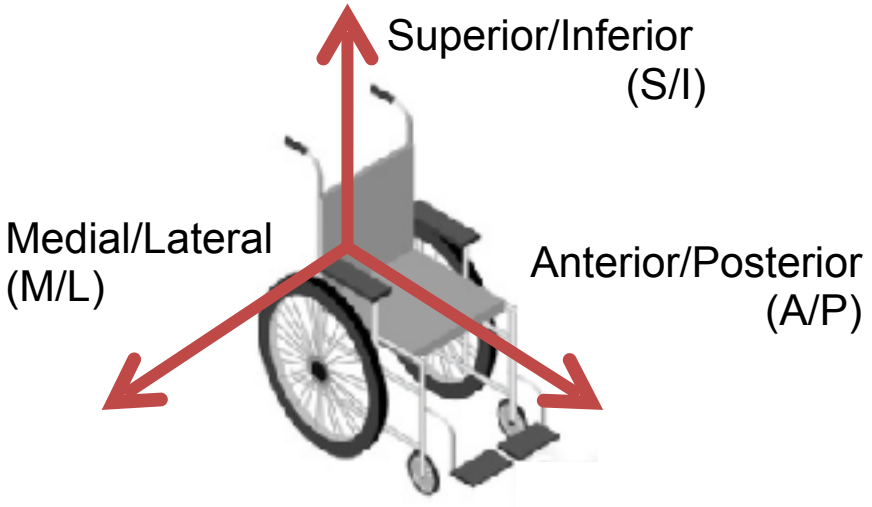
Kukke S, et al. IEEE TNSRE 12, 2004
Triolo R et al., APMR 90, 2009
Triolo R et al., APMR 94, 2013a, 2013b
Murphy J et al., JRRD 51, 2014
Audu ML et al., JNER 12(8), 2015.

Research Aims

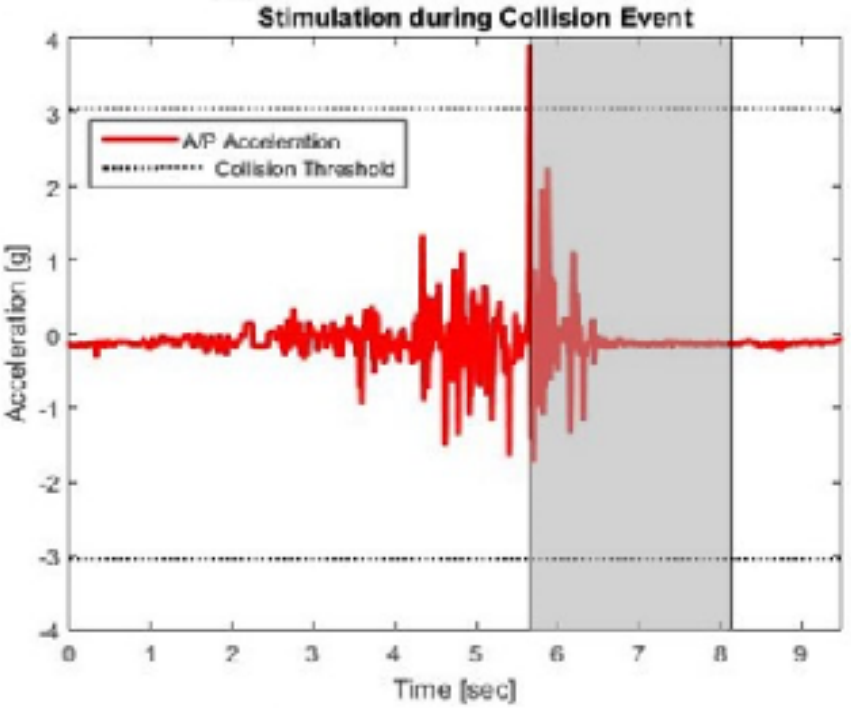
1. Develop algorithms to automatically detect potentially destabilizing wheelchair conditions
    - Collisions
    - Sharp Turns
2. Generate appropriate stimulation patterns to activate hip and trunk muscles to regain or maintain stability
3. Evaluate system effectiveness in terms of objective and subjective measures

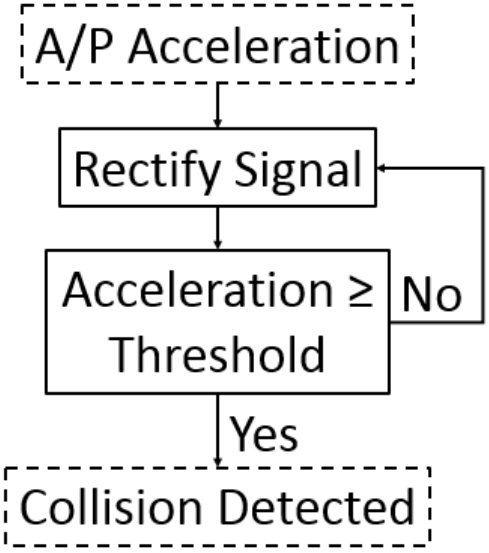
Instrumentation

- Anthropomorphic Crash Dummy
  - Avoid potentially injurious experiments with live subjects
  - Collect preliminary data to standardize methods
- Wireless IMU (Inertial Measurement Unit)
  - Tri-axial accelerometers & gyroscopes
  - Affix to center rear crossbar
- VICON motion capture system



Collision Algorithm





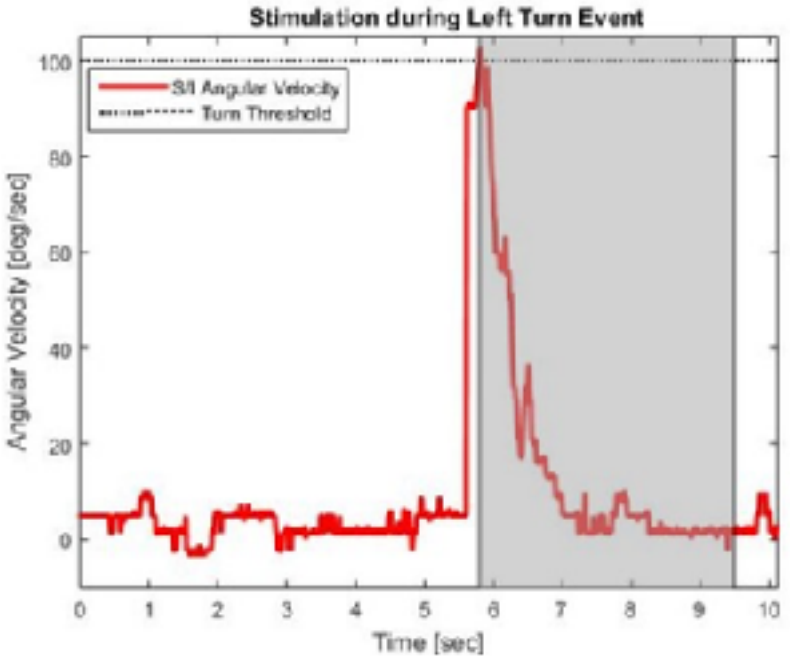
*Critical velocity = 1.75m/s

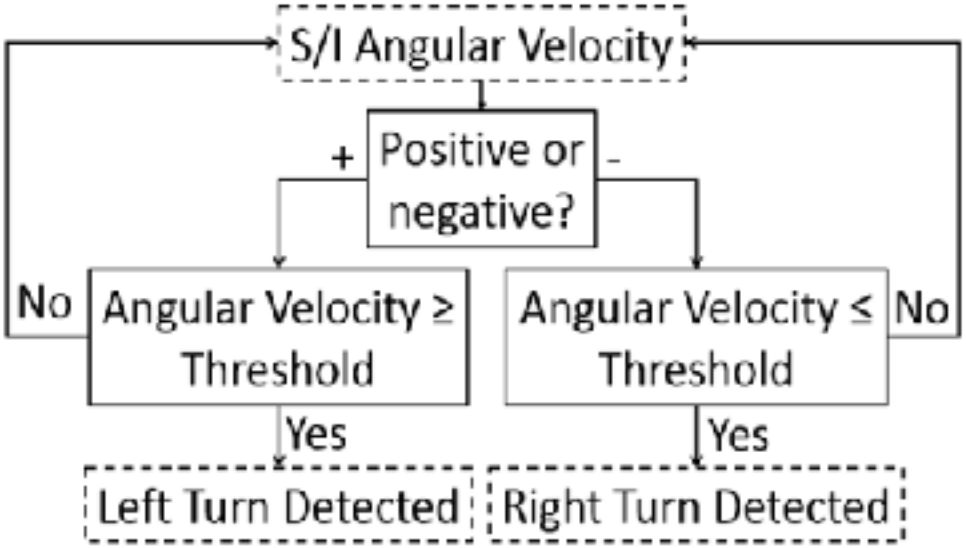
Consistent velocity ~ 1.5 m/sec
Peak deceleration ~ 4g

Threshold = Mean Peak $|AP_{acc}|$ - 2SD

*Cooper RA, et al. JRRD 29, 1992

Turn Algorithm





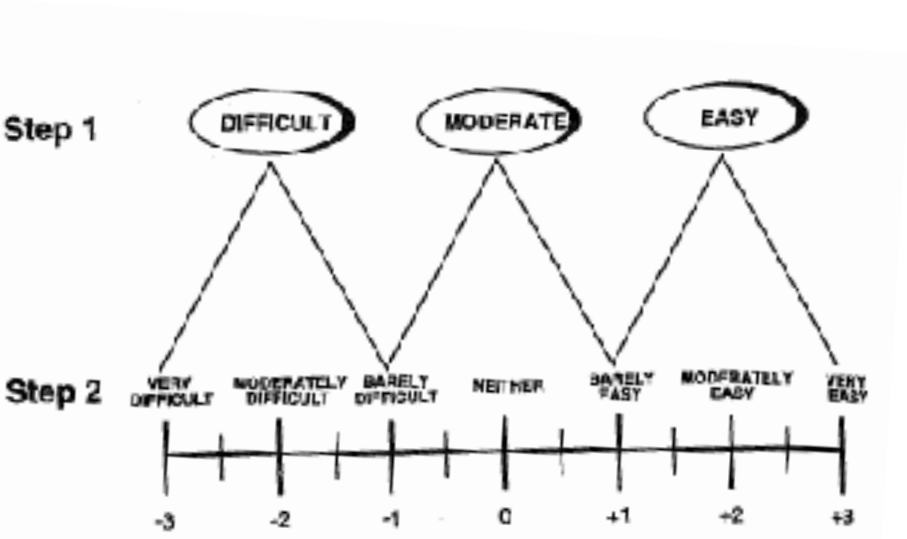
*Rollover risk > 1.5m/s @ 25cm radius

Turn threshold= Mean Peak $|SI_{av}|$ - 2SD

*Cooper RA, et al. JRRD 29, 1992.

SCI Testing

Subject	Age	Gender	Injury Level	AIS Grade	Date of Injury
S1	51	M	C7	B	10/11/2002
S2	41	F	T3	A	2/13/2012
S3	59	M	T4	B	3/9/2008
S4	44	F	C7	C	3/13/1998



- Four implant recipients
- 20 Calibration Trials
  - WITHOUT stimulation
- 10 *Randomized* Test Trials
  - 5 WITH stimulation
  - 5 WITHOUT stimulation
- **Quantitative Outcomes**
  - Detection Accuracy
  - Detection Delay
  - Maximum Trunk Angle
  - Time to Restabilize Posture
- **Qualitative Outcomes**
  - Usability Rating Scale

Steinfeld E, Danford GS. Enabling Environments, 1999.

Results: Collisions

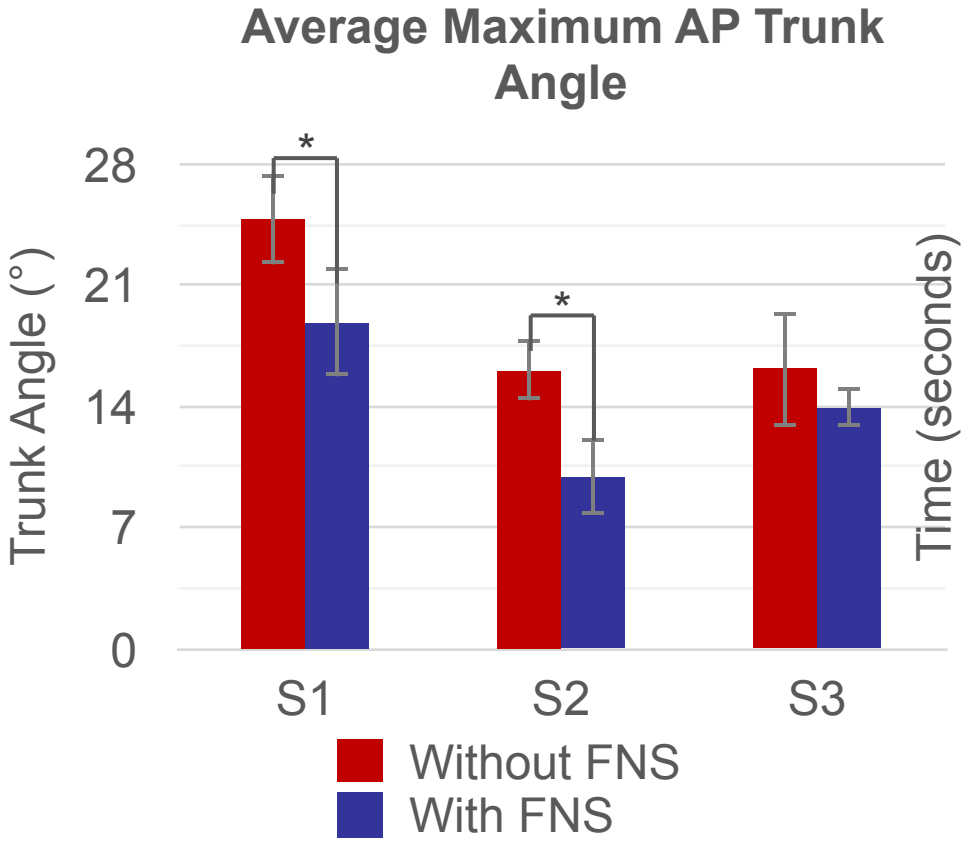
WITHOUT Stimulation

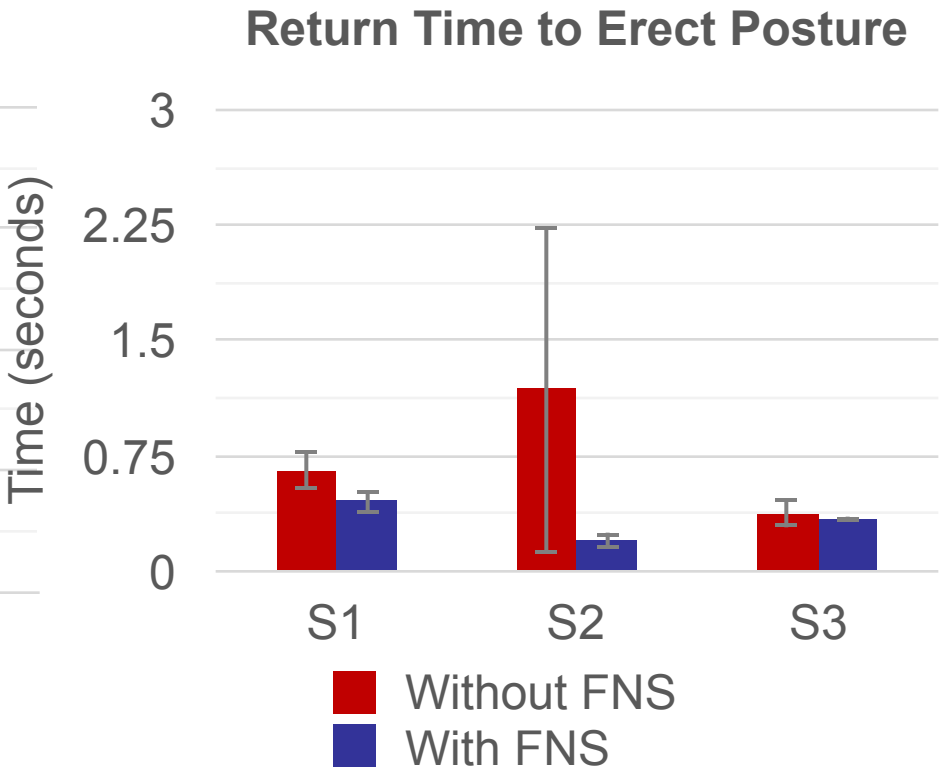
C7 AIS C

WITH Stimulation

Results: Collisions

Detection Accuracy	Detection Delay
93%	63 ± 48 ms





Results: Collisions

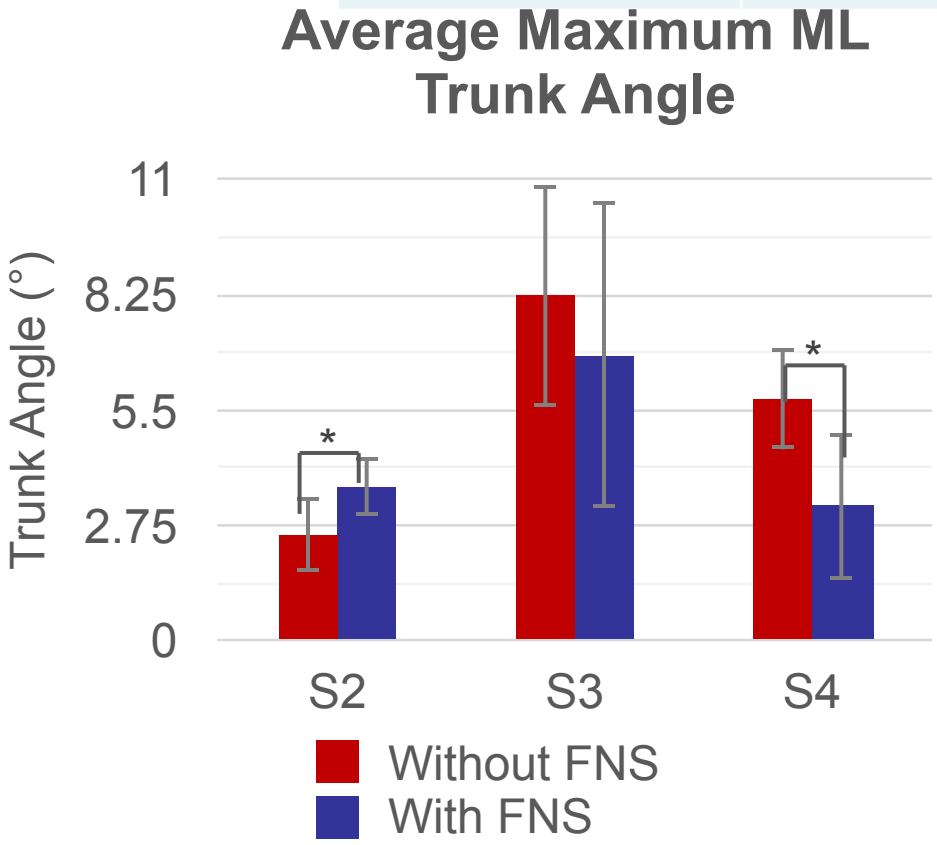
WITHOUT Stimulation

T4 AIS B

WITH Stimulation

Results: Turns

Detection Accuracy	Detection Delay
90%	302 ± 90 ms



ML Lean Effects Mixed:

- S2 increased
- S3 unchanged
- S4 reduced

Turn detection may be too slow to be effective

Preparatory strategies prior to turn

Results: URS

Median URS		S1	S2	S3	S4
Collisions	Without FNS	0	2	3	-
	With FNS	1	3	3	-
Turns	Without FNS	-	-3	2	-1
	With FNS	-	0	2	1

Subjective perceptions of ease/difficulty **improved** (S1, S2, S4) **or unchanged** (S3) with automatically triggered neural stimulation for BOTH collisions and turns, regardless of physical measurements

Summary

- Simple algorithms and inertial measurements accurately detect WC collisions (93%) and turns (90%)
- Appropriately timed hip & trunk muscle activation can improve recovery from forward collisions
  - Forward lean significantly reduced ($p<0.05$) or unchanged
  - Return time varied but trended toward improvement
  - Collisions detected rapidly (63 ms) from WC acceleration
- Turns detected from WC angular velocity, while accurate, were too slow (309 ms) to be consistently effective
  - ML lean and recovery time results with stimulation mixed
  - Predictive inertial parameters (angular acceleration) need to be investigated
- Subjective ratings of difficulty improved with stimulation consistently (3/4 subjects) for both collisions & turns

Acknowledgements

- **Team:**
  - Kiley Armstrong
  - Musa Audu
  - Kevin Foglyano
  - Lisa Lombardo
  - Gilles Pinault
  - Rescue Randy
  - S1, S2, S3, S4

T6 AIS A
(with stimulation)

- **Funding:**
  - Merit Review (B6406T) from Rehabilitation R&D Service of the U.S. Department of Veterans Affairs