An Evaluation of Sensor-Placement-Agnostic Sonomyography
For Continuous Control by Users with Heterogenous Capabilities

Gavin Sueltz, Vikram Athithan, Emma Ferran, Maria Herrera, Carson J. Wynn, and Laura A. Hallock

2026.04.17

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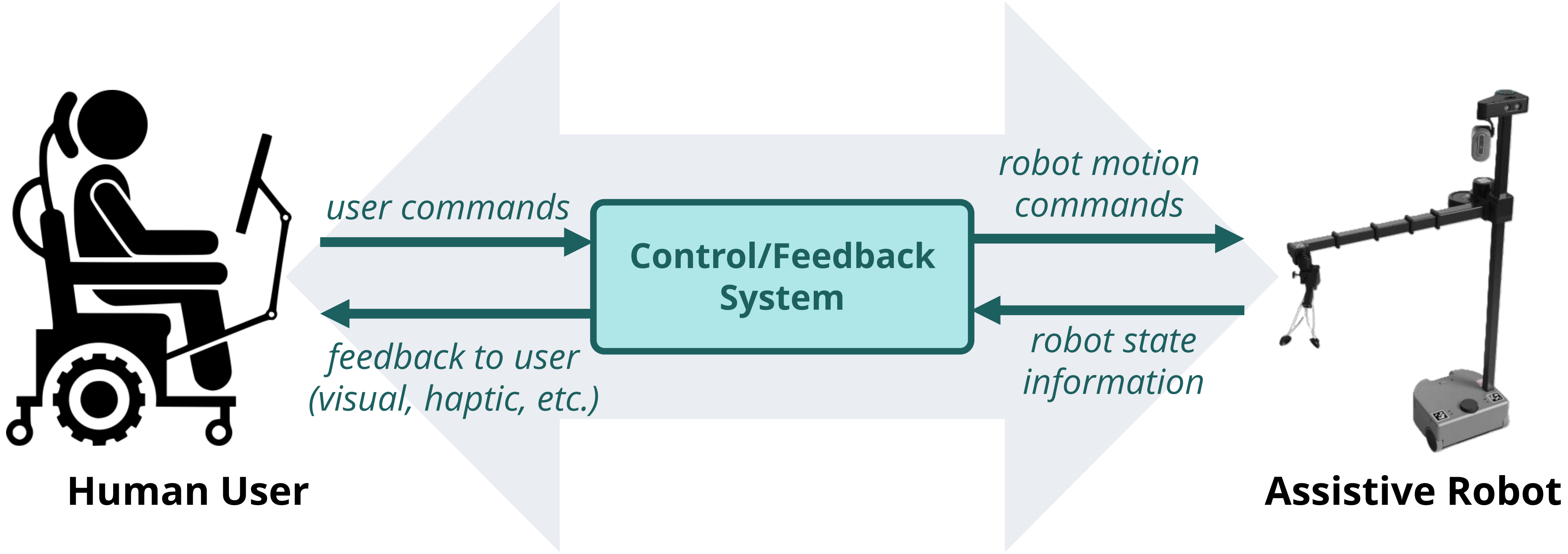
Motivation: Assistive Manipulator Control

- **There are over 300,000 SCI survivors** in the United States [1].
- SCI survivors could benefit from **intuitive control of (high-DOF) assistive robotic manipulators, regardless of residual function**.



[1] National Spinal Cord Injury Statistical Center

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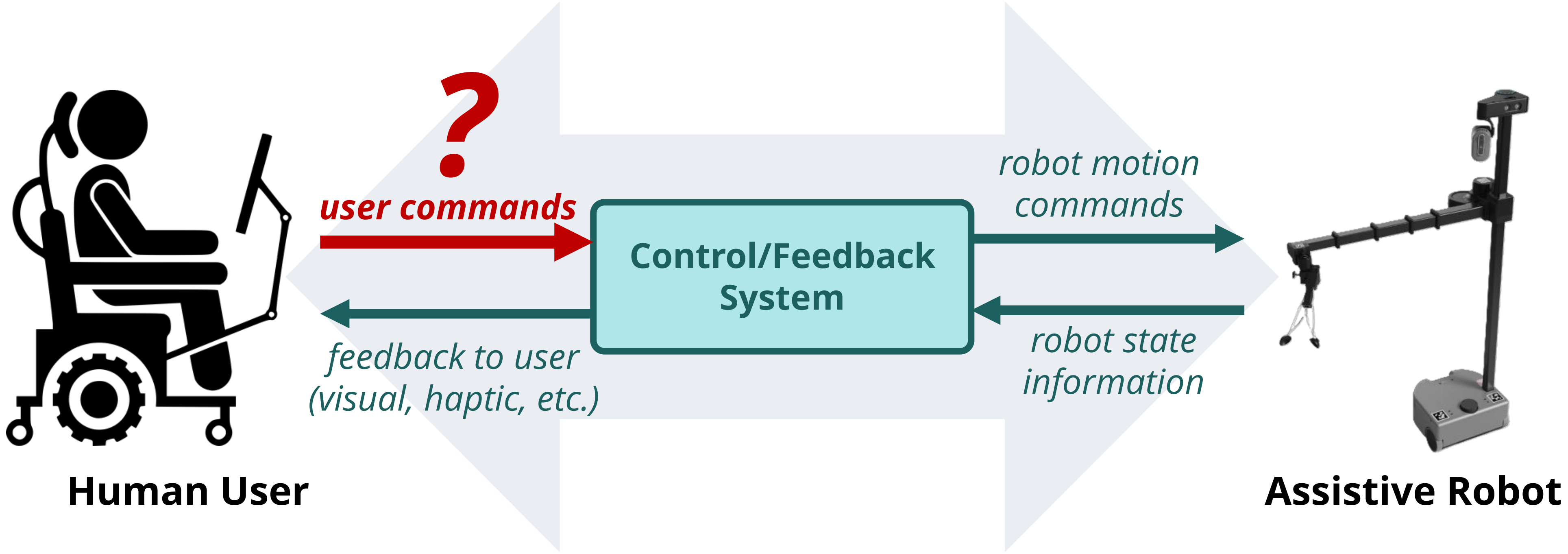

State of the Art: Assistive Device Control

Commercial Interfaces

Device	**Sensor Placement/Target**	**Signal Type**	**Degrees of Freedom**	**Training/Calibration Data Required**
Sip-and-puff [2] 	Mouth	Discrete (lim. continuous)	2–4 DOF	Low
Joystick [3] 	Hand, wrist, jaw	Continuous	2–3 DOF	Low

[2] Mougharbel et al. (2013) [3] Rulik et al. (2022)

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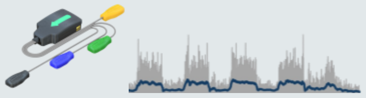
Biosensing	sEMG [4], [5] 	Surface muscles (e.g., residual limb)	Discrete, classification	n differential [4] 29 classes [5]	High

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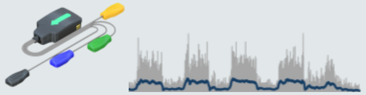
Biosensing	sEMG [4], [5] 	Surface muscles (e.g., residual limb)	**Discrete, classification**	n differential [4] 29 classes [5]	**High**

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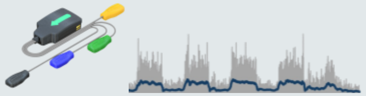
Biosensing	sEMG [4], [5] 	Surface muscles (e.g., residual limb)	Discrete, classification	n differential [4] 29 classes [5]	High
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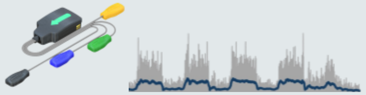
Biosensing	sEMG [4], [5] 	Surface muscles (e.g., residual limb)	Discrete, classification	n differential [4] 29 classes [5]	High
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[6] Dhawan et al. (2019) [7] Lu et al. (2026)

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Commercial Interfaces: Sip-and-puff, Joystick
Biosensing: sEMG, SMG

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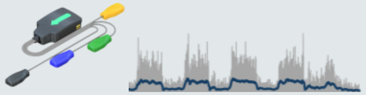
sEMG [4], [5] 	Surface muscles (e.g., residual limb)	Discrete, classification	n differential [4] 29 classes [5]	High
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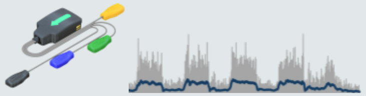
Biosensing	sEMG [4], [5] 	Surface muscles (e.g., residual limb)	Discrete, classification	n differential [4] 29 classes [5]	High
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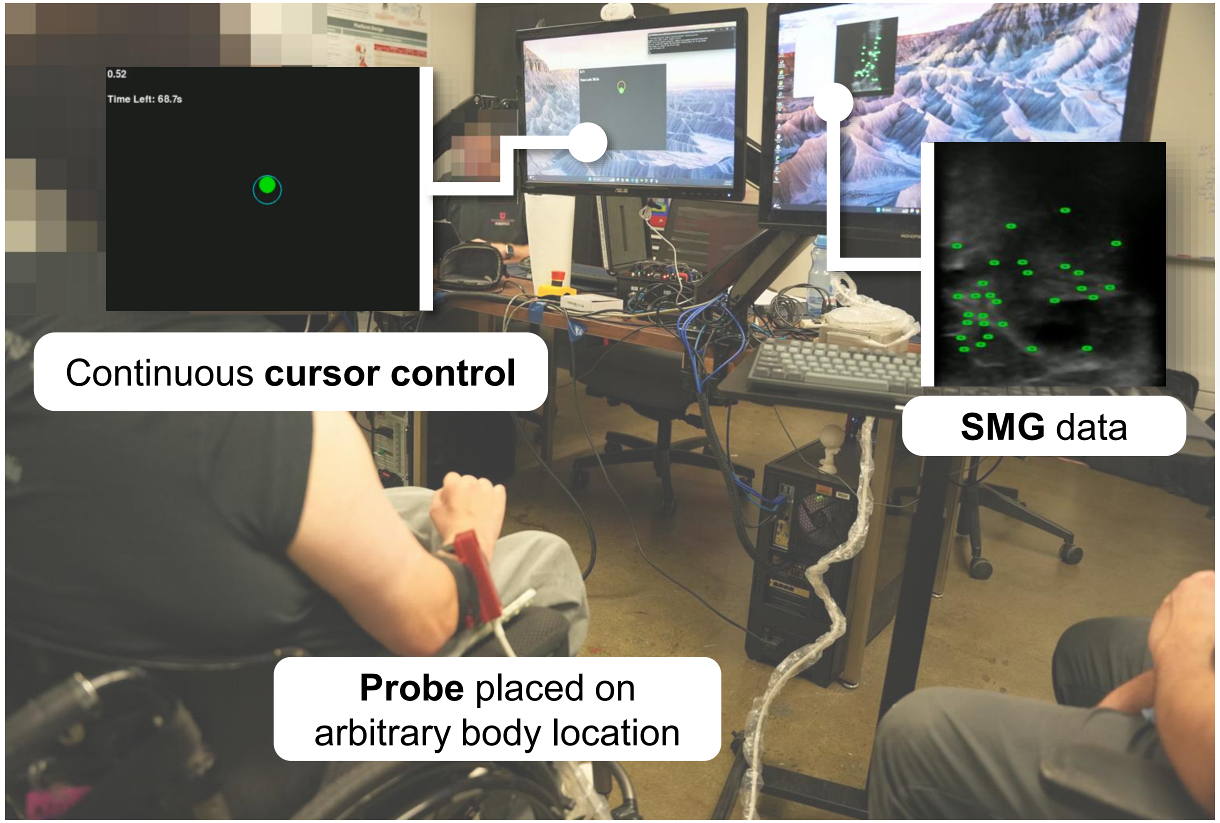
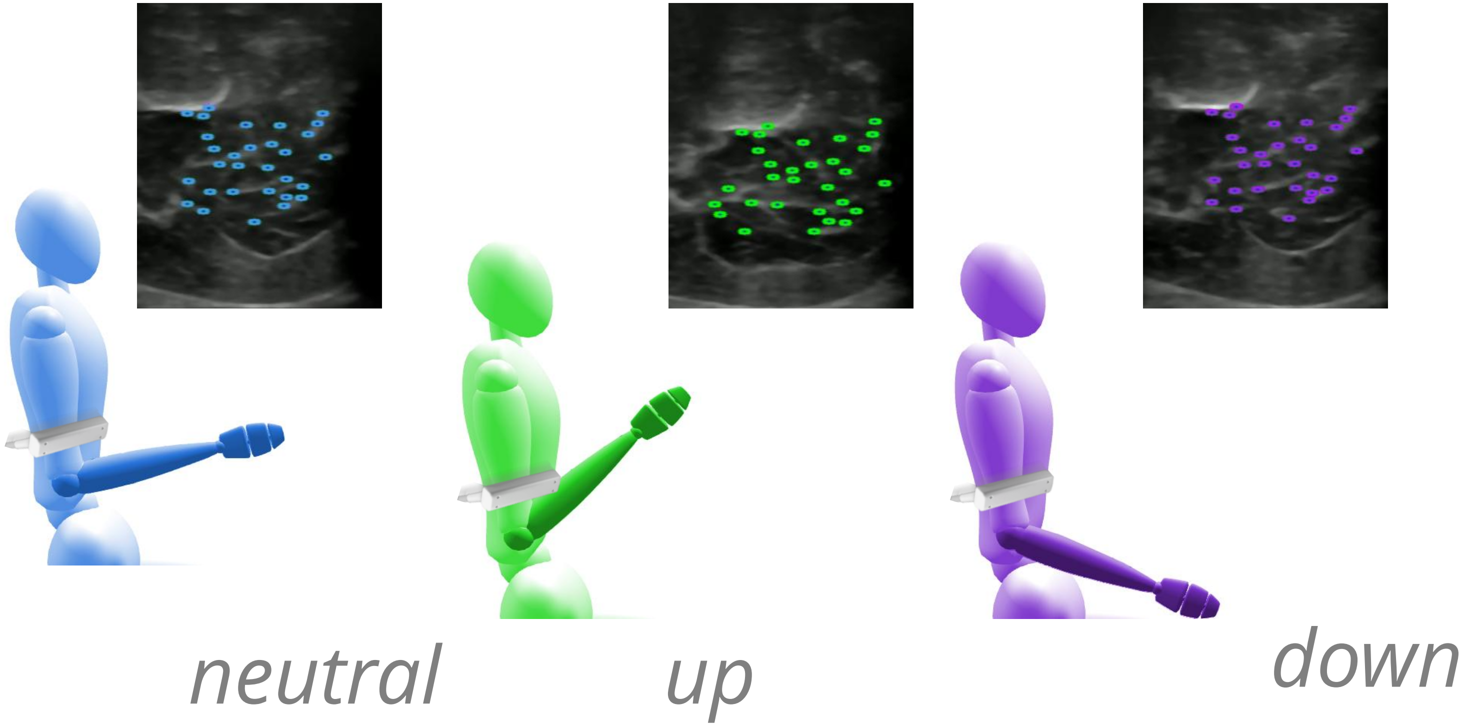
	Ideal/Goal	**Anywhere**	**Continuous**	**As many as possible**	**Low**
	Ours (SMG)	**“Anywhere”**	**Continuous**	**1 (~2) DOF**	**Very Low (3 pt)**

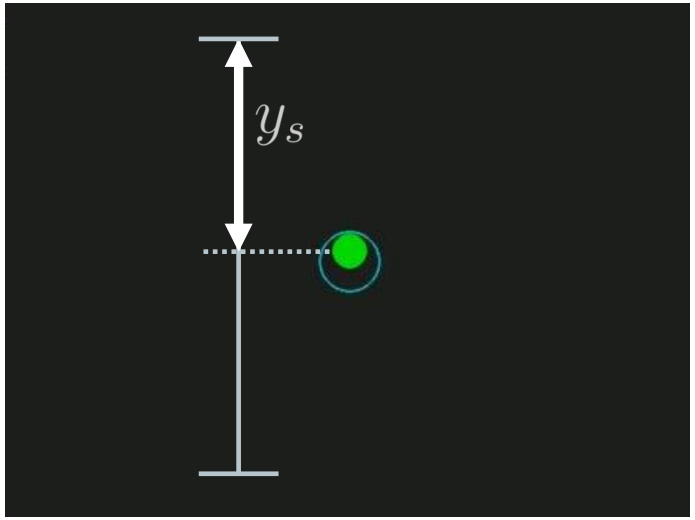
Contribution:
Sensor-Location-Agnostic SMG Interfaces

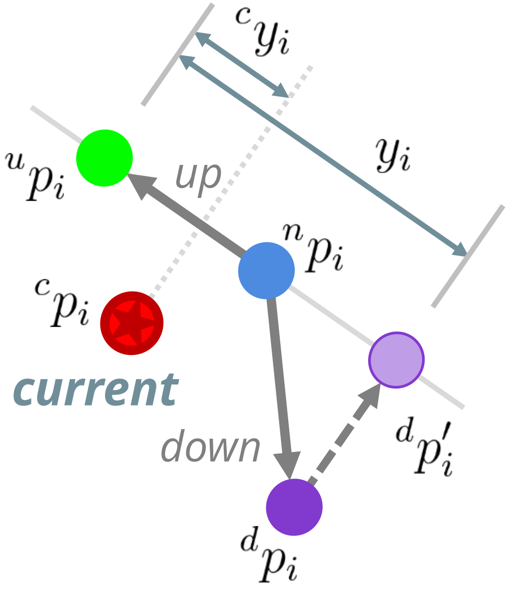
- We have developed a **novel optical flow-based SMG interface** enabling
  - continuous 1-DOF control
  - with **minimal 3-pose calibration**
  - from **any sensor location** at which the user can generate tissue motion.
- We also demonstrate **preliminary 2-DOF control**.



1-DOF Algorithm







Feature points are tracked via Lucas–Kanade sparse optical flow [8].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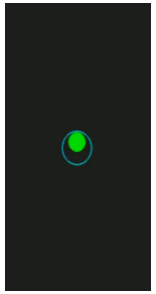
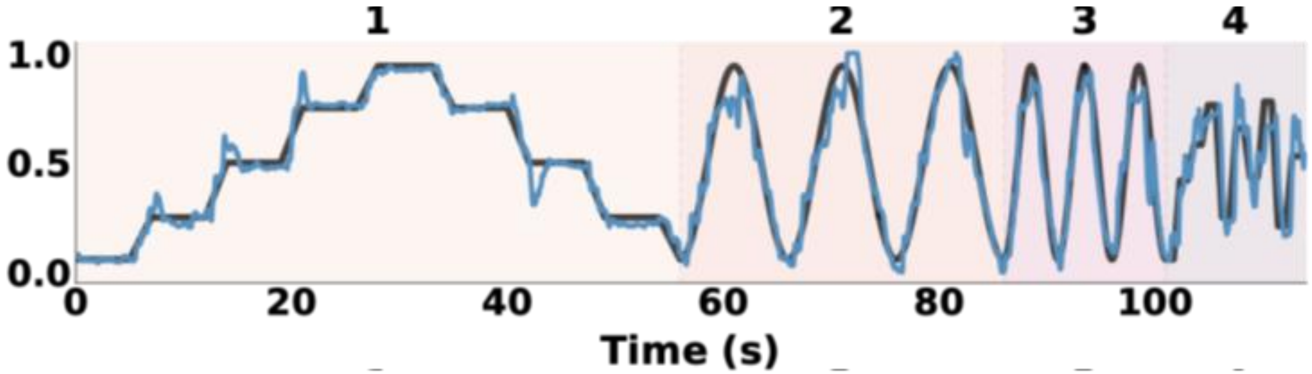
1-DOF Evaluation: Experimental Design

- 9 participants:
  - **3 cervical SCI survivors** (all with some residual arm function)
  - 6 uninjured individuals
- **Trajectory tracking task**





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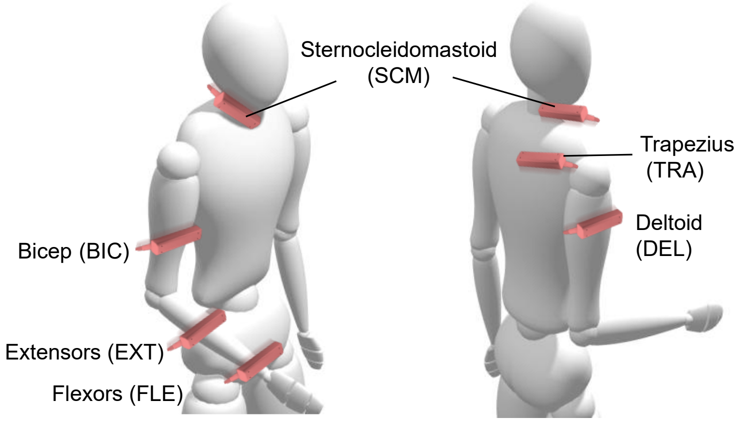

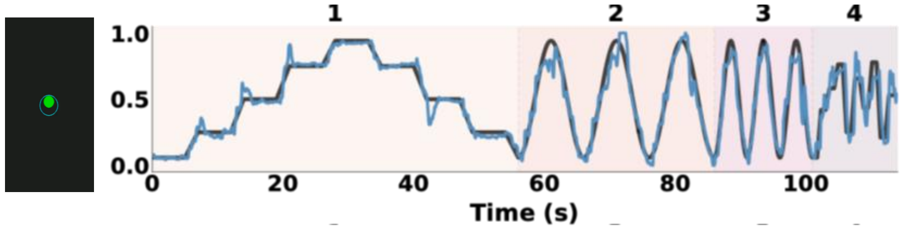

ID	Location
BIC	Biceps
SCM	Sternocleidomastoid
TRA	Trapezius
DEL	Deltoid
EXT	Wrist Extensors
FLE	Wrist Flexors

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  - **3 cervical SCI survivors** (all with some residual arm function)
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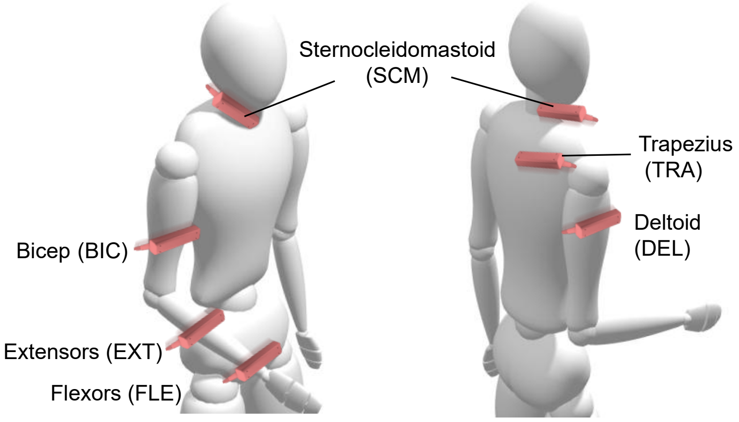
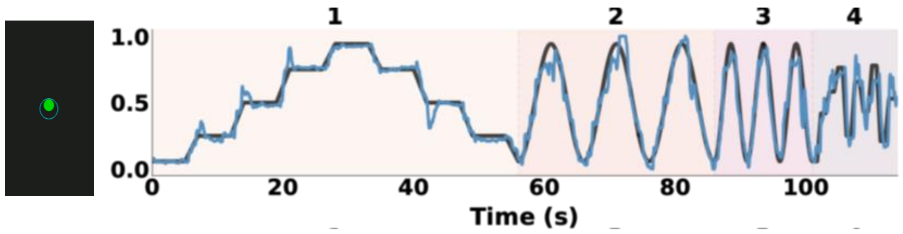
- **Trajectory tracking task** across:
  - **6 different sensor placements** across the upper body.
  - **2 motions** each (prescribed and self-selected)
  - 2 trials each





ID	Location	Prescribed Motion	Self-Selected Motion
BIC	Biceps	elbow flexion / extension	forearm supination / pronation (1, 2, 4), shoulder internal / external rotation (3, 5--9)
SCM	Sternocleidomastoid	right / left head tilt	head flexion / extension (1, 3--9), looking right / left (2)
TRA	Trapezius	shoulder elevation / depression	shoulder protraction / retraction (1, 2, 5, 7--9), shoulder abduction / adduction (3, 6), shoulder flexion / extension (4)
DEL	Deltoid	shoulder abduction / adduction	shoulder external / internal rotation (1, 4, 8), shoulder protraction / retraction (2), shoulder flexion / extension (3, 5--7, 9)
EXT	Wrist Extensors	wrist flexion / extension	forearm supination / pronation (1--3, 7, 8), hand open / close (4--6, 9)
FLE	Wrist Flexors	wrist flexion / extension	forearm supination / pronation (1--3, 5--7, 9), hand open / close (4, 8)

1-DOF Evaluation:
Performance Across Sensor Placement

- Every participant demonstrated some level of **control with each sensor placement**
- No clear worst-performing sensor placement
- Control possible even when probe was placed across muscles of which the user had **no volitional control**, as long as tissue motion could be generated (e.g., via antagonist)

SCI Survivors (*boxed*)

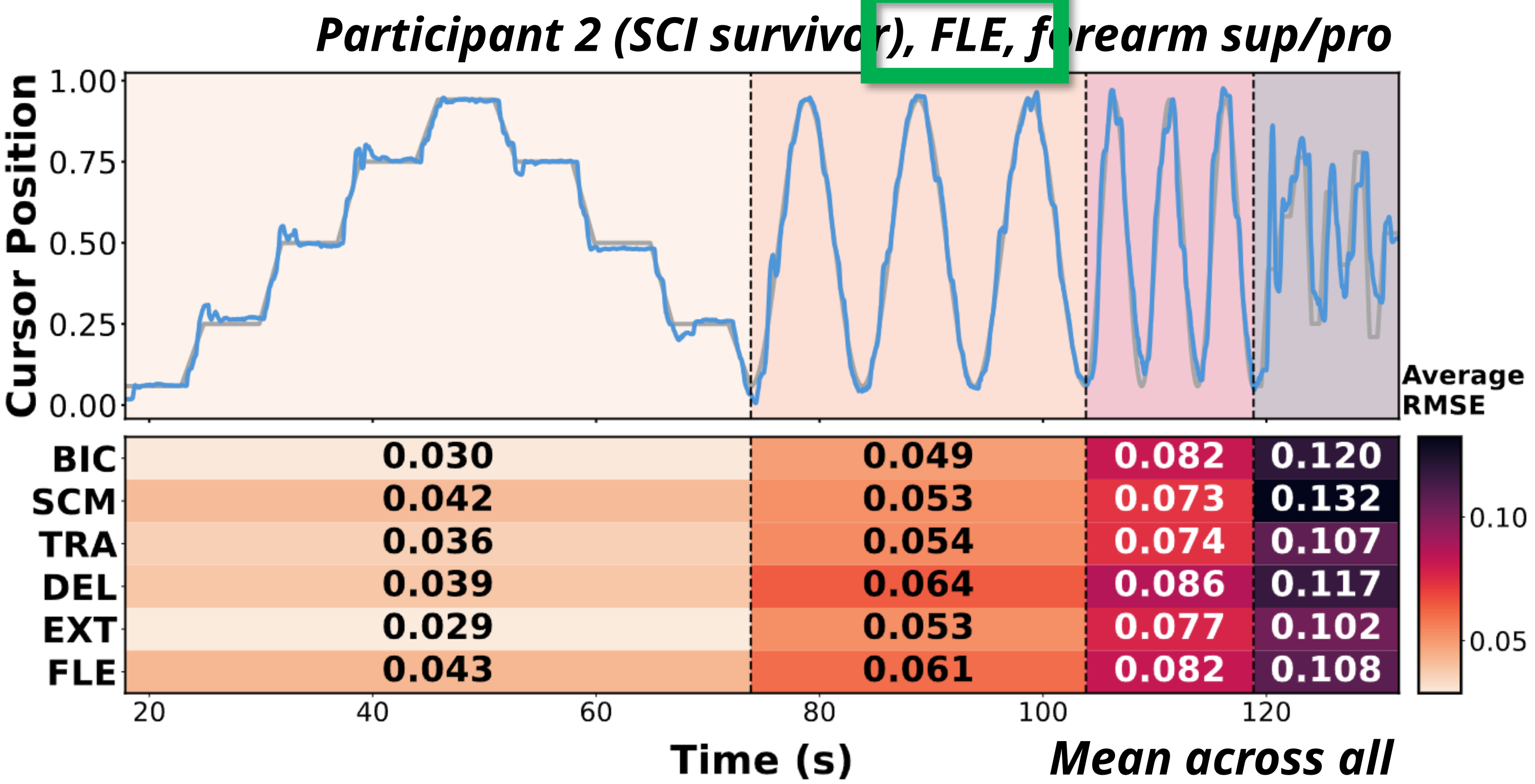
Average RMSE

Participant	BIC	SCM	TRA	DEL	EXT	FLE
1	0.095	0.048	0.038	0.099	0.054	0.058
2	0.081*	0.076	0.053*	0.078	0.054	0.108*
9	0.036	0.066	0.053	0.094	0.038	0.052
7	0.070	0.133*	0.164*	0.062*	0.054	0.110
3	0.046	0.048	0.048	0.049	0.034	0.036
4	0.033	0.045	0.046	0.031	0.035	0.044
5	0.036	0.033	0.039*	0.037	0.059	0.030
6	0.051	0.049	0.066	0.050	0.078	0.052
8	0.041	0.072	0.064	0.044	0.040	0.078
Mean RMSE:	5.4%	6.3%	6.3%	6.0%	4.9%	6.3%

Placement

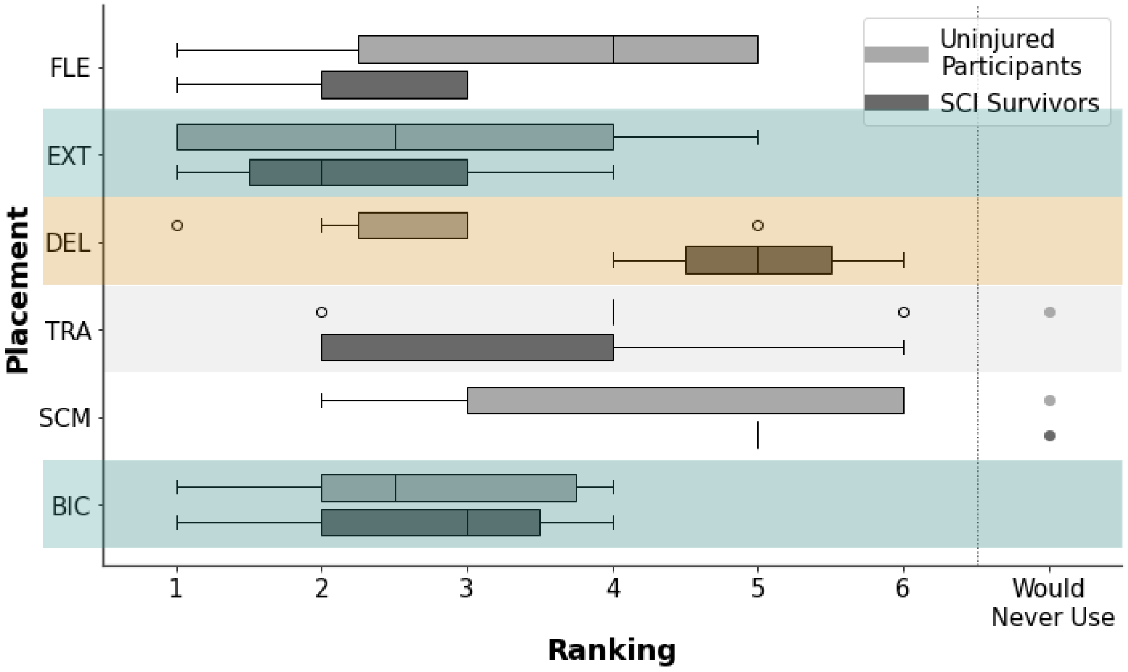
1-DOF Evaluation: Performance Across Trajectory Tasks

RMSE increases with each trajectory segment, but many users are able to **maintain RMSE of ~10%**.



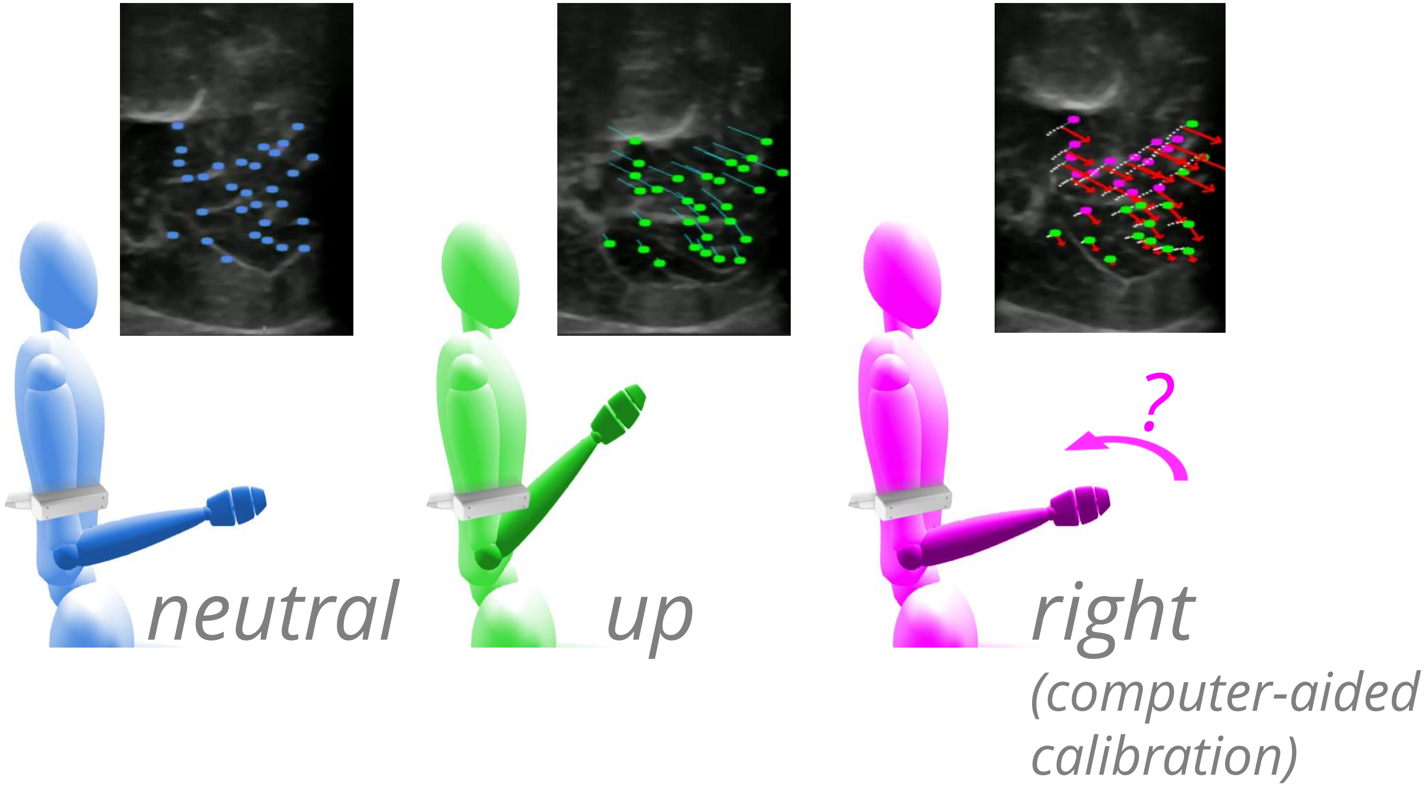
Mean across all participants and motions

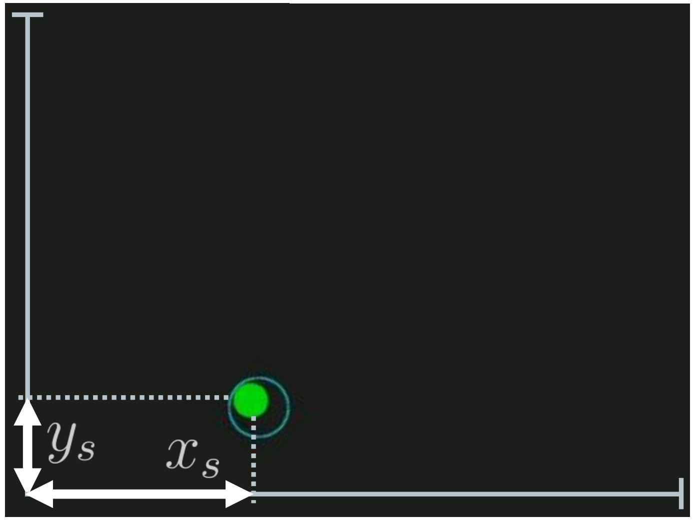
1-DOF Evaluation: User Preferences

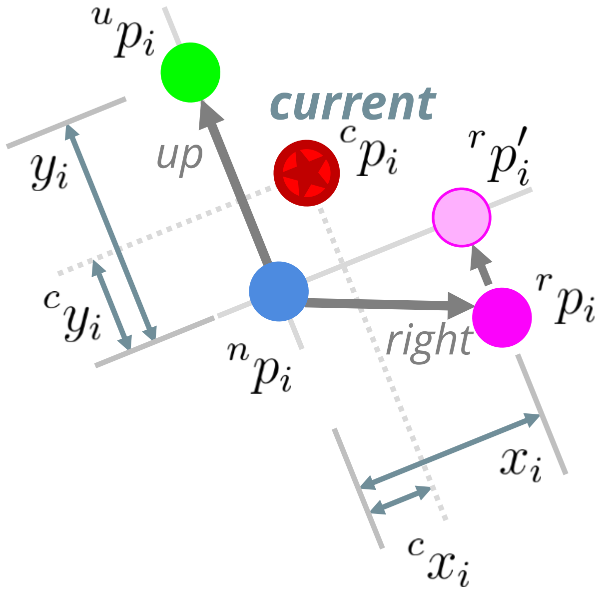


- Users' placement preferences were heterogeneous
- The most preferred locations were the **bicep (BIC)** and **extensor (EXT)**
- **Deltoid (DEL) usage impacted balance** for SCI survivors
- Participants highlighted control schemes for which motions of the body and the on-screen cursor were **kinematically similar**

2-DOF Algorithm







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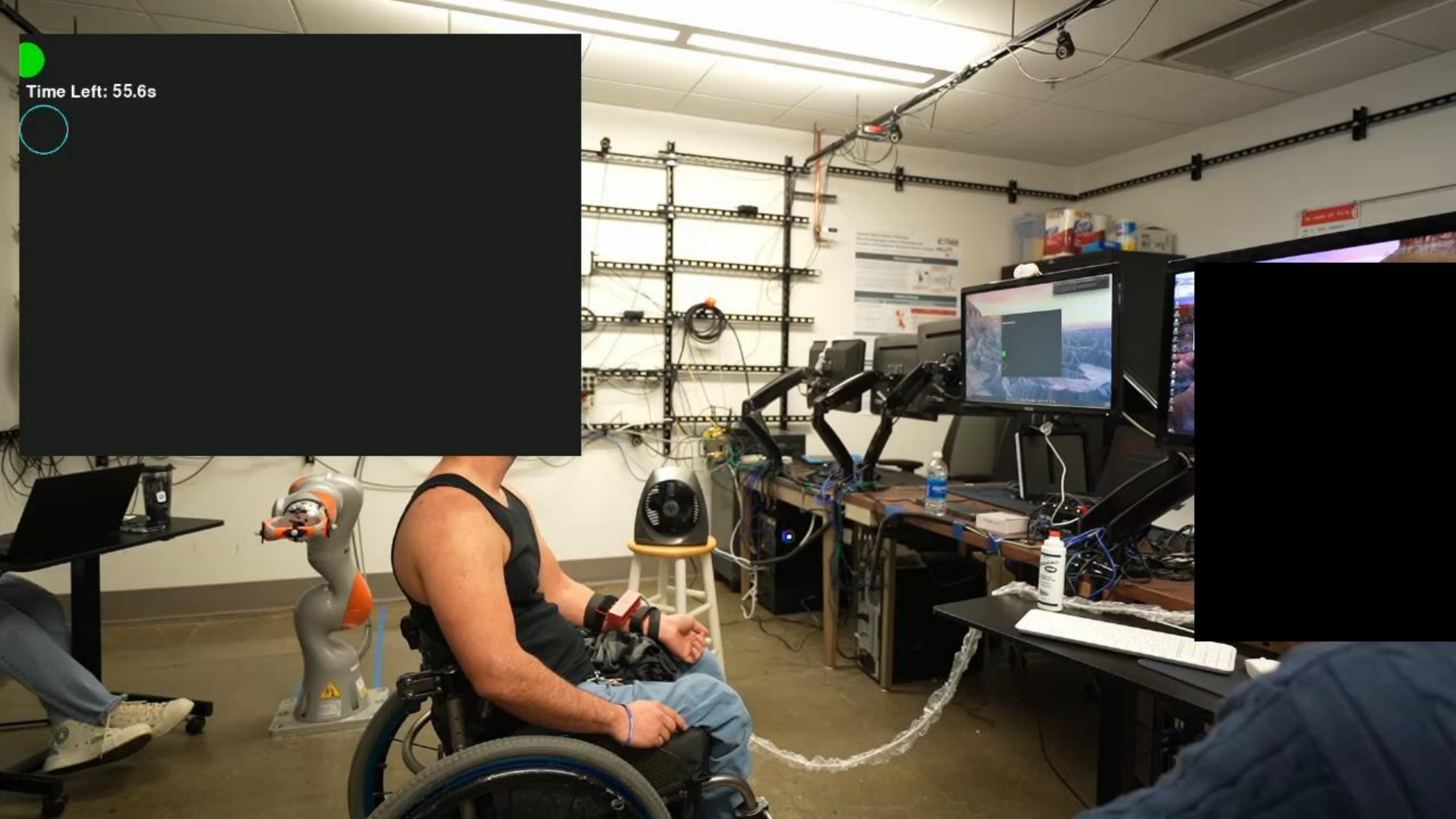
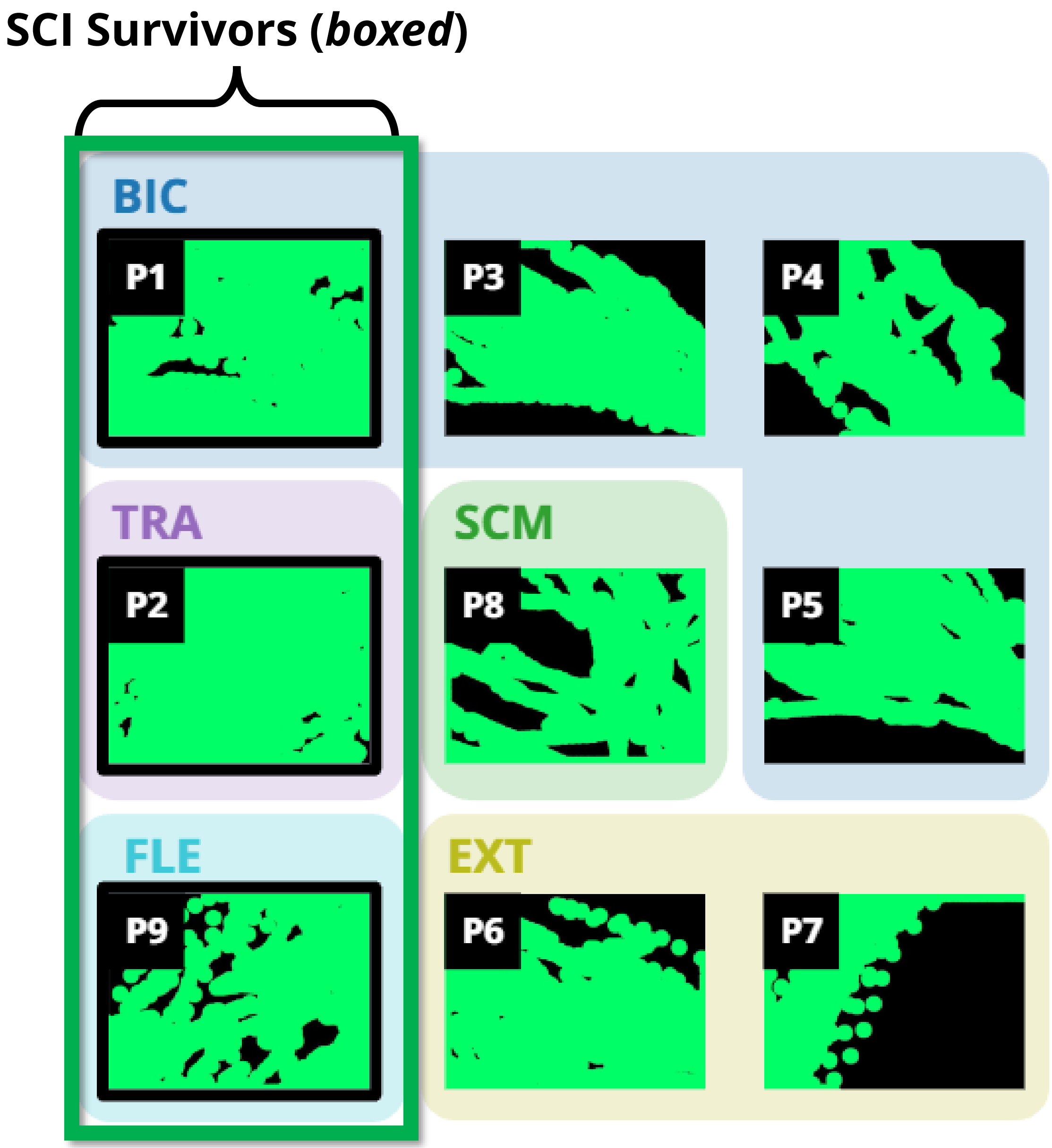
[8] Lucas and Kanade (1981)


Time Left: 55.6s

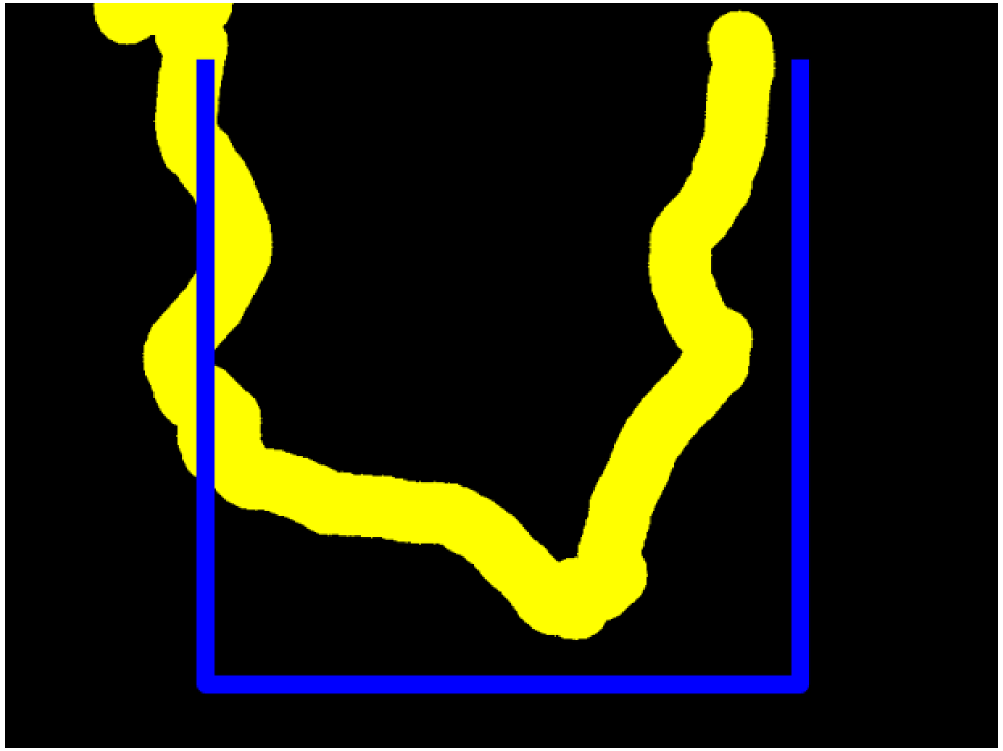
2-DOF Evaluation: Workspace Traversal

- All participants were able to **generate a multi-dimensional signal with the naïve 2-DOF algorithm**.
- **SCI survivors achieved more comprehensive workspace traversal**, possibly due to extended practice.



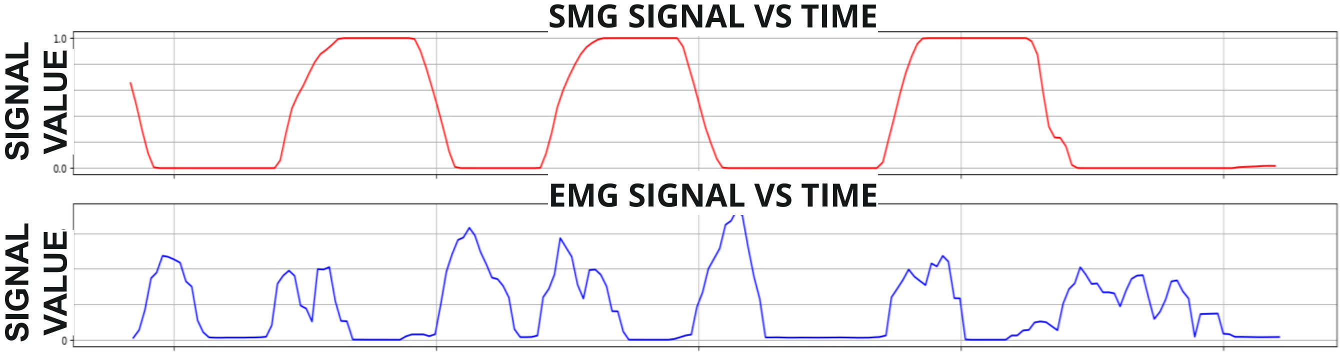
2-DOF Evaluation: Trajectory Following

- Some participants were able to **complete a simple trajectory following task**, demonstrating independent signal modulation.
- To our knowledge, this is the **first demonstration** of sensor-location-agnostic sonomyographic control in 2 continuous, independently-modulated dimensions.



Participant 8 (uninjured), SCM

Current Extensions



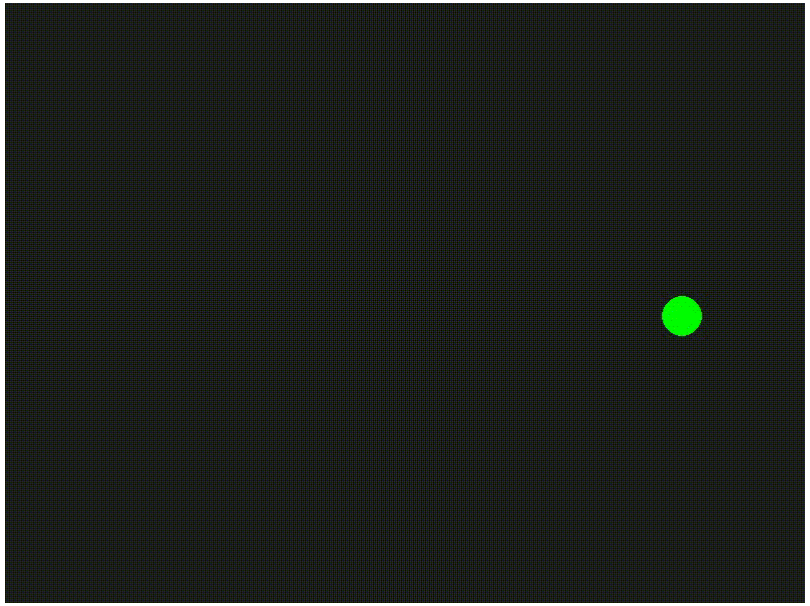
- **System improvements**
  - SMG + sEMG/IMU sensor fusion techniques for a more robust control signal (drift mitigation, etc.)
  - 2-DOF algorithm expansion/development to address coupling/artifacts
  - Additional DOF?
- **System usage**: assistive manipulator control

A Modular Platform for Customizable Biosignal-Based Control of a Simulated Assistive Robot

Carson J. Wynn*, Simon S. Padgen*, and Laura A. Hallock

Poster S1-08 (Friday)

Gavin Sueltz, Vikram Athithan*, Emma Ferran*, Maria Herrera*, Carson J. Wynn*, and Laura A. Hallock. “**Sensor-Placement-Agnostic Sonomyography: Toward Continuous High-Dimensional Control by Users with Tetraplegia**.” *IEEE BioRob* 2026 (accepted).



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ROCKY MOUNTAIN American Society of Biomechanics