Robotic Rehabilitation for Stroke and Spinal Cord Injury

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Mission of the MAHI Lab at Rice

Design, manufacture and test mechatronic or robotic systems to model, rehabilitate, enhance or augment the human sensorimotor control system

Robot-assisted rehabilitation for stroke

- Stroke statistics
  - About 800,000 persons annually in the United States suffer a cerebral vascular accident (CVA), or stroke, with the total number of survivors estimated at 6.5 million (AHA website, July 2009)
  - Direct and indirect costs due to stroke are estimated as $68.9 billion for 2009
- Robotic-assisted rehabilitation offers a number of potential benefits
  - Therapist can oversee multiple patients simultaneously
  - In-home tele-rehabilitation is possible
  - Quantitative data recorded by robotic device can track patient progress
  - Programmable nature of robotic system enables bespoke treatment
  - Technology motivates patients and improves outcomes

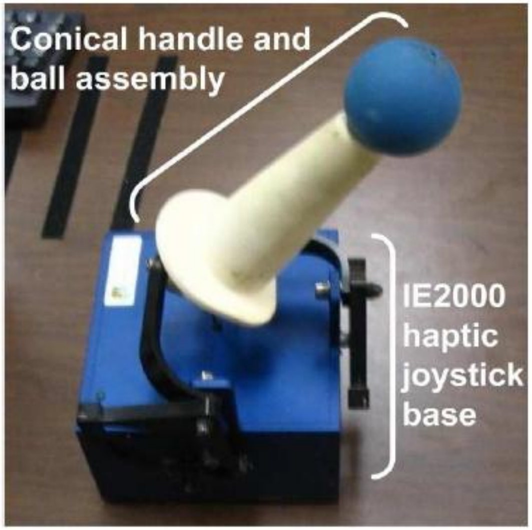
Robotic measures of motor impairment: Motivation

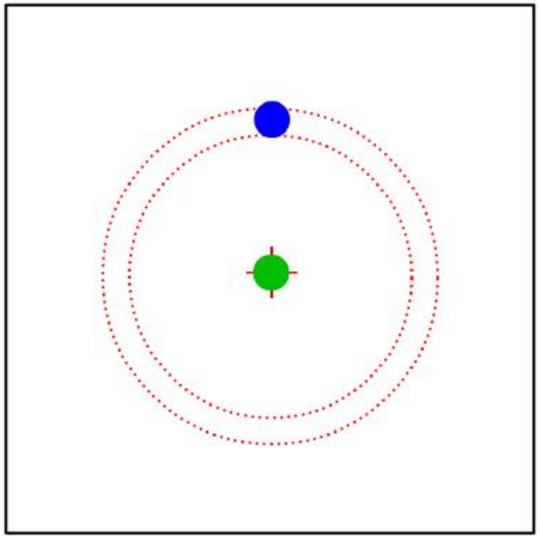
- Benefits of robotic rehabilitation
  - Repetitive movements
  - Controlled delivery
  - Quantitative metrics
- Need for known correlation between robotic measures and clinical measures

Clinical and robotic measures have their own advantages and drawbacks

	Clinical Measures	Robotic Measures
Efficient to compute and evaluate		✓
Objective measure of performance		✓
Widely accepted by clinical community	✓	
Independent of task or procedure	✓	

A target-hitting task was completed by patients using a haptic joystick



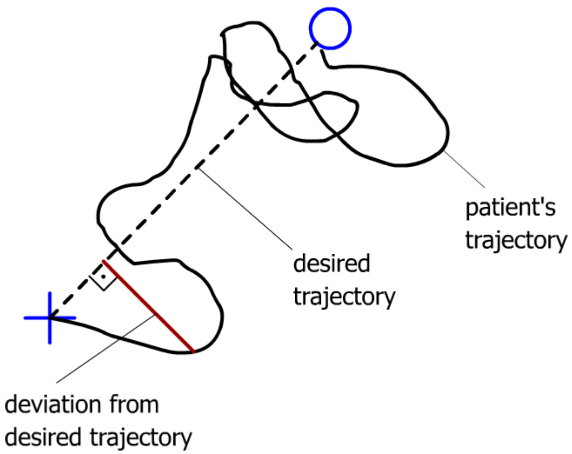


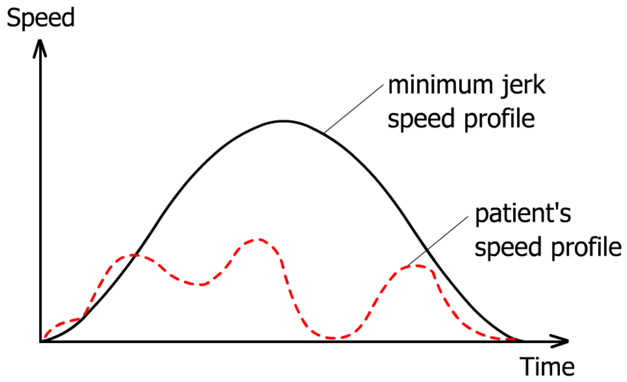
Four clinical measures administered pre- and post-treatment

- Clinical motor impairment measures
  - Fugl-Meyer (FM) upper-limb component (0-66)
  - Action Research Arm Test (ARAT) (0-57)
- Clinical functional use measures
  - Jebsen-Taylor (JT) Hand Function Test (time in sec)
  - Motor Activity Log (MAL) (0-6)

Four robotic measures of movement quality and movement speed

- Movement quality measures based on minimum jerk principle
  - Trajectory Error (TE)
  - Smoothness of Movement (SM)
- Movement speed measures
  - Average target hits per minute
  - Mean tangential speed





Rehabilitation program

- Nine patients
- Three days a week, 4 hours each therapy day
- Hybrid robotic and traditional rehabilitation program
  - 60% traditional constraint induced movement therapy (CIMT) activities
  - 40% robotic therapy
- Four weeks of therapy
- Follow-up session one month after the last session

Participant characteristics

Patient number	Gender	Age (years)	Months since stroke	Side affected	Stroke location
1	M	62	24	R	L BS
2	F	63	12	L	R BG
3	M	62	121	R	L MCA
4	M	65	50	R	L BG and T
5	F	48	20	L	R MCA
6	M	67	14	R	L IC
7	M	57	25	L	R BG
8	M	66	77	L	R Pons
9	M	57	13	L	R IC

Abbreviations:

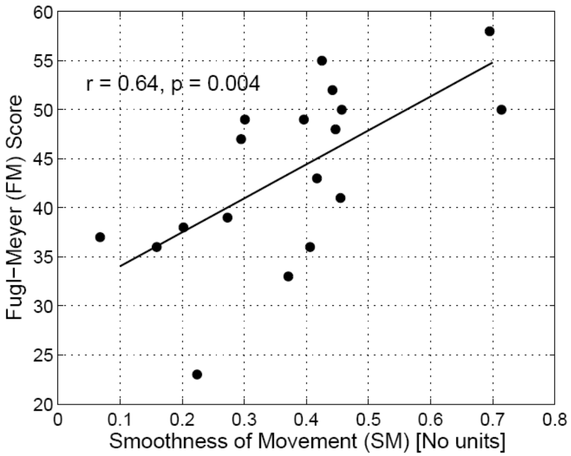
BS	BRAIN STEM
HEM	HEMMORHAGIC
MCA	MIDDLE CEREBRAL ARTERY
BG	BASAL GANGLIA
IC	INTERNAL CAPSULE
T	THALAMUS

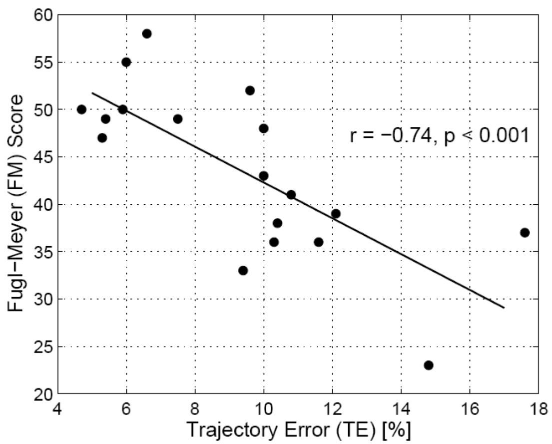
Correlations of clinical and robotic measures

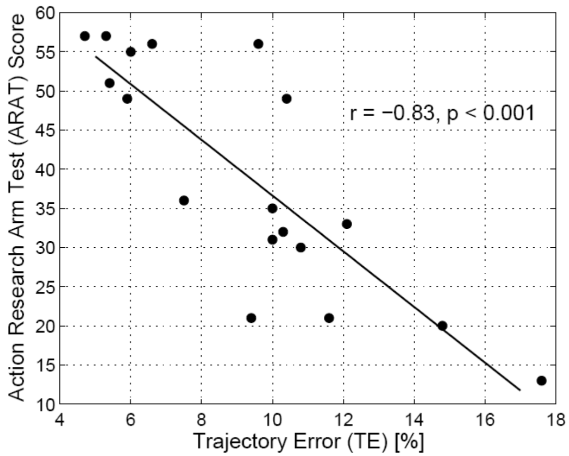
- Movement quality measures strongly correlated with motor impairment measures

Correlation coefficient r is listed.
* denotes significant correlation ($p<0.05$)

	TE	SM	HPM	MTS
FM	-0.74*	0.64*	0.54*	0.22
ARAT	-0.83*	0.51*	0.37	0.00
JT	0.63*	-0.49*	-0.53*	-0.32
MAL	-0.49*	0.57*	0.46	0.21







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Movement quality measures strongly correlate with motor impairment measures

- Trajectory error and smoothness of movement measures can be used for
  - estimation of clinical measures (additional data needed for validation)
  - adjustment of robotic therapy online based on patient's progress
  - comparison of different protocols/devices

(Celik et al, IEEE ICRA 2008)
(Celik et al, IEEE TNSRE 2010)

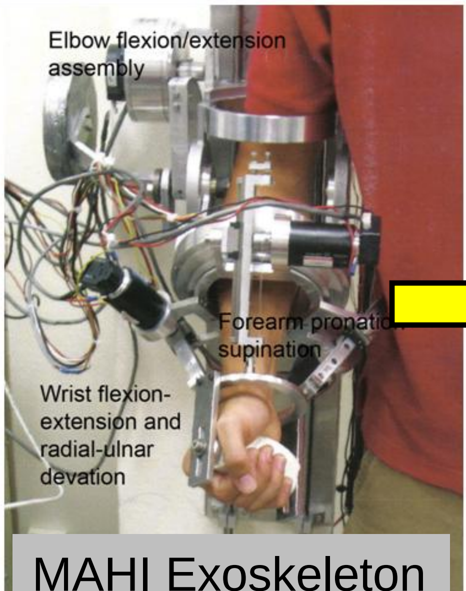
Upper Limb Robotic Rehabilitation for SCI

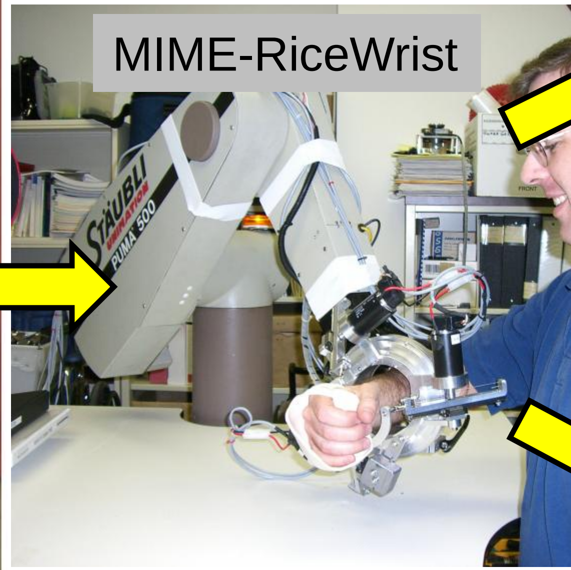
- Tetraplegia is the most frequent neurologic category reported to the SCI Model Systems
- Upper limb function is a significant factor in quality of life after tetraplegia
- Repeated practice can induce brain and spinal plasticity and result in significant UL improvements
- Robotic devices can help therapists deliver repeated practice
- No established methods exist for delivering UL repeated practice to persons with SCI
- Clinical evaluation can provide guidance to the community

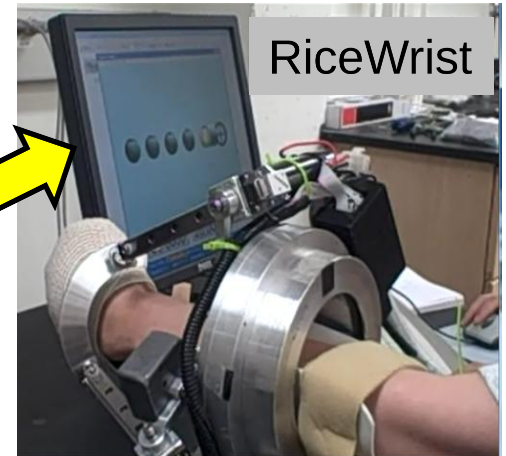
Aims

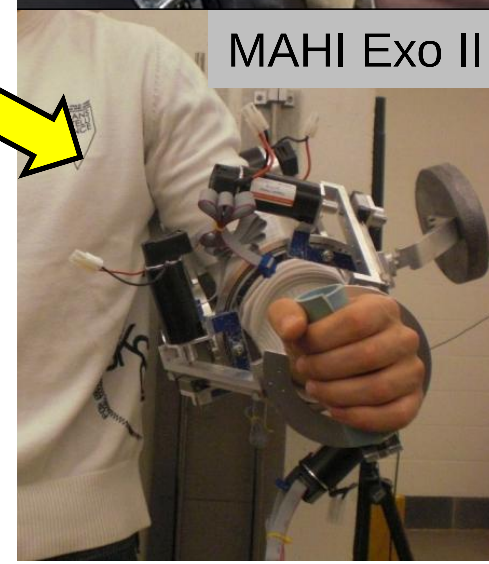
- Describe the design features of the RiceWrist and MAHI-Exo-II devices
- Confirm the feasibility of using these devices for upper limb training in tetraplegic persons with incomplete SCI
- Detect motor progress using robotic and clinical measures

MAHI exo and RiceWrist Evolution









Gupta and O'Malley, ASME/IEEE TMECH 2006

Gupta et al., IJRR 2008

Pehlivan et al., ICORR 2011

Kadivar et al., ICORR 2011

RiceWrist evaluation: Participant

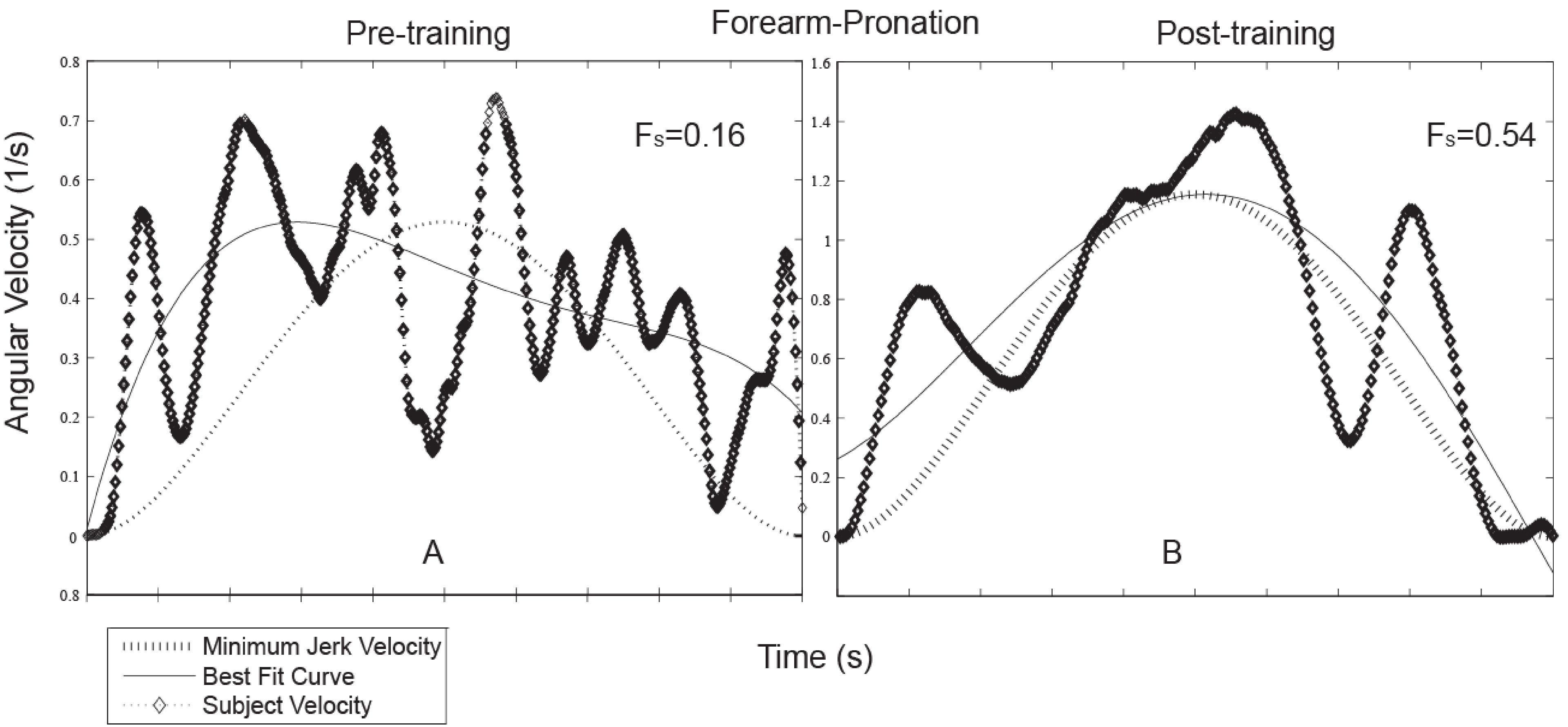
- 24-year-old male
- Incomplete SCI at C4
- 6.5 months post-injury
- ASIA D according to American Spinal Injury Association Impairment Scale
- Minimum voluntary movement on the weaker right upper limb
- Moderate level of voluntary movement on the stronger left limb

RiceWrist evaluation: Training

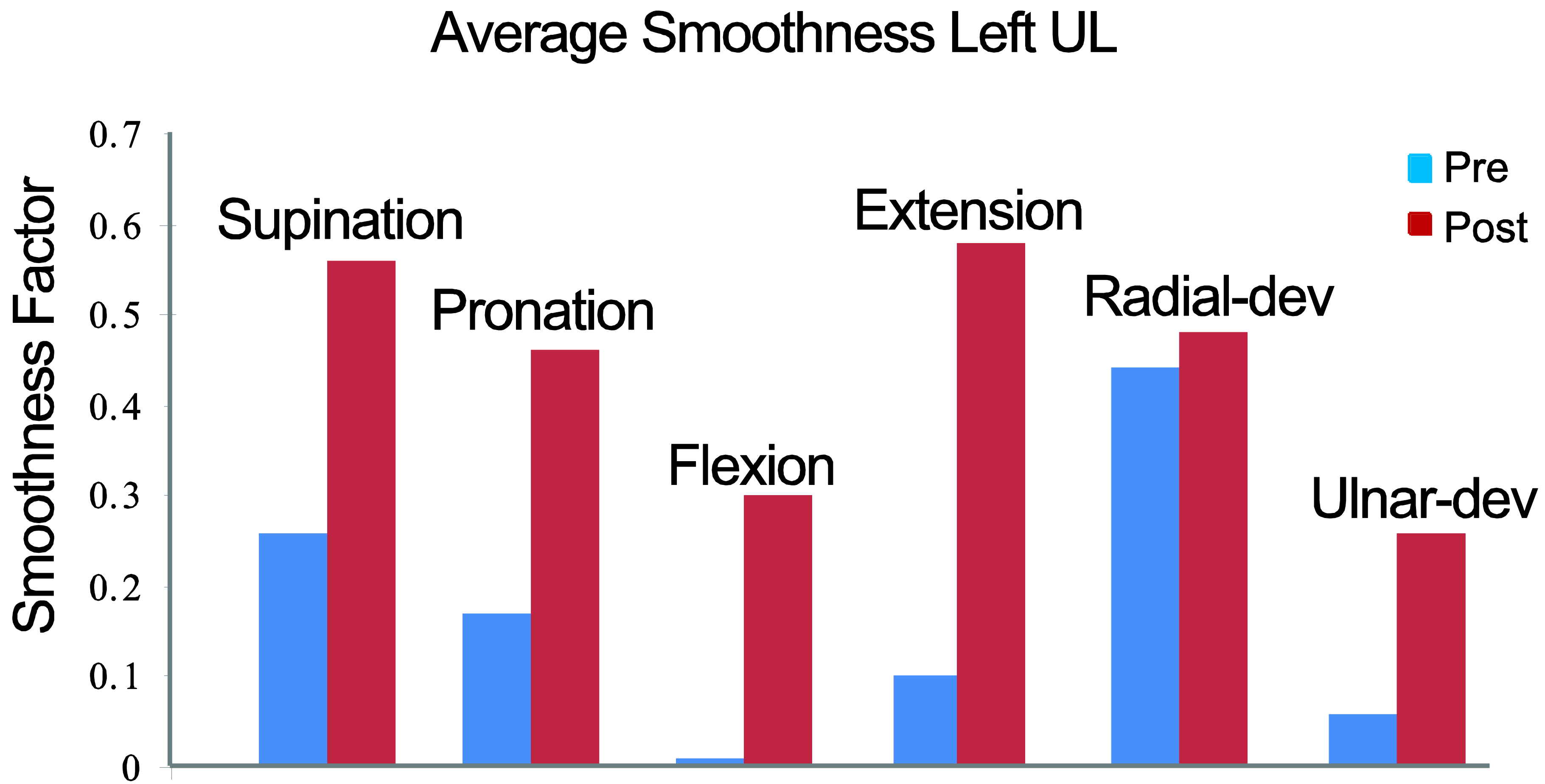
- Three hours per day,10 consecutive weekdays for the right and left upper limbs
- Sessions customized using passive, active constraint and triggered modes
- Collected measures:
  - Smoothness factor (Fs)
  - Jebsen Taylor Hand Function Test

Jebsen-Taylor Hand Function Subtest	**Right**		**Left**	
	Pre	***Post***	***Pre***	***Post***
Simulated page turning (5 cards)	n/a	150(5)	11.82	7.09
Lifting small common objects (2 paper clips, bottle cap, pennies, cup)	n/a	180(2)	20.88	20.44
Simulated feeding (5 kidney beans)	n/a	n/a	17.53	15.25
Stacking checkers (4 checkers)	n/a	180(2)	44.13	20.03
Lifting large light objects (5 cans)	n/a	n/a	6.87	5.87
Lifting large heavy objects (5 cans)	180(2)	180(4)	6.85	6.28

Results: Smoothness Factor



Results: Smoothness Factor



Data from Sessions 2 and 10 were used for pre- and post-assessment

MAHI Exo II evaluation: Participant

- 28-year-old female
- Incomplete SCI at C2
- 29 months post-injury
- ASIA C according to American Spinal Injury Association Impairment Scale
- Minimum voluntary movement on the weaker right upper limb
- Moderate level of voluntary movement on the stronger left limb

MAHI Exo II evaluation: Training

- Three hours per session,12 sessions over four weeks
- Sessions customized using passive, active constraint and triggered modes
- Performance measures:
  - Smoothness factor (Fs)
  - ASIA
  - ARAT
  - Jebsen Taylor Hand Function Test

Functional scores before and after robotic-assisted training

ASIA: American Spinal Injury Association, ARAT: Action Research Arm Test, JTHFT: Jebsen Taylor Hand Function Test. The JTHFT was ended after 180sec. Lower times represent better performance.

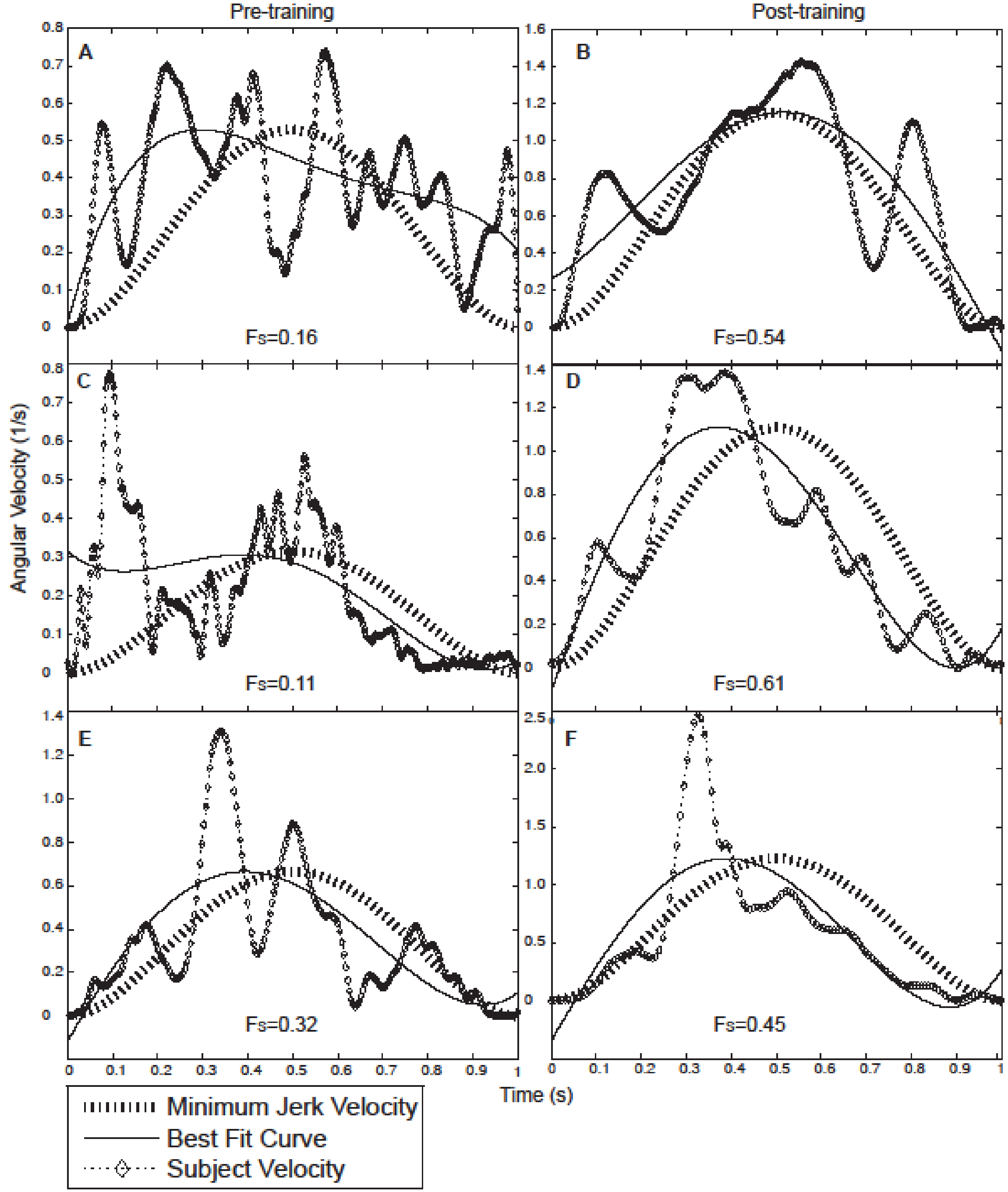
Task	Side	Pre-treatment	Post-treatment
ASIA – upper extremity motor score (0-25)	Right	7	9
	Left	18	19
ARAT (0-57)	Right	3	3
	Left	41	49
JTHFT (total time in seconds)	Right	1080	1080
	Left	151.64	80.4

Angular velocity profiles pre- and post- treatment

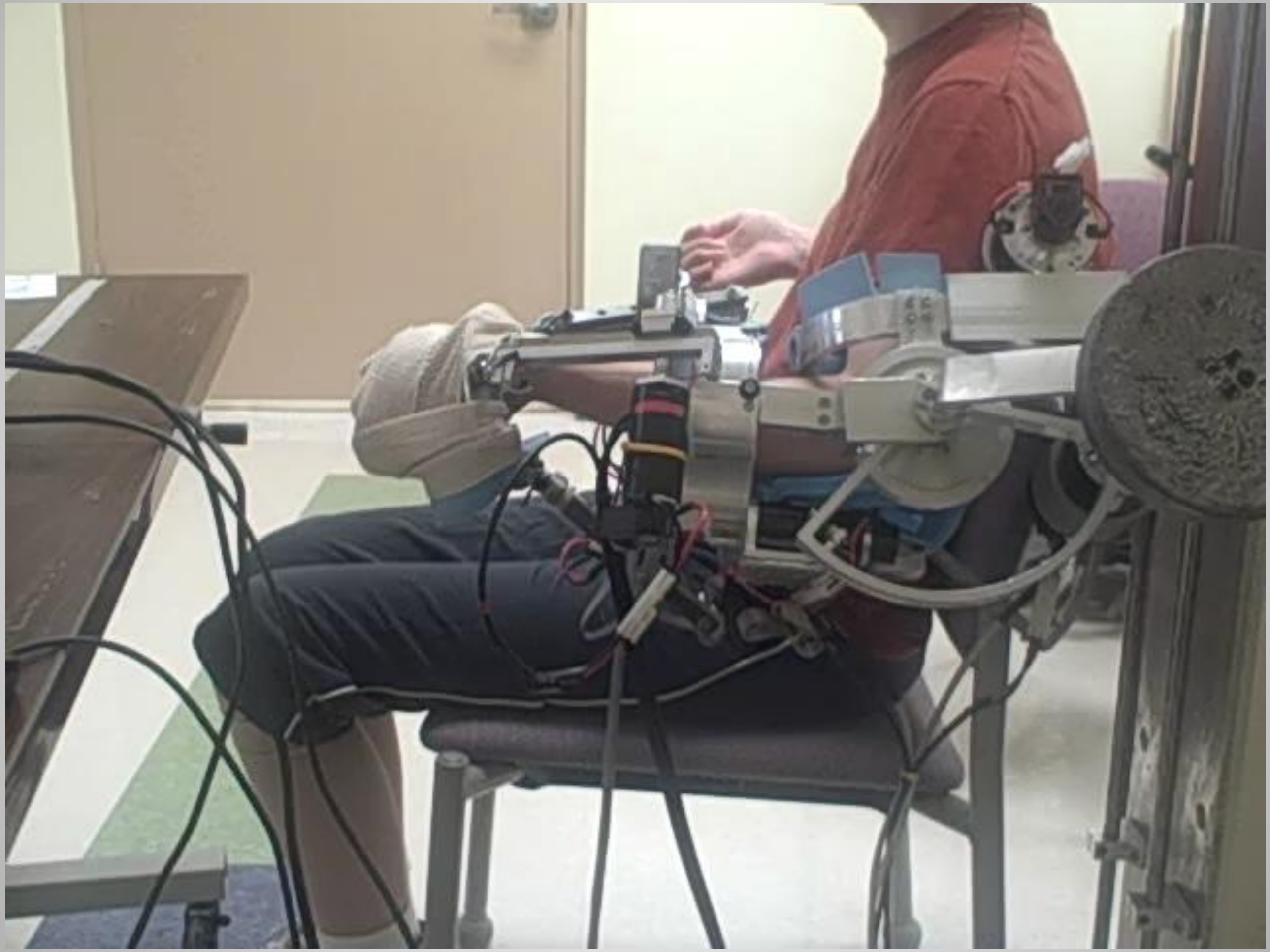
(A/B) forearm supination

(C/D) wrist radial deviation

(D/E) wrist extension



MAHI Exo II Evaluation



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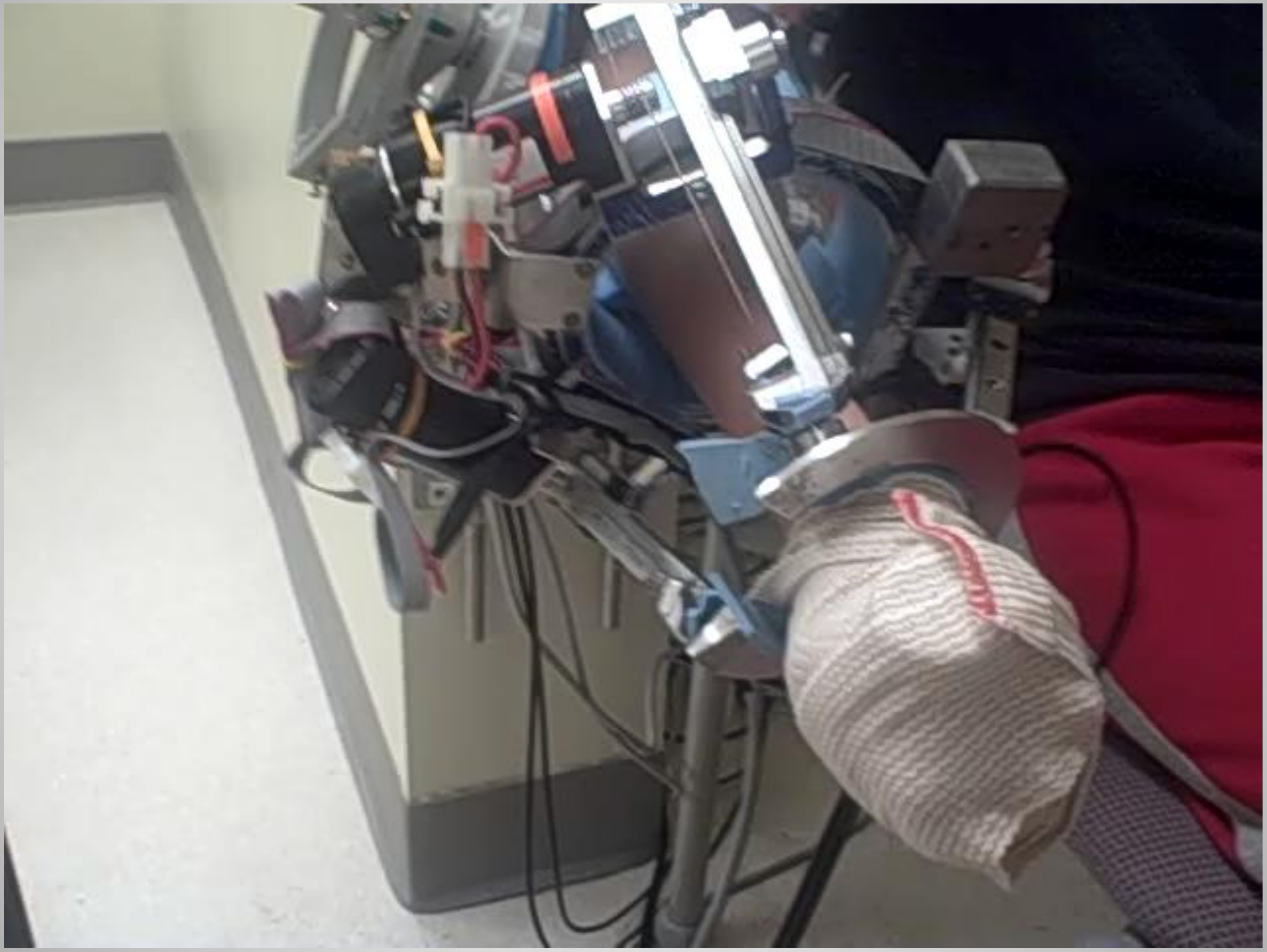

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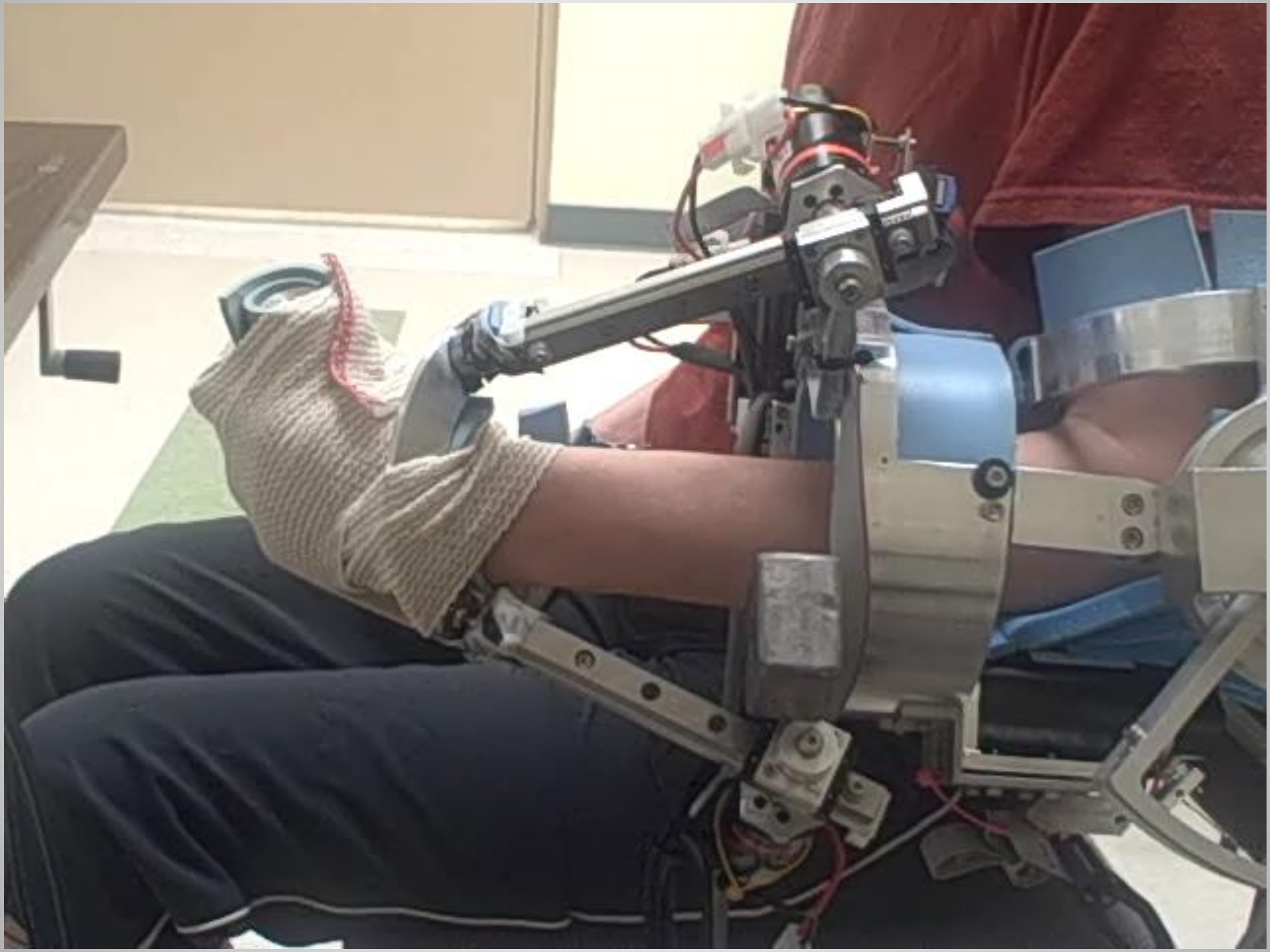
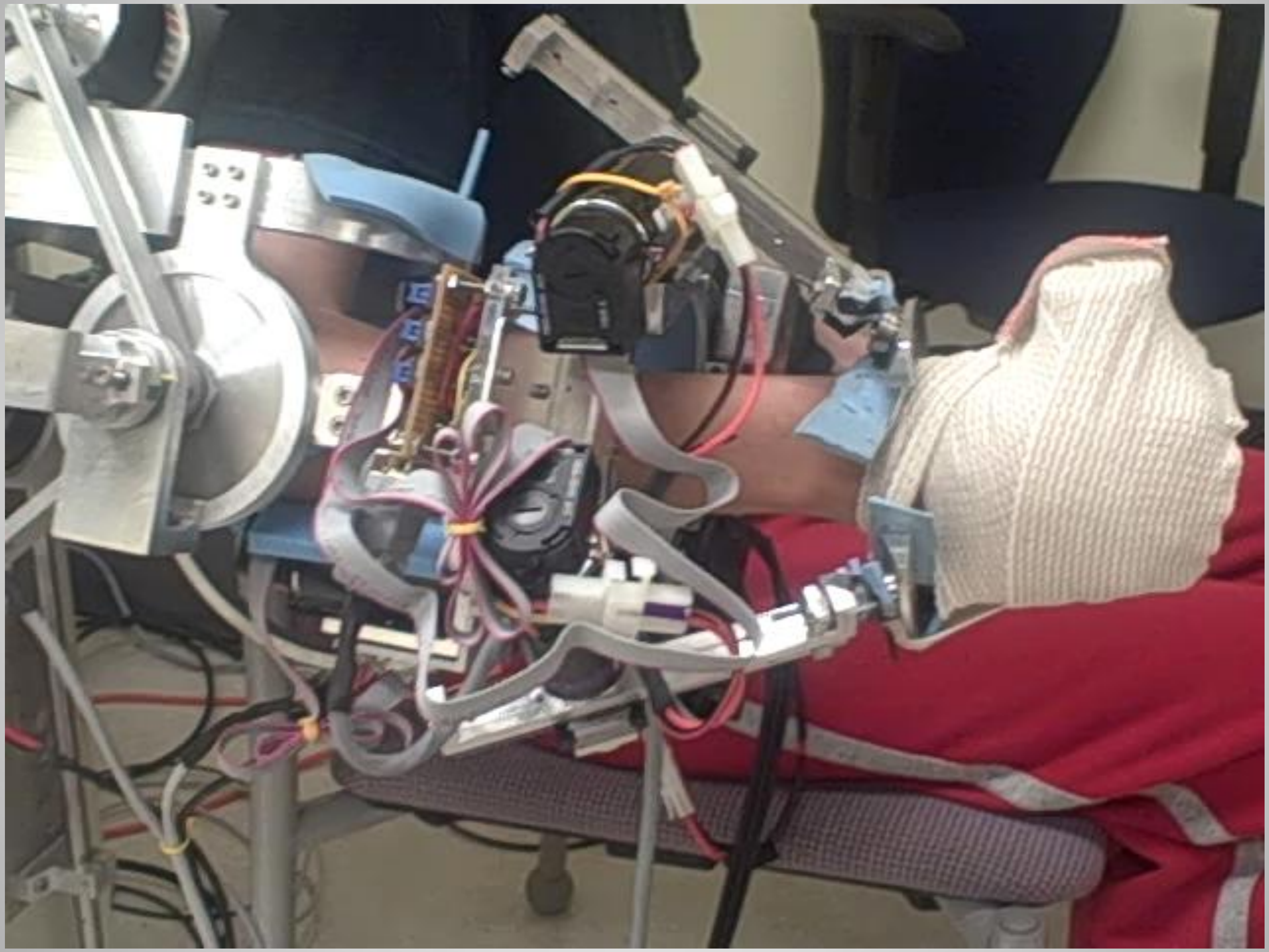


MAHI Exo II Evaluation



Summary of Results

- Subjects are able to successfully complete multiple sessions of robot-assisted training with RiceWrist and MAHI Exo II
- Kinematic performance measures show mixed results, but analysis incomplete
  - Large improvements in movement smoothness observed for left upper limb
  - No observed improvements in movement smoothness for right upper limb
- Clinical performance measures capture some UL improvements

Mechanisms of recovery

- Reorganization of remaining neural circuits
- Formation of new circuits at cortical and sub-cortical regions including the spinal cord below the lesion
- Minimum improvements for right upper limb (the weaker limb) suggestive of longer or combined forms of therapy?
- Spontaneous recovery cannot be ruled out

Conclusions

- Robotic devices can potentially play an important role in the rehabilitation of distal degrees of freedom of the upper limb after SCI
- Robotic devices as assessment tools can generate valuable objective measures
- Potential exists for customized and performance-based therapeutic strategies

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