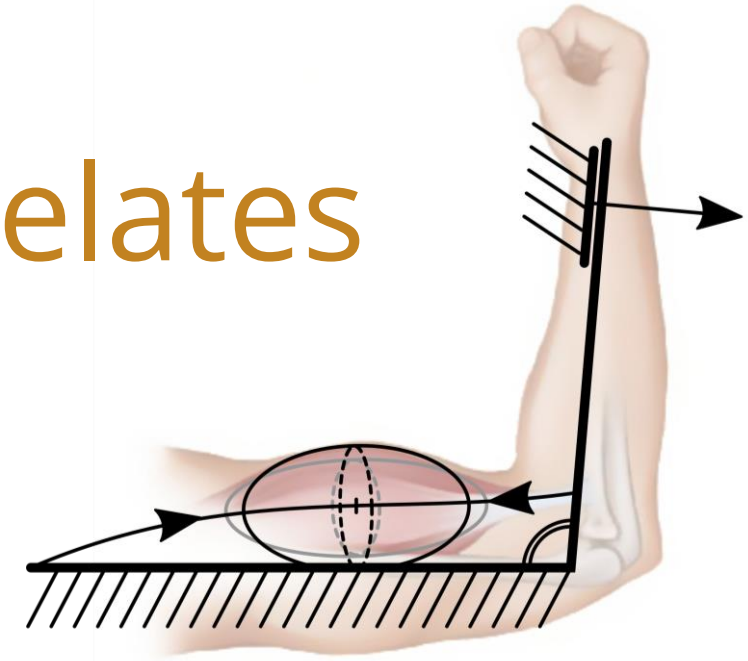
Muscle deformation correlates with output force during isometric contraction



Laura A. Hallock, Akash Velu, Amanda Schwartz, and Ruzena Bajcsy
Correspondence: lhallock@eecs.berkeley.edu

BIOROB 2020 NYC

HART Lab
Human-Assistive Robotic Technologies

Berkeley
UNIVERSITY OF CALIFORNIA

Why measure muscle output force?

Muscles are the actuators of the human body, and knowing the forces they exert is critical to understanding the **capabilities of human motion**.

Understanding of Highly Dexterous Movements

Contact juggling, GIPHY

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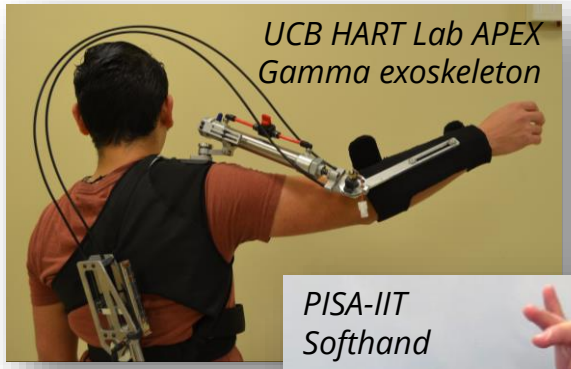
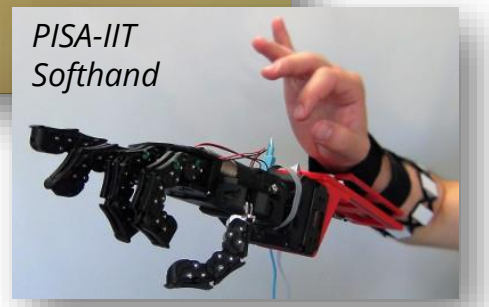
Understanding of Highly Dexterous Movements

Safe and Expressive Assistive Devices





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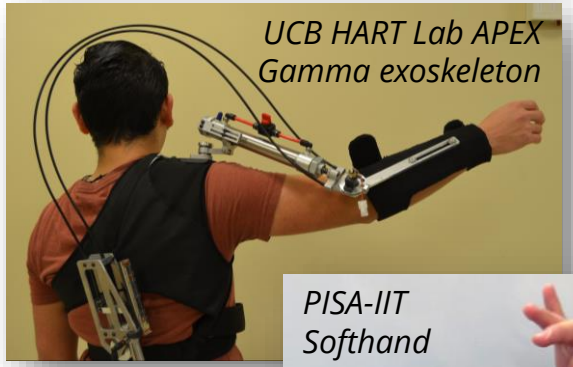
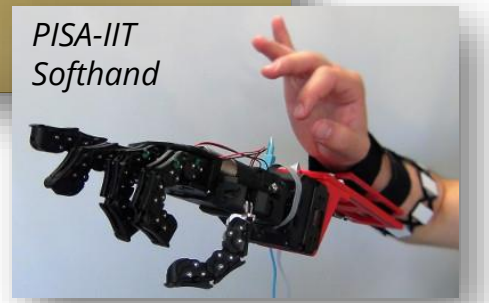


UCB HART Lab APEX Gamma exoskeleton

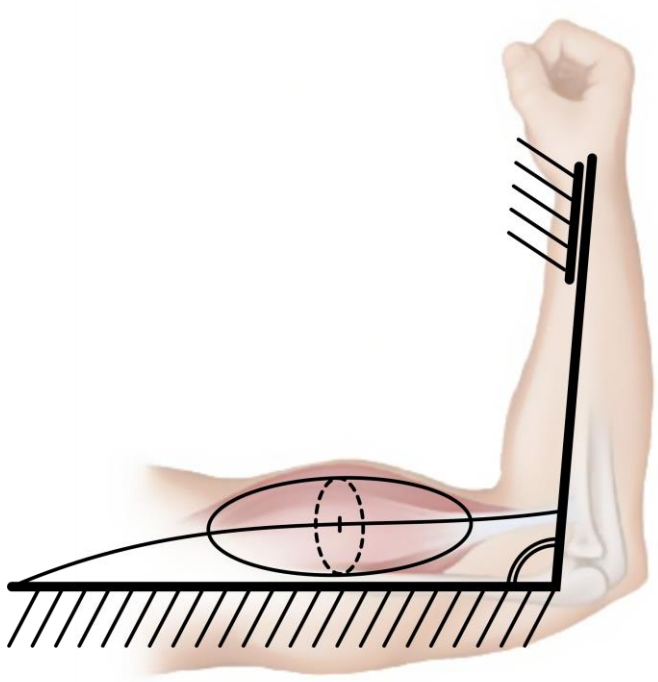


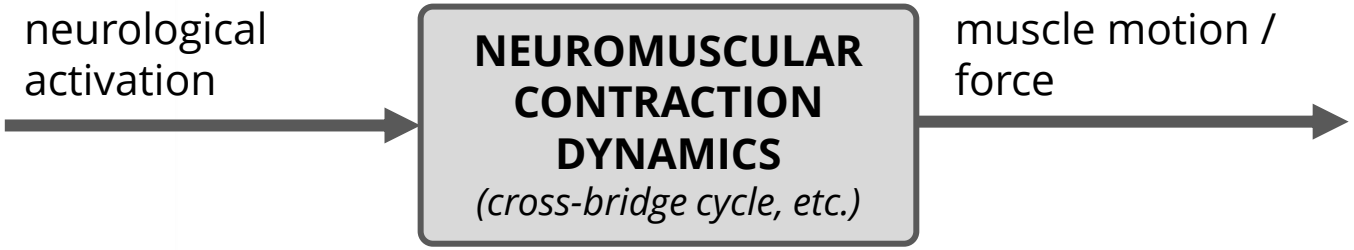
PISA-IIT Softhand

Dexterous Teleoperation

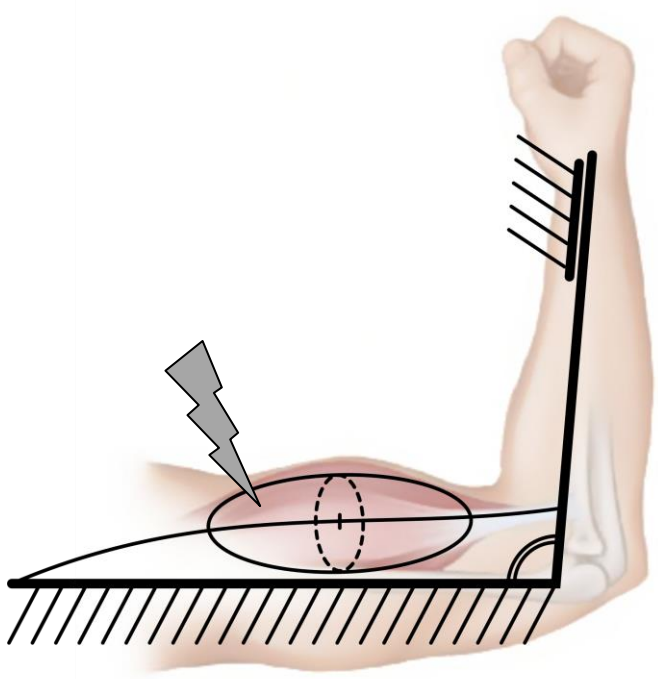
Capio Upper Body Exoskeleton for Teleoperation, DFKI GmbH Robotics Innovation Center

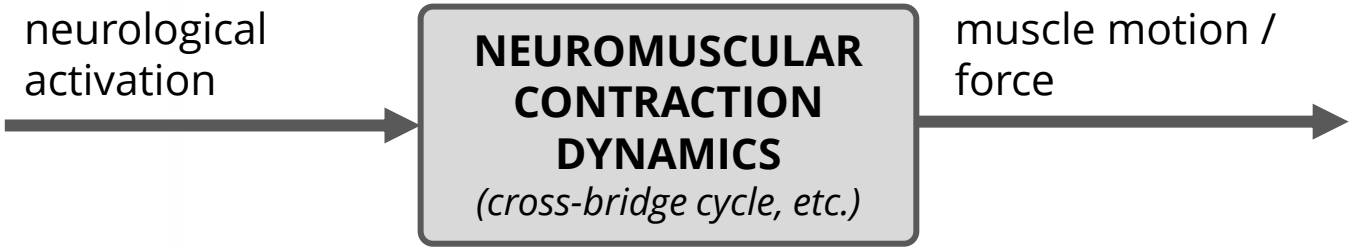
Muscle Force Inference





Muscle Force Inference





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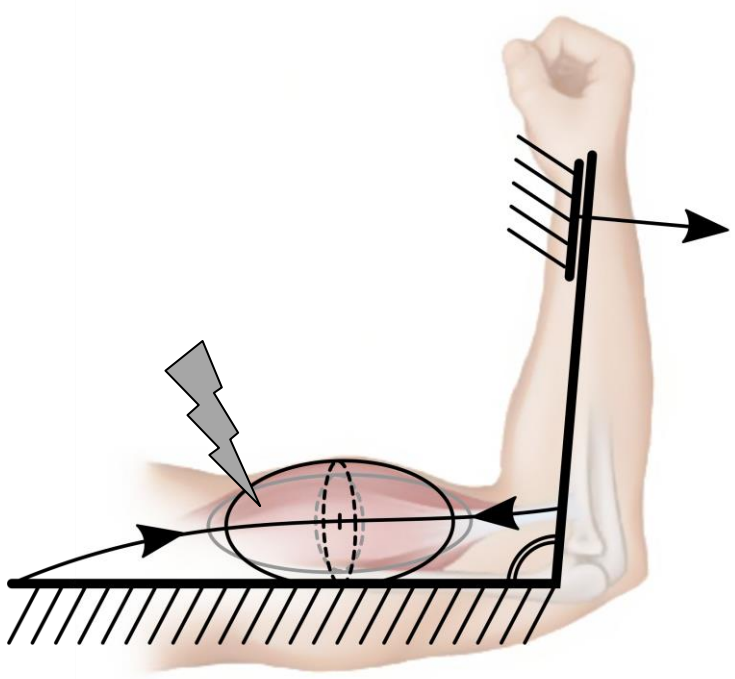
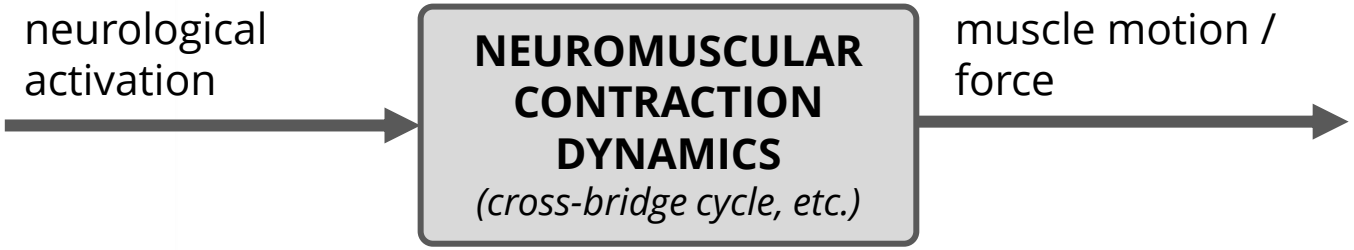
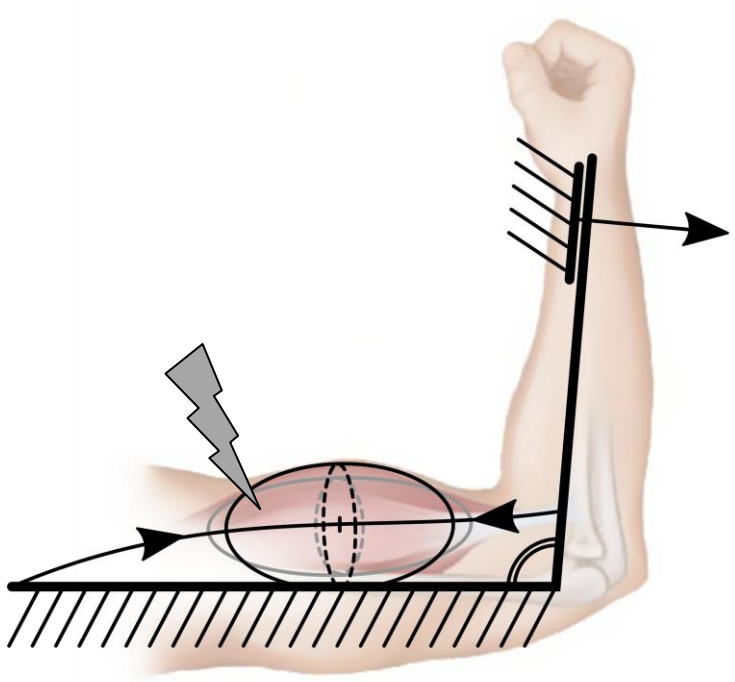
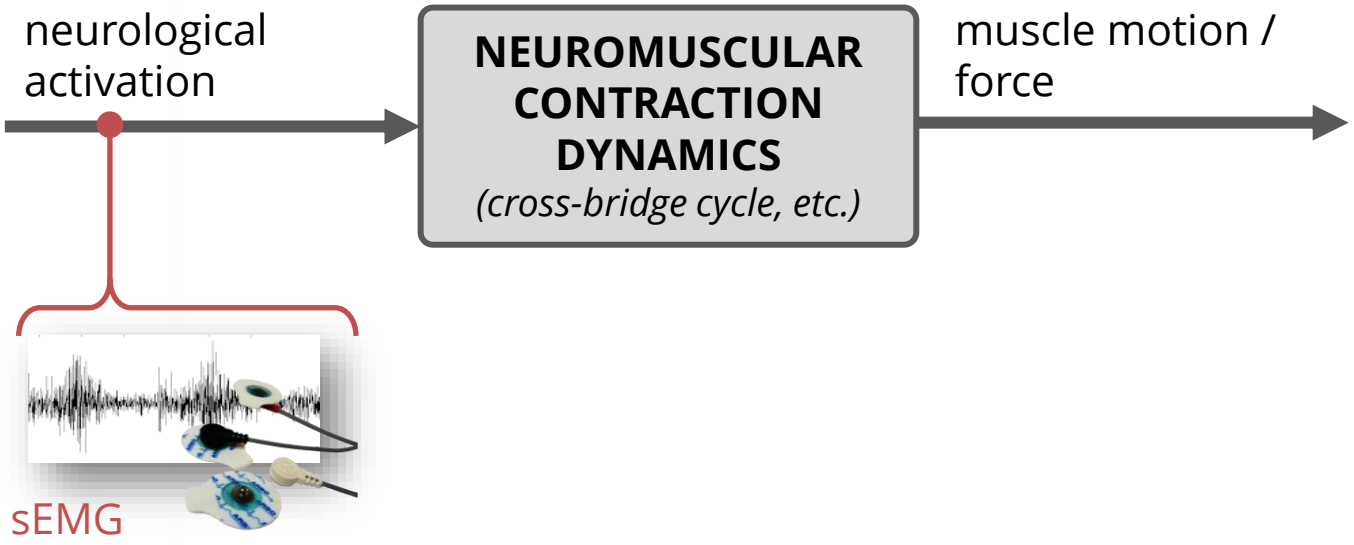




Muscle Force Inference: State-of-the-Art





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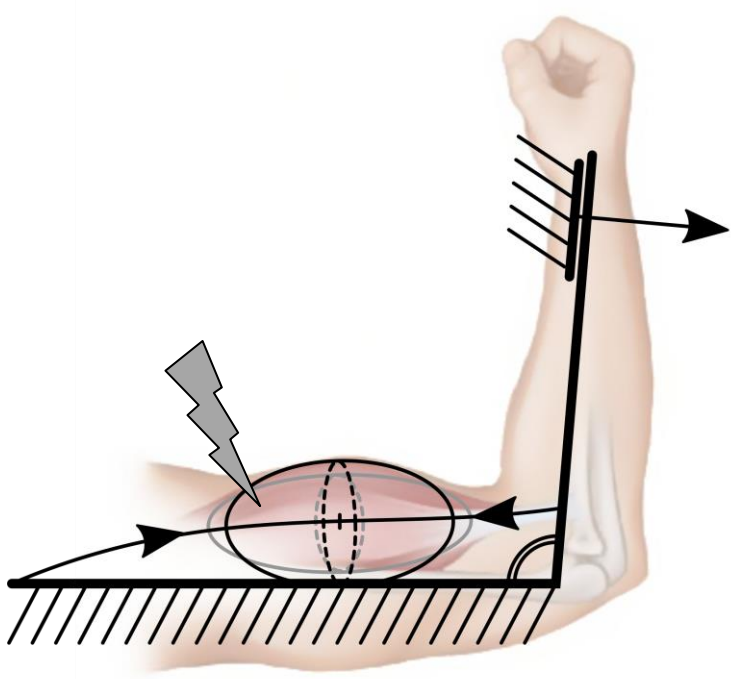
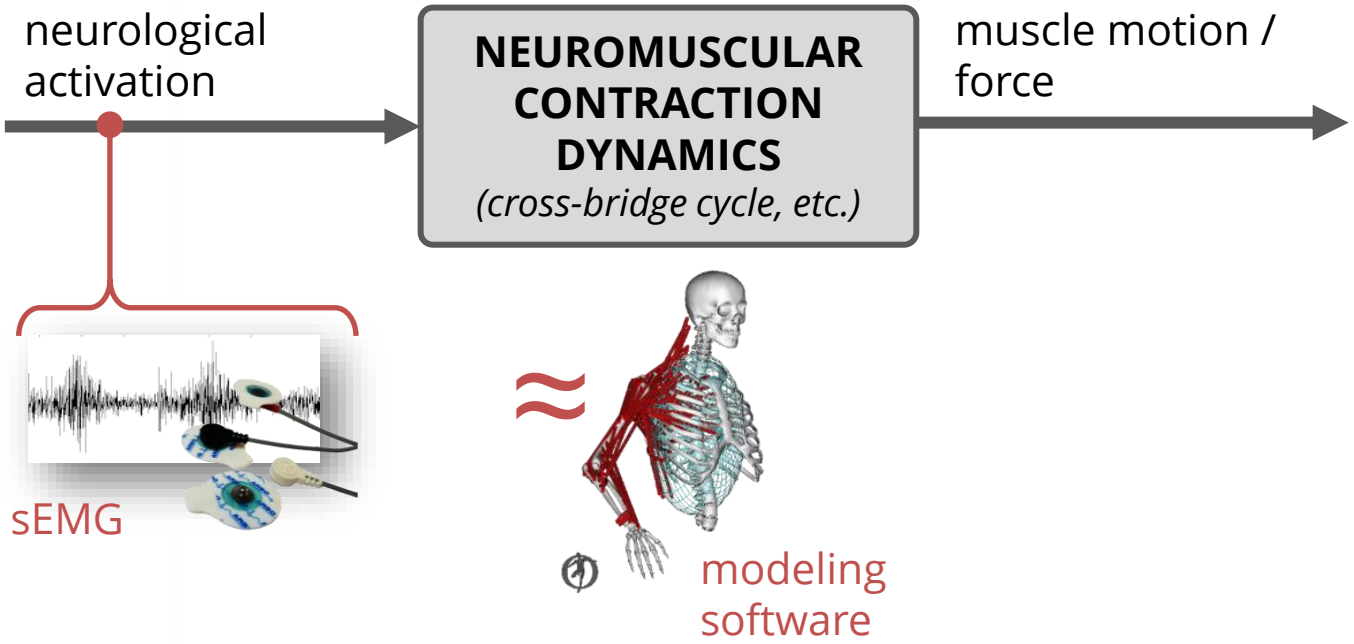
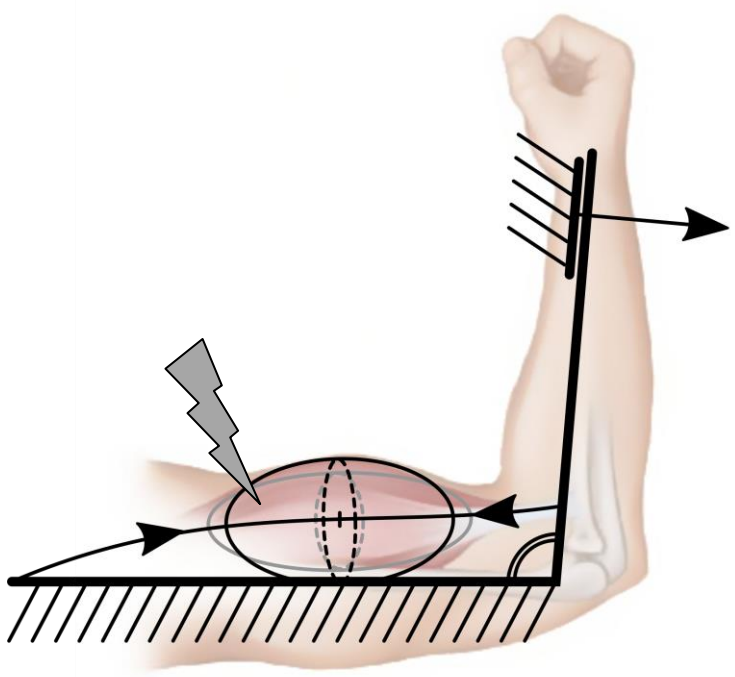




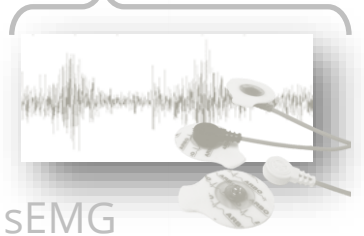
Muscle Force Inference: Our Approach



neurological activation

NEUROMUSCULAR CONTRACTION DYNAMICS
(cross-bridge cycle, etc.)

muscle motion / force



sEMG

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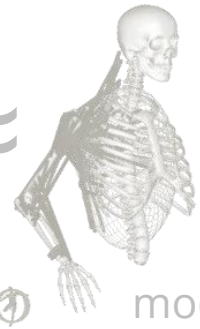
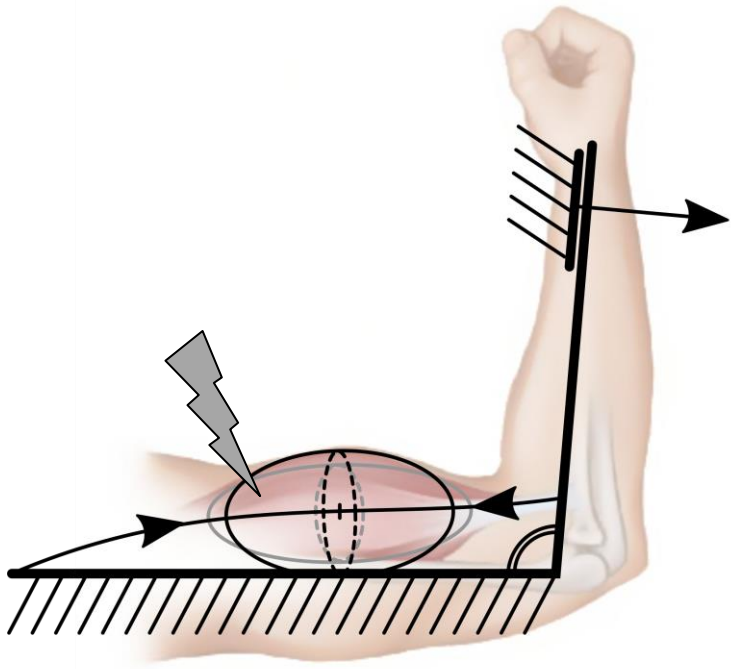


modeling software

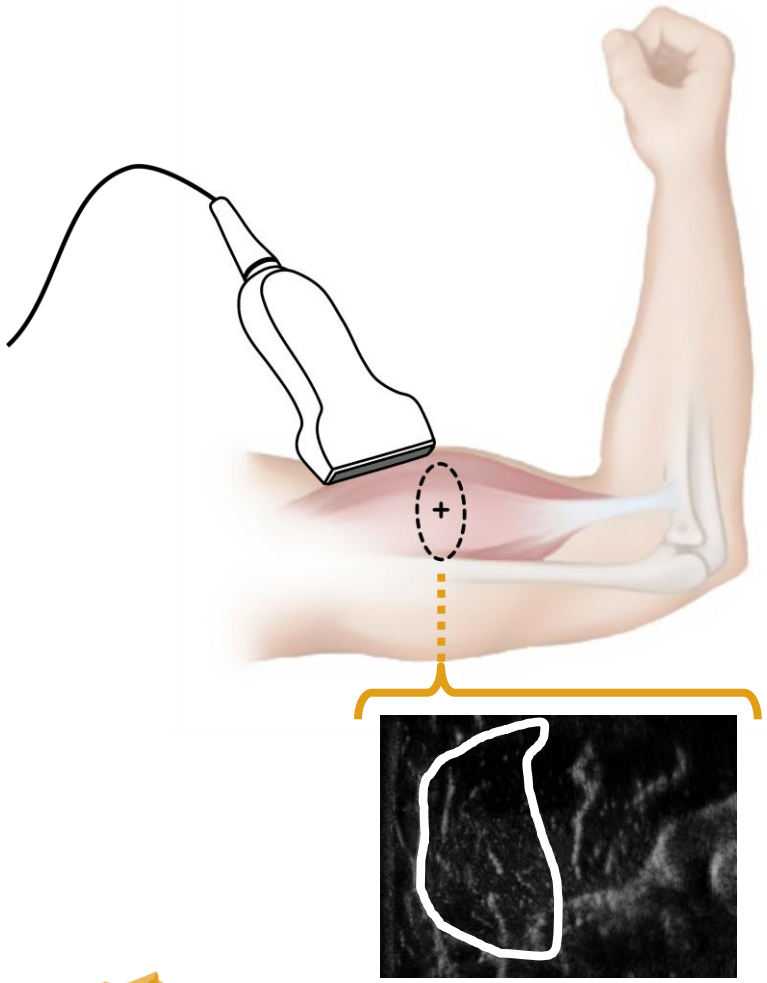
ultrasound

Muscle Force Inference: Contributions



CONTRIBUTIONS

Muscle Force Inference: Contributions

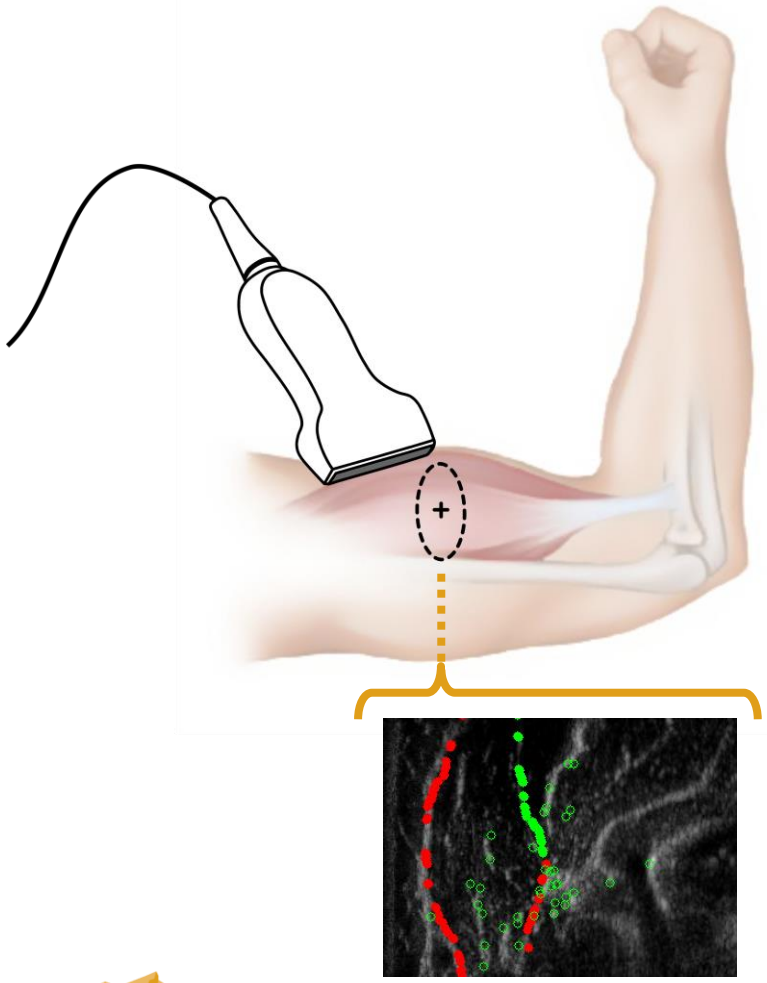


CONTRIBUTIONS

We show that:

I. **Simple measures of muscle deformation**, including cross-sectional area, thickness, and aspect ratio, **are correlated with output force**.

Muscle Force Inference: Contributions



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We show that:

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II. **This deformation can be tracked** through time series ultrasound frames using optical flow techniques.

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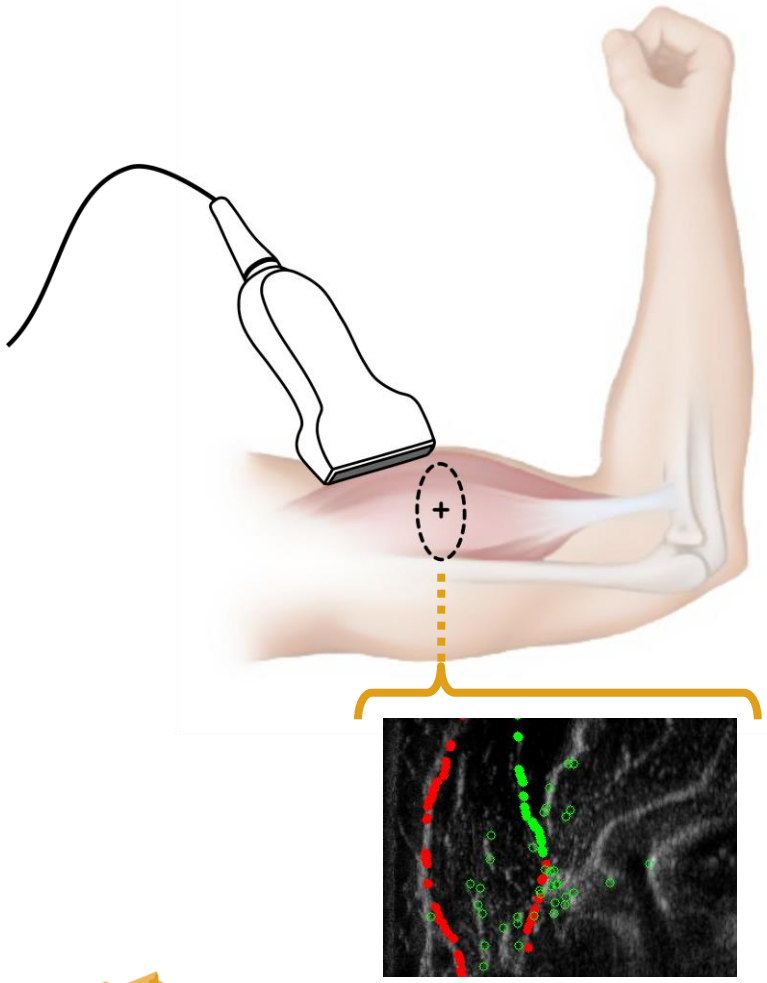

CONTRIBUTIONS

All code and data at:
simtk.org/projects/openarm

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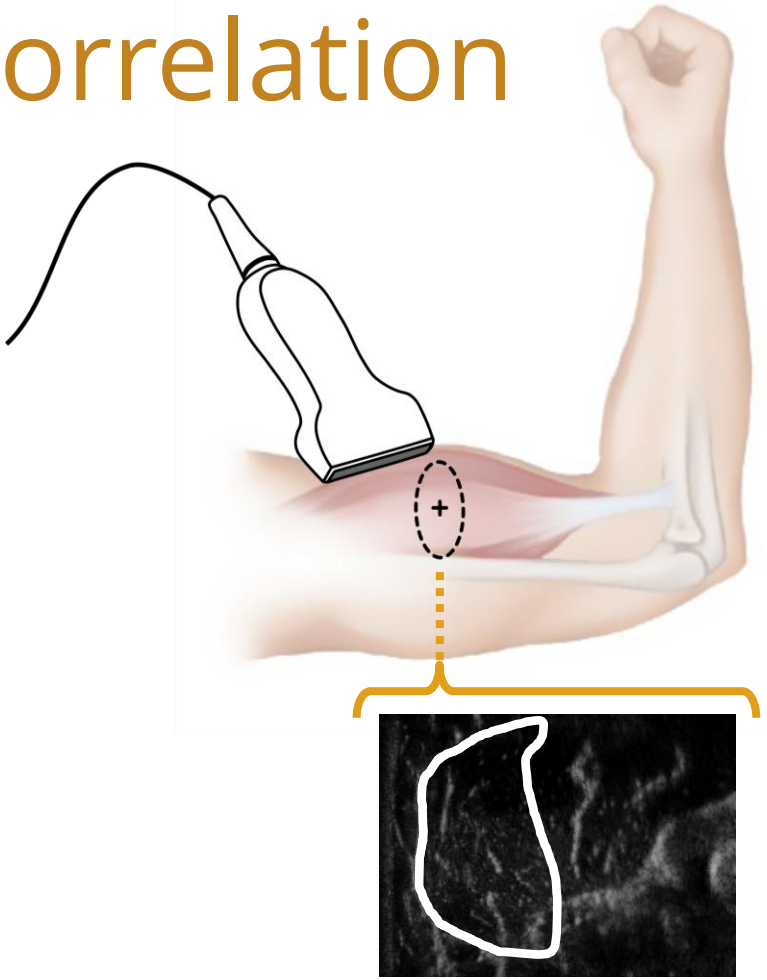
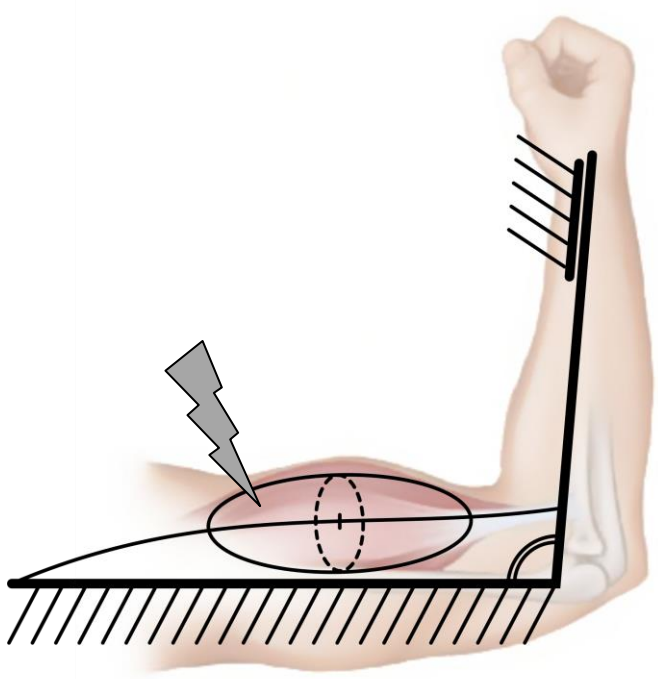
CONTRIBUTION I

Muscle Force–Deformation Correlation



Muscle Force–Deformation Mechanics



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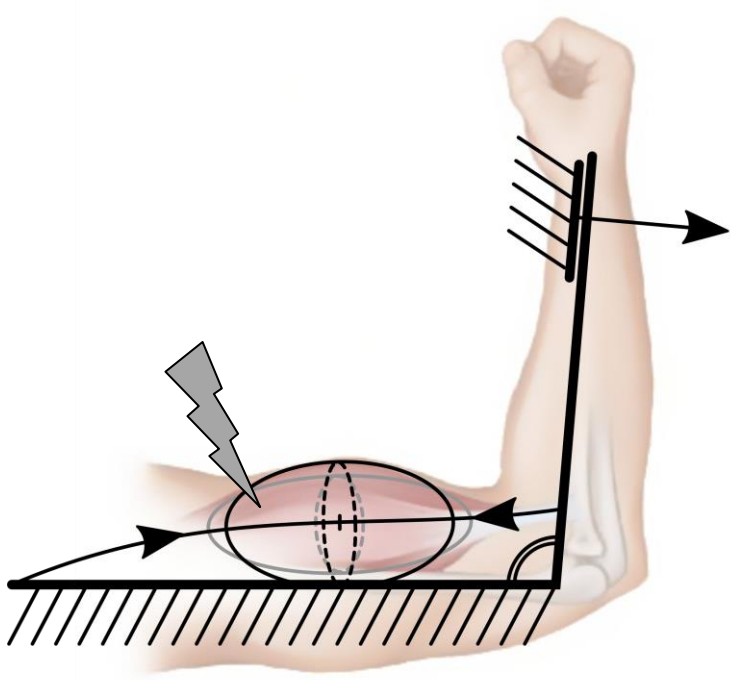
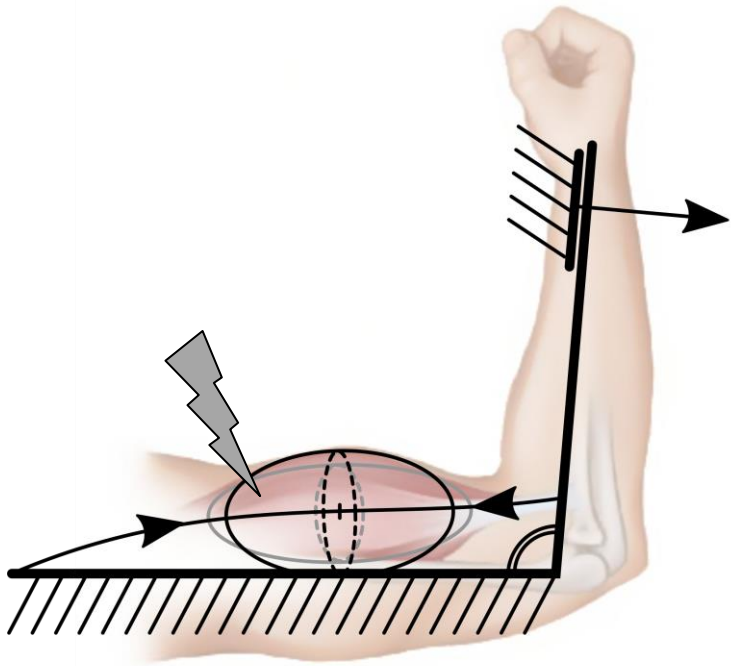
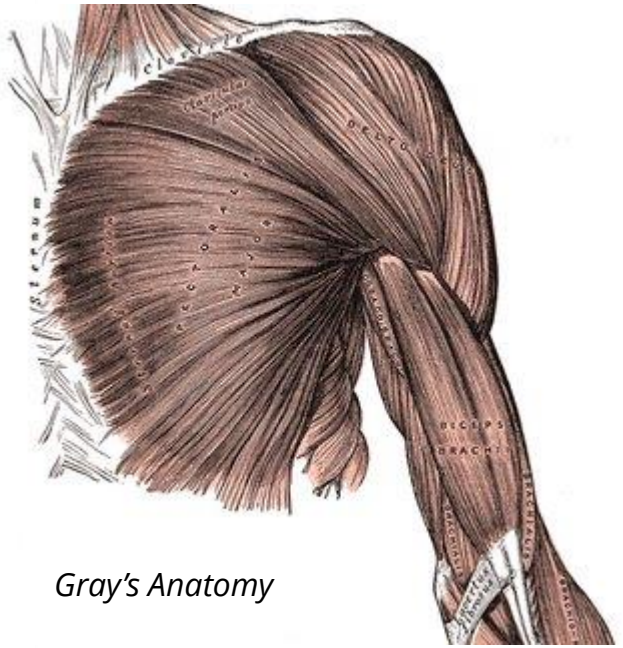


Muscle Force–Deformation Mechanics: Complexities

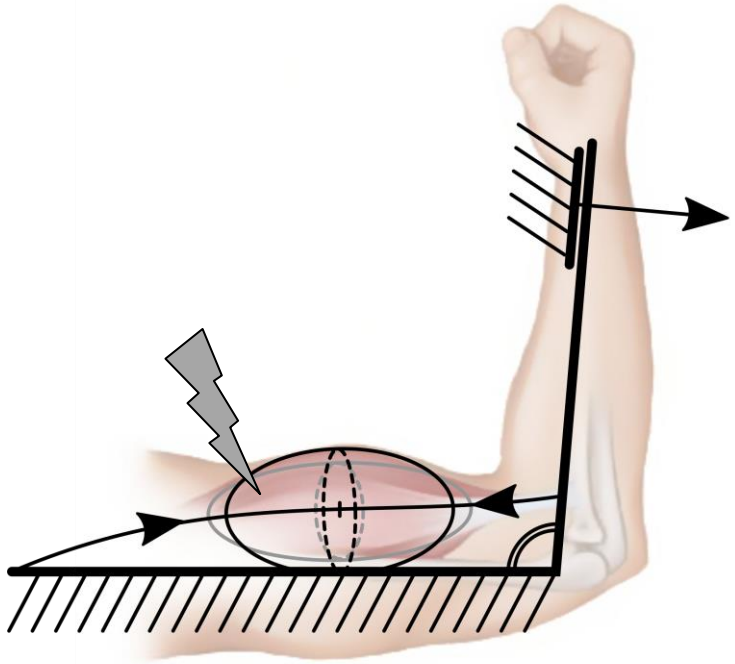


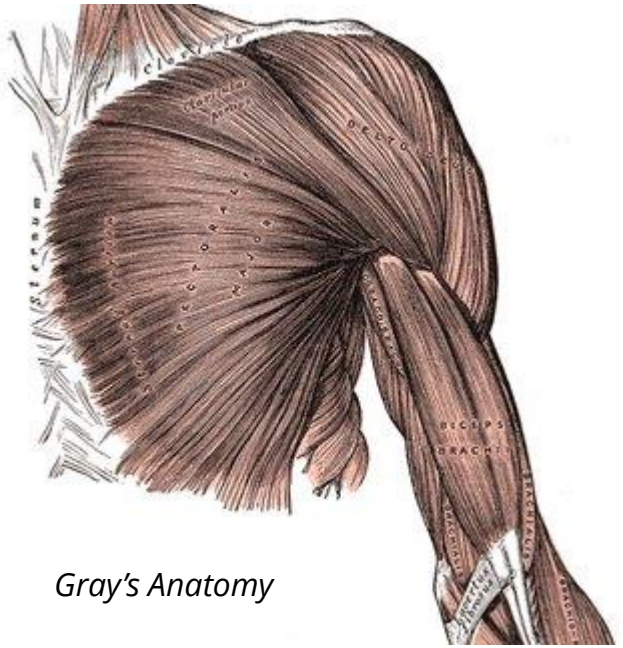


Gray's Anatomy

geometric complexity,
contact dynamics

Muscle Force–Deformation Mechanics: Complexities





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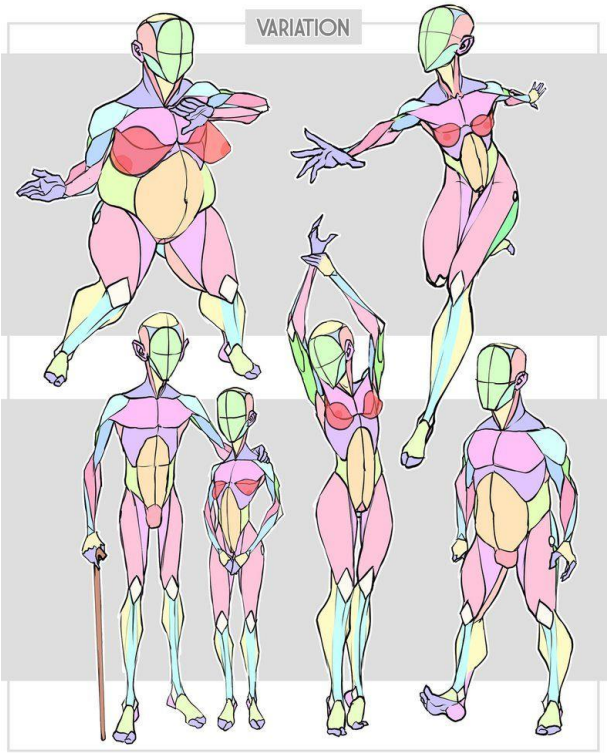
geometric complexity, contact dynamics

morphological variation



Sycra, DeviantArt

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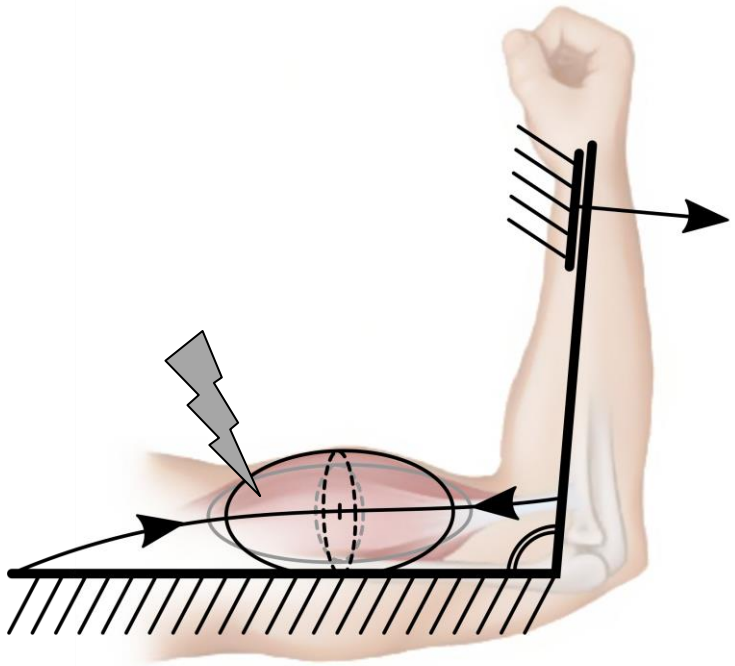

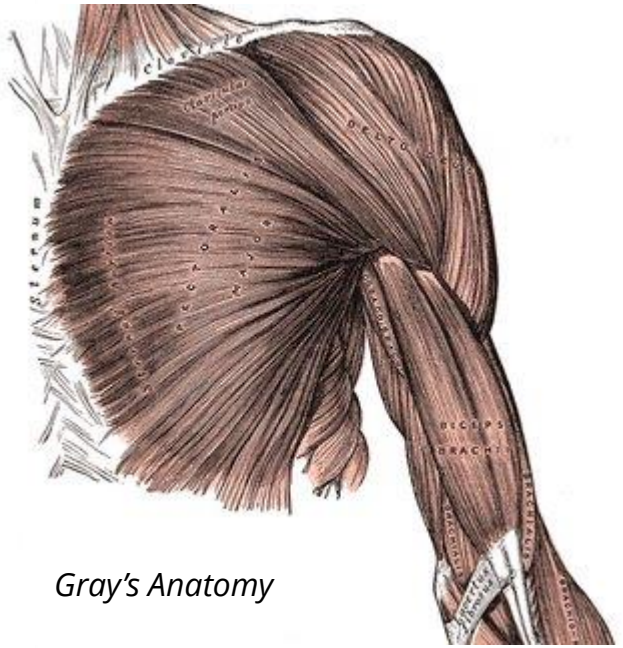

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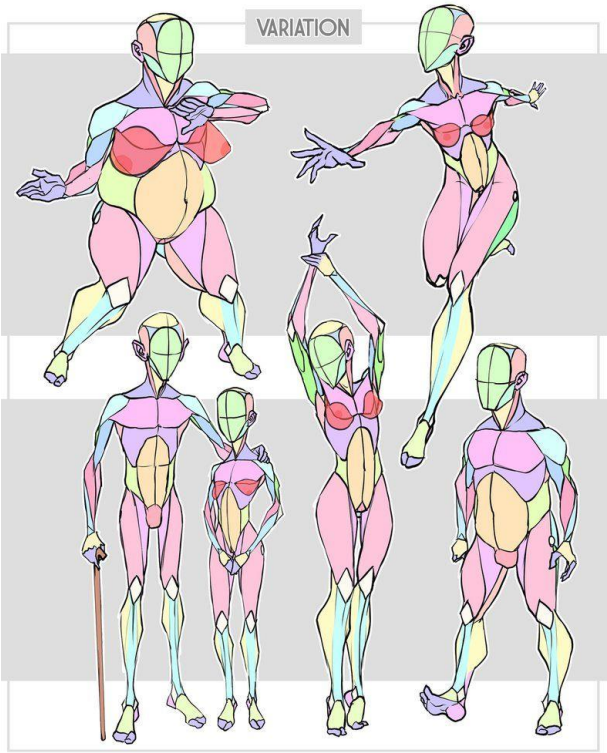
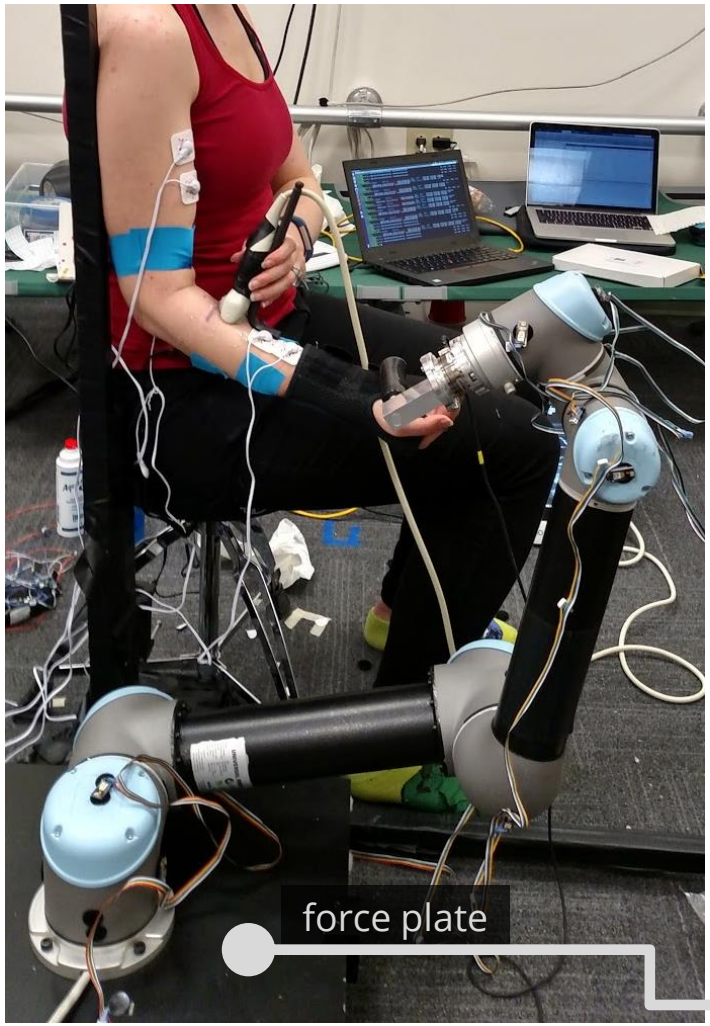
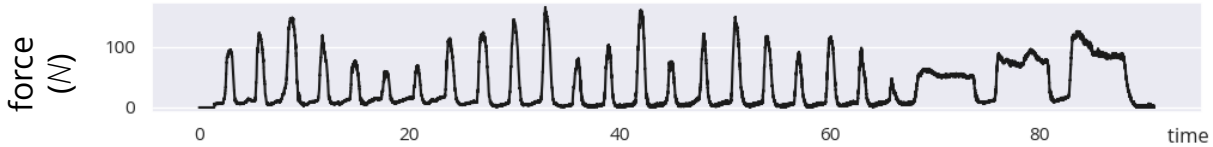


Sycra, DeviantArt

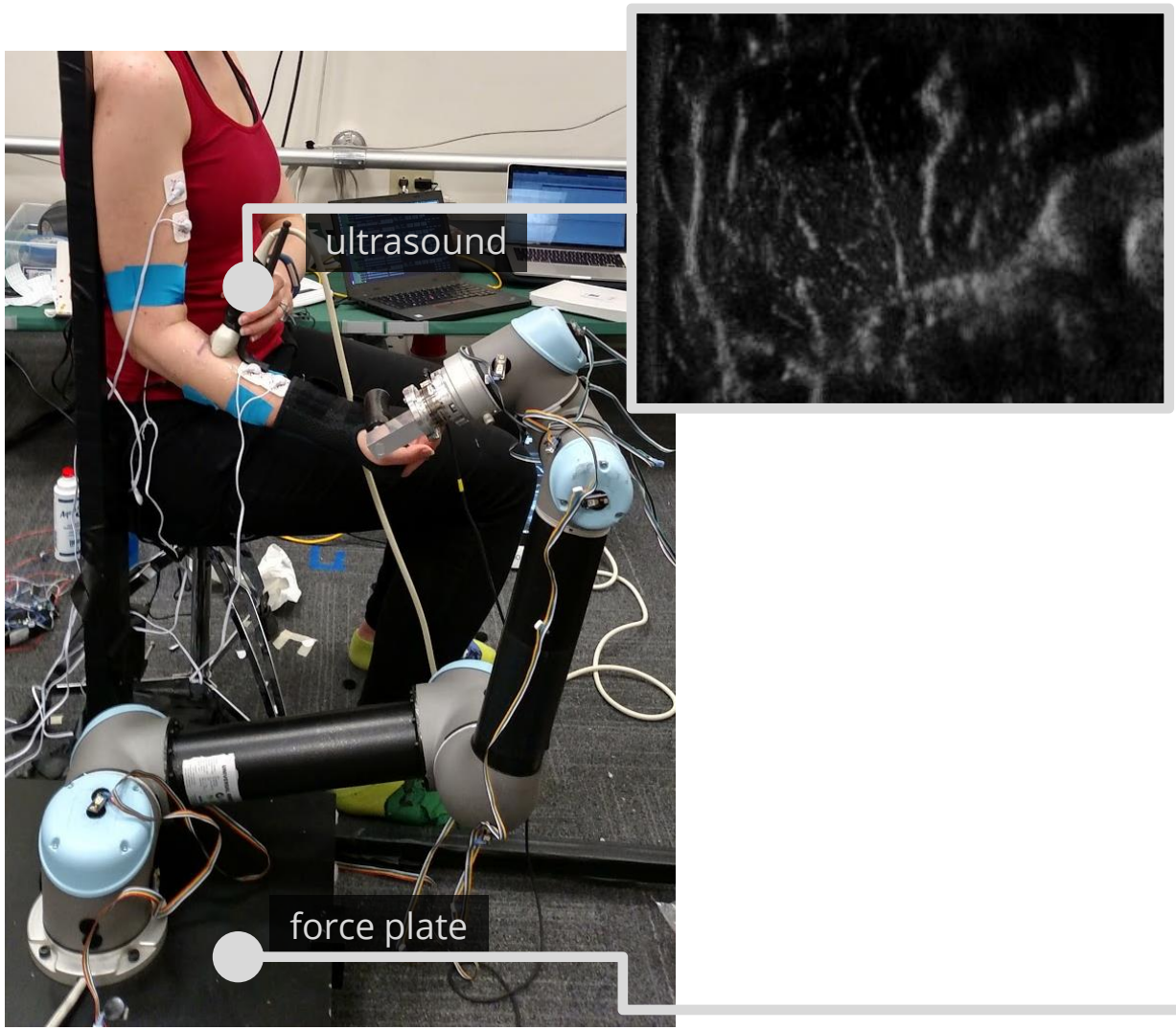
Starting point: Can we correlate simple muscle deformation signals with output force?

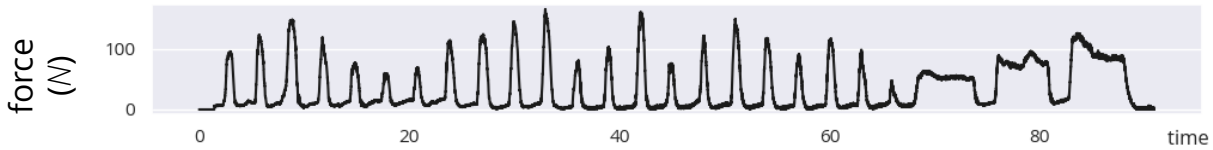
Correlation Analysis: Data Collection





Correlation Analysis: Data Collection





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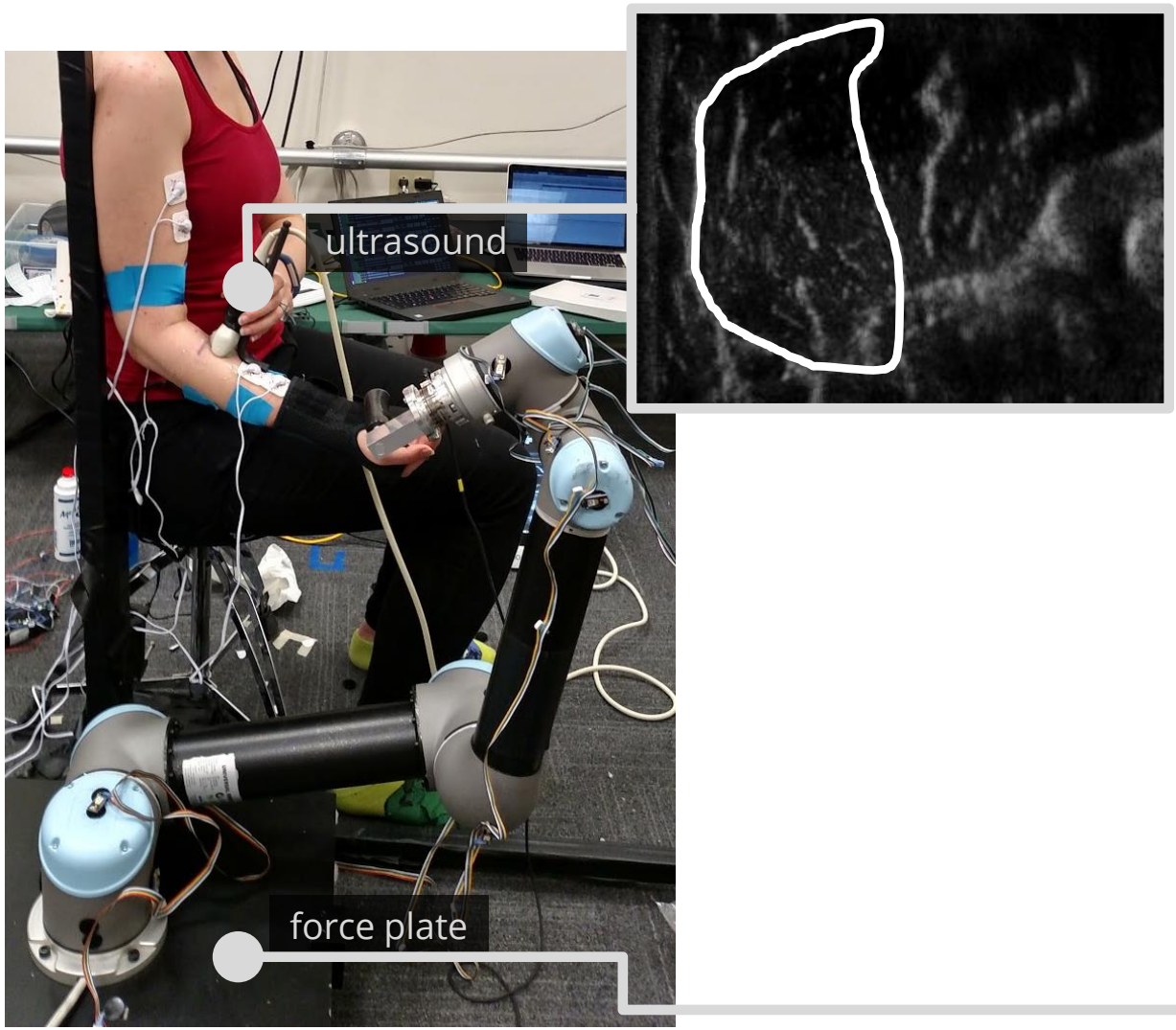

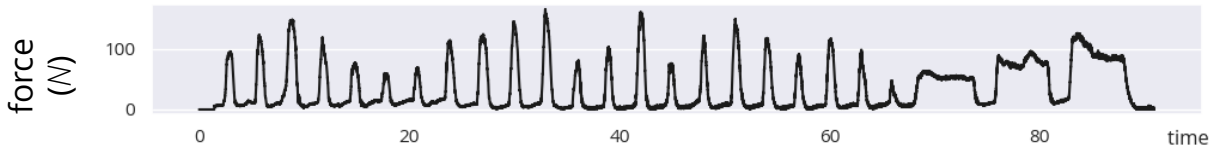

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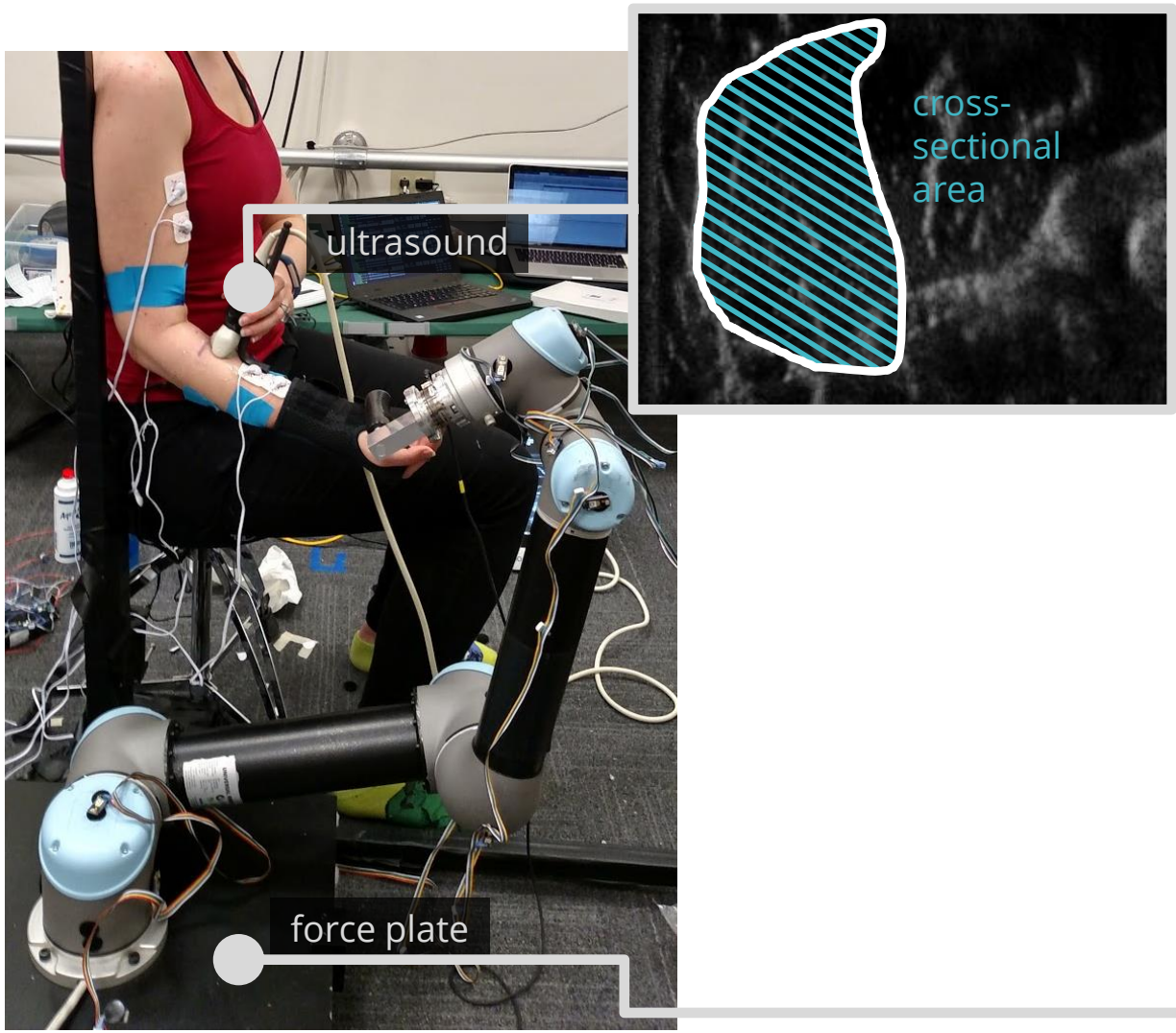

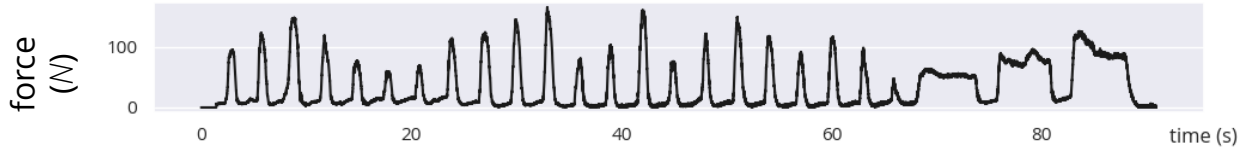

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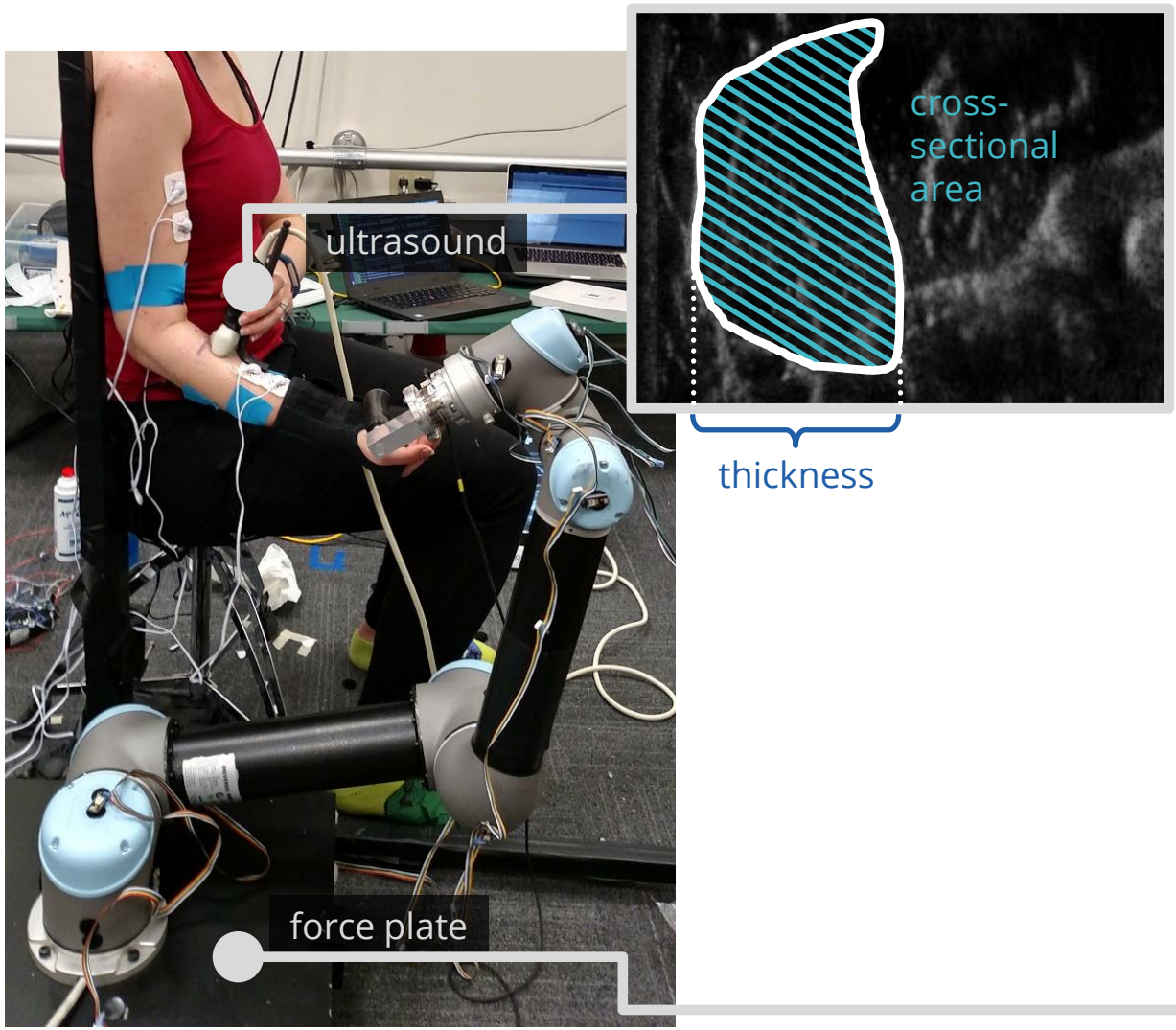

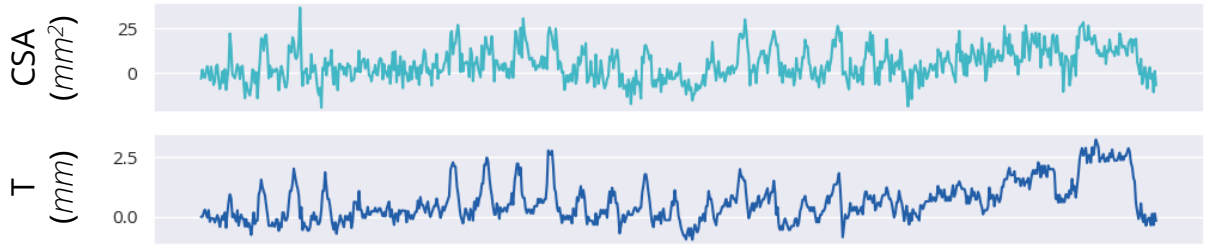

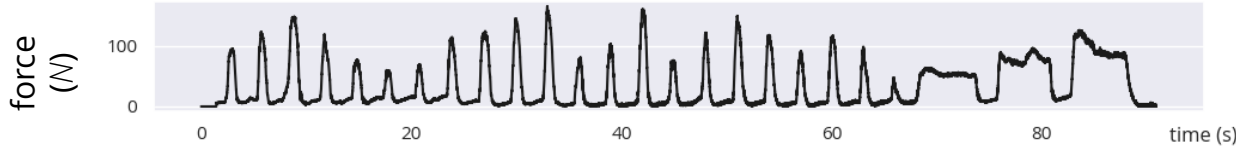

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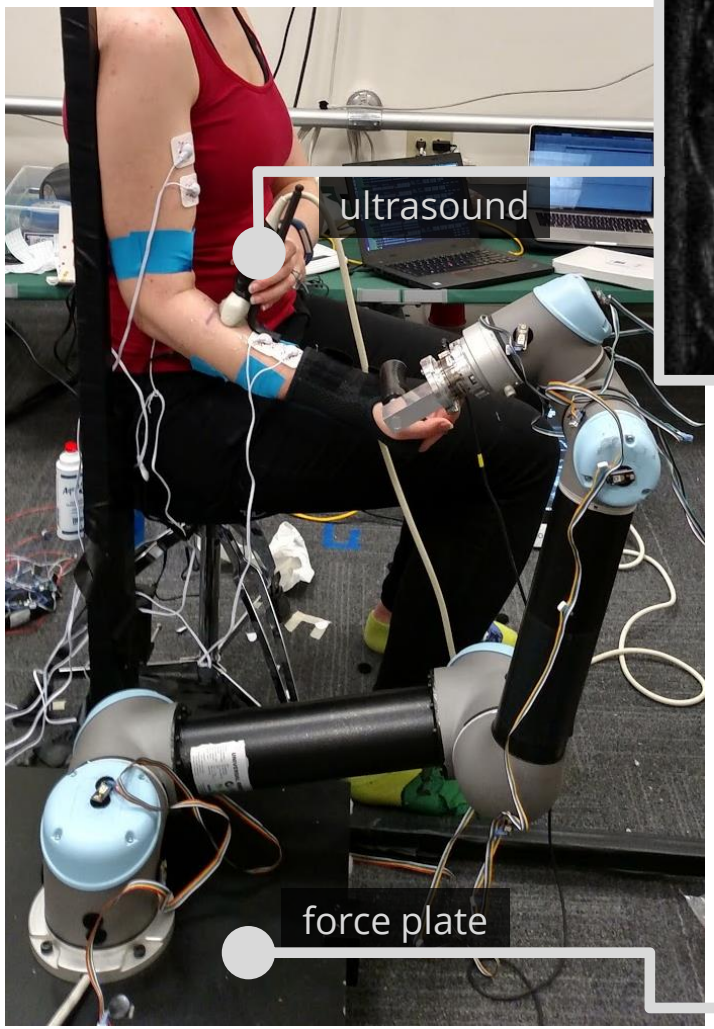
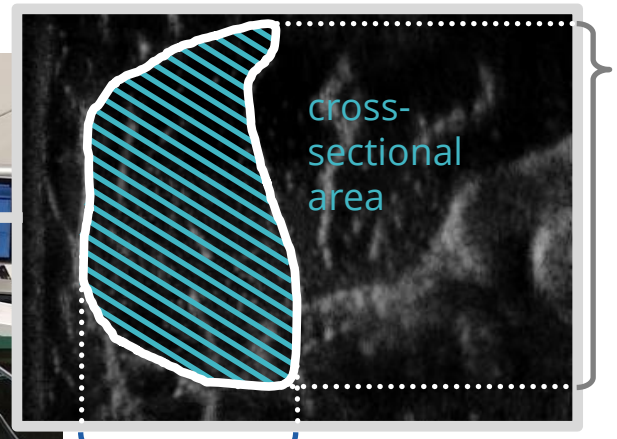
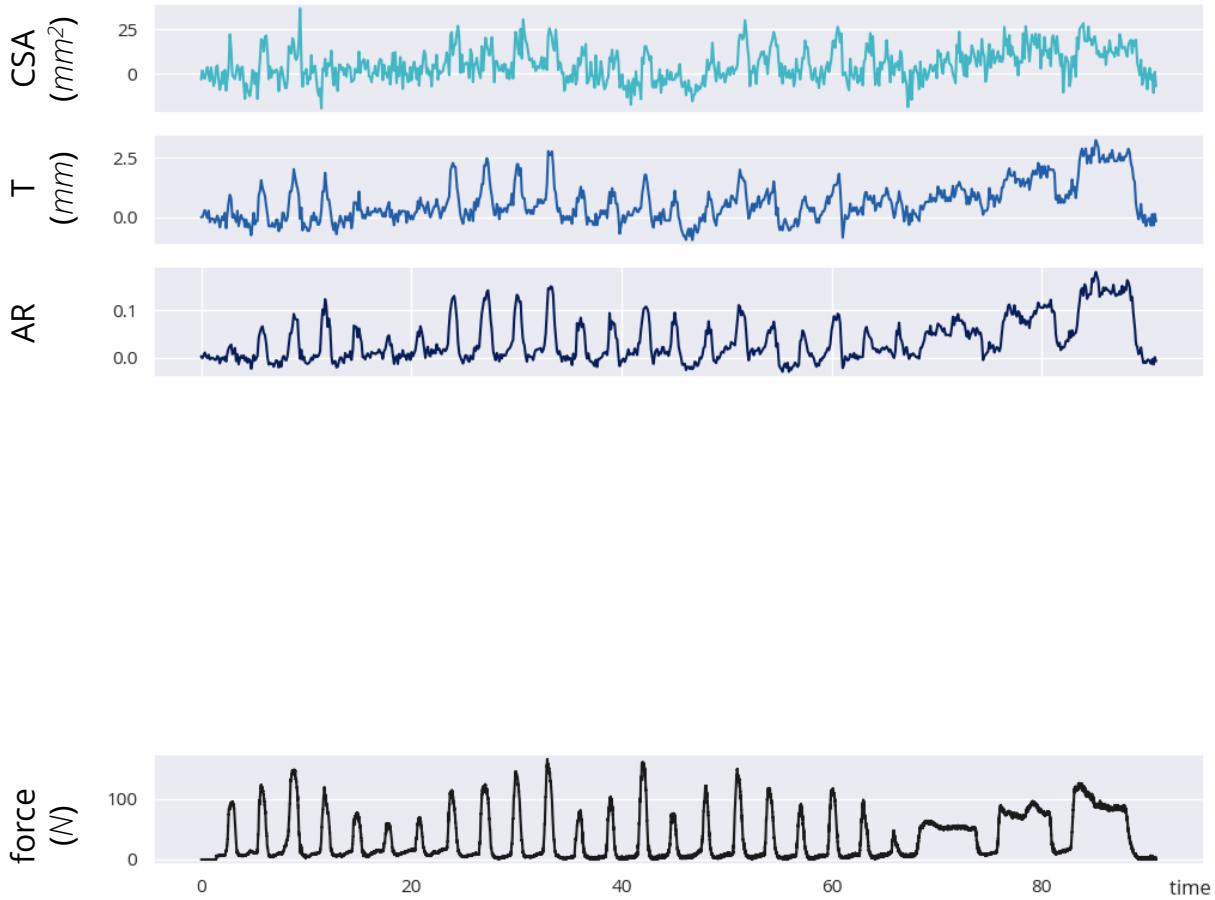




$$\text{aspect ratio} = \frac{\text{thickness}}{\text{width}}$$



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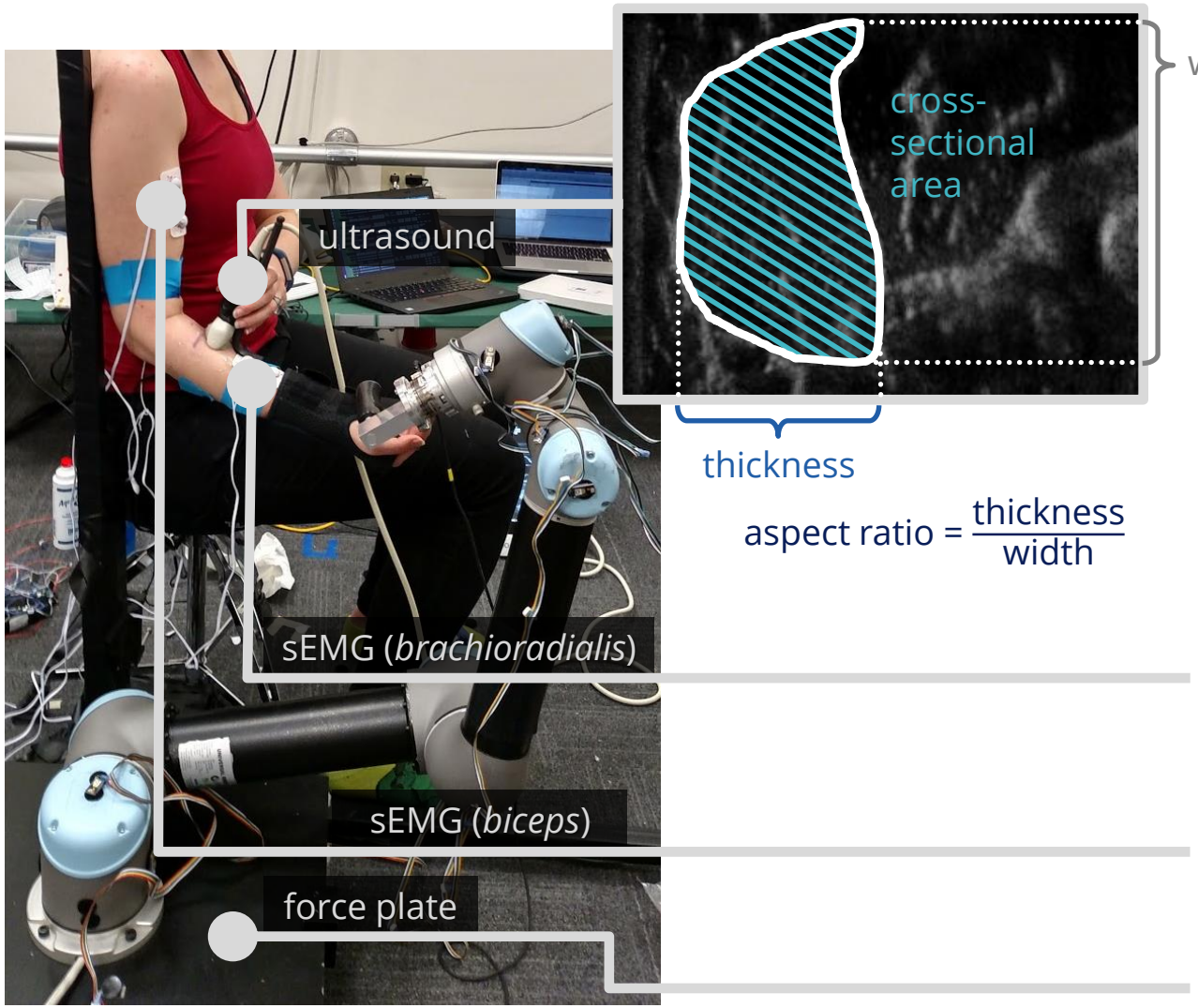

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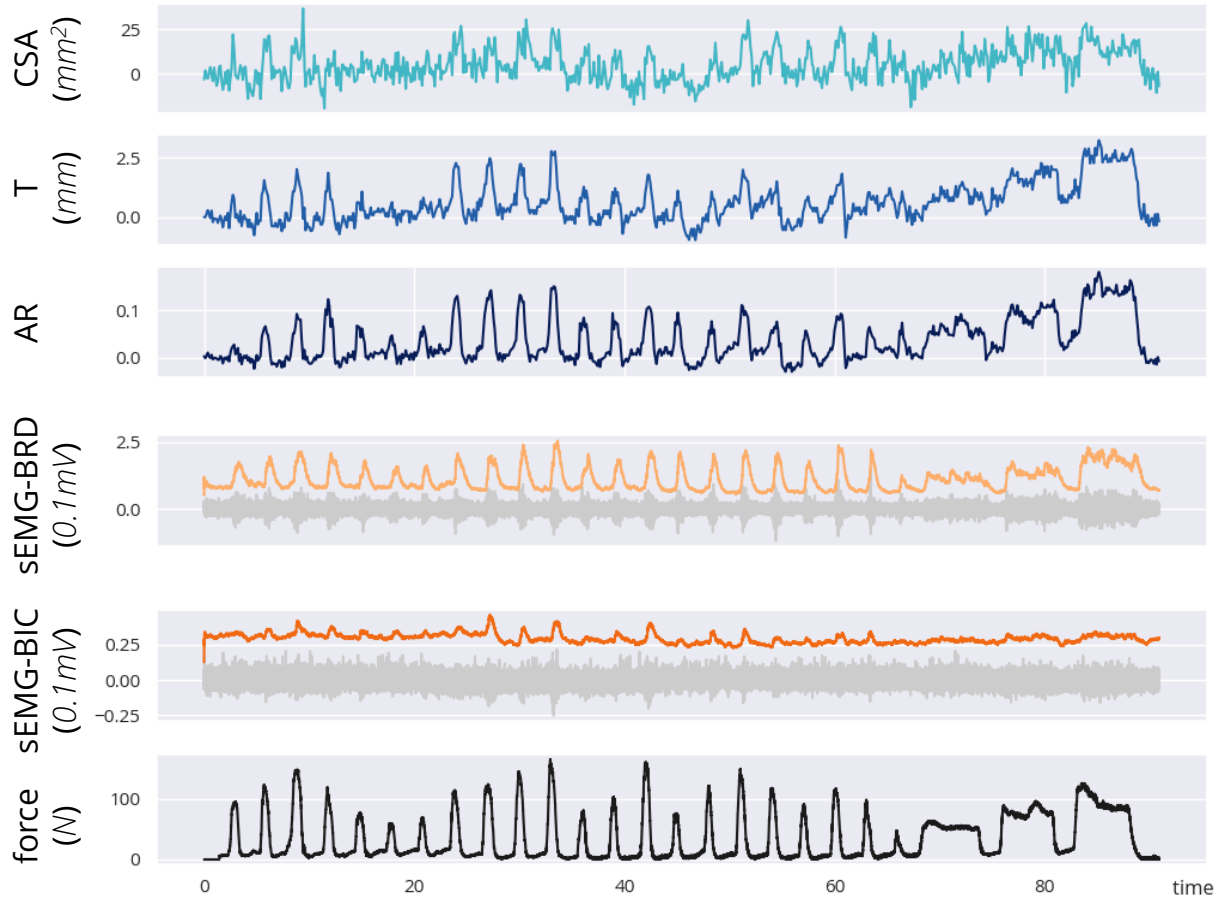
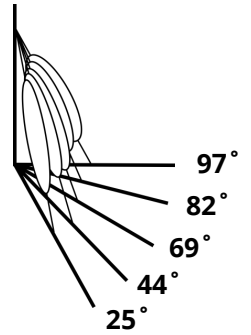
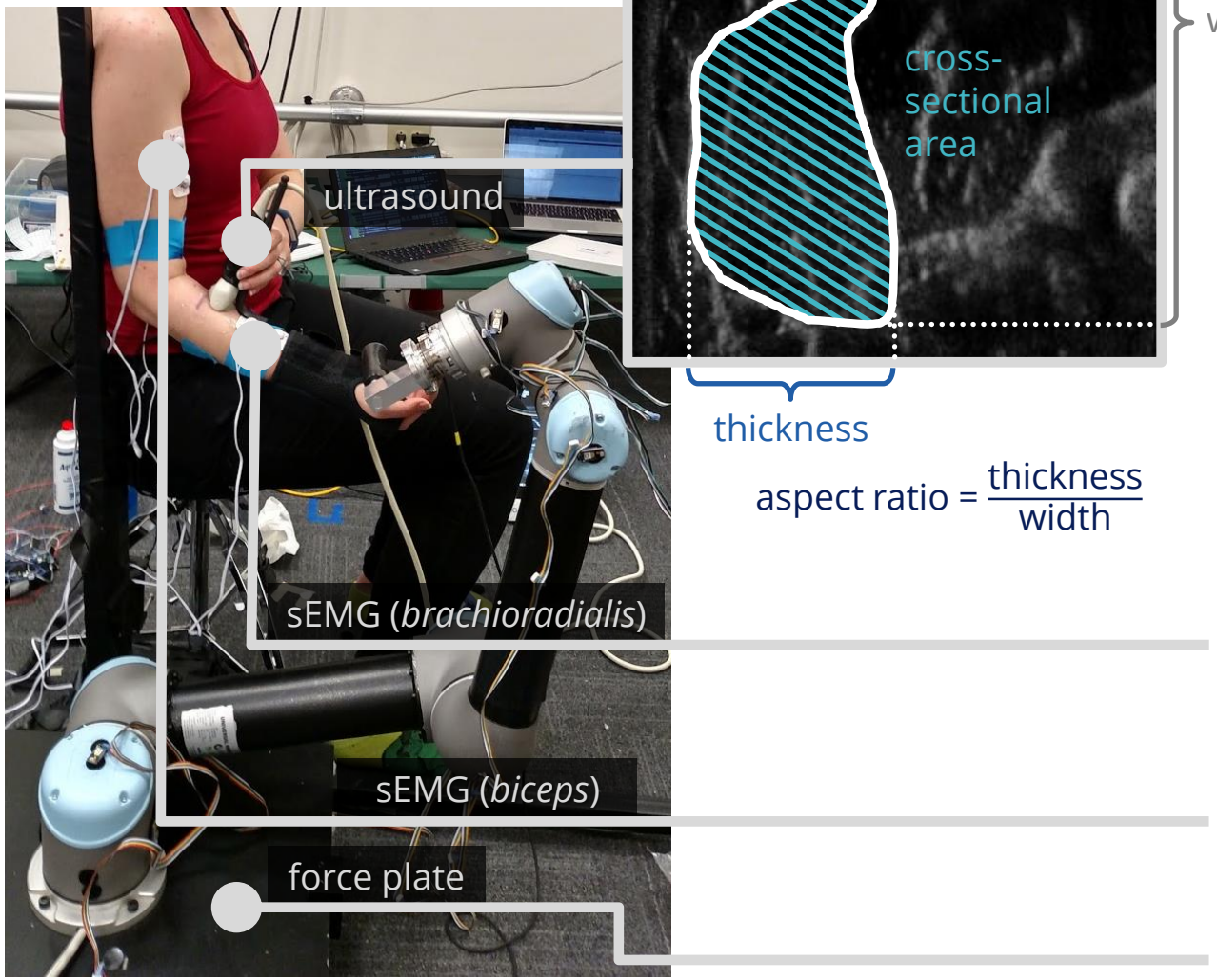


Correlation Analysis: Data Collection

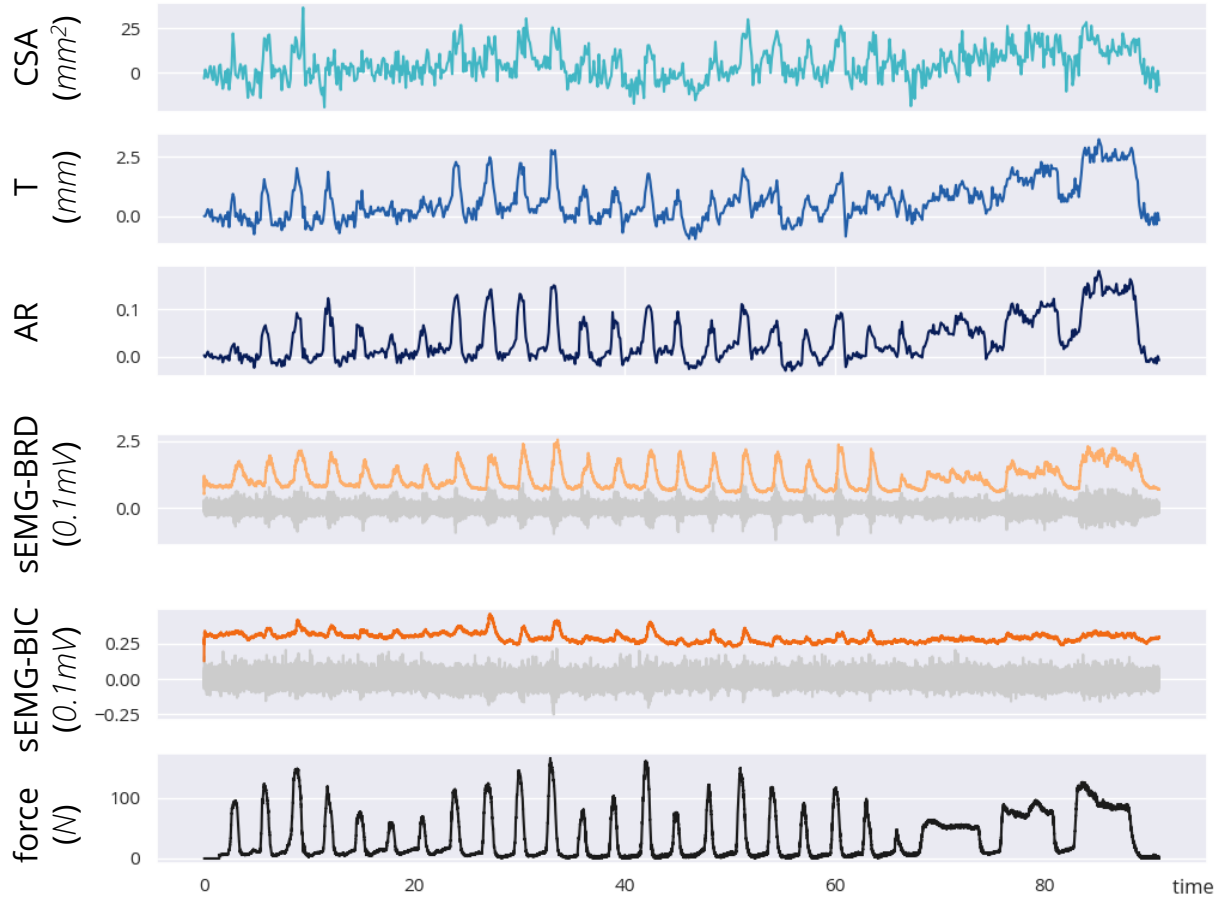
SCOPE:

5 elbow angles
5 subjects

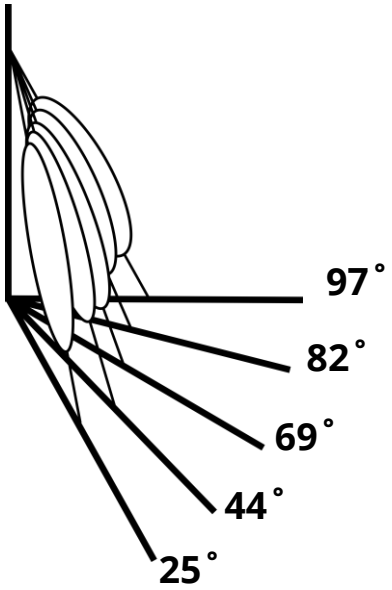


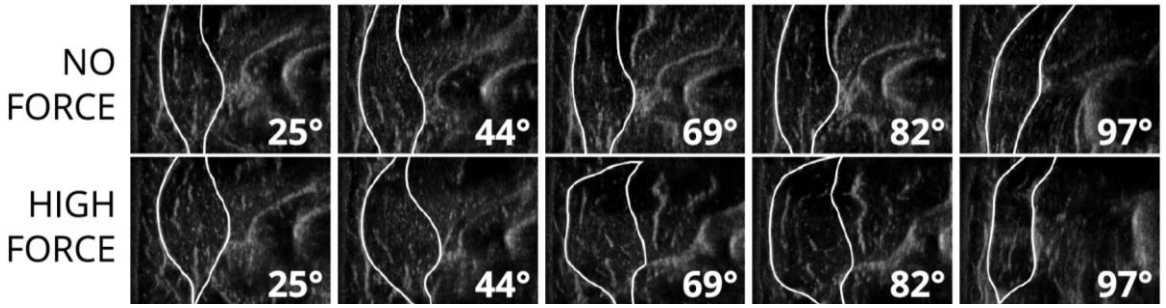


$$\text{aspect ratio} = \frac{\text{thickness}}{\text{width}}$$



Correlation Analysis: Elbow Angles





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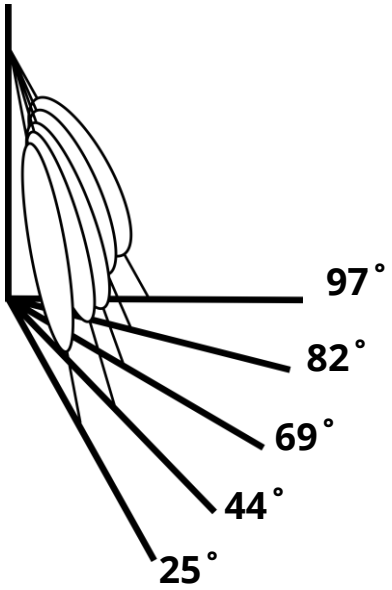
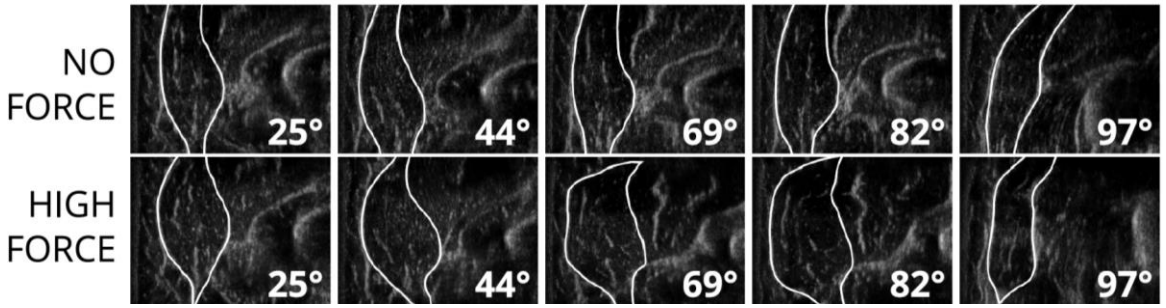
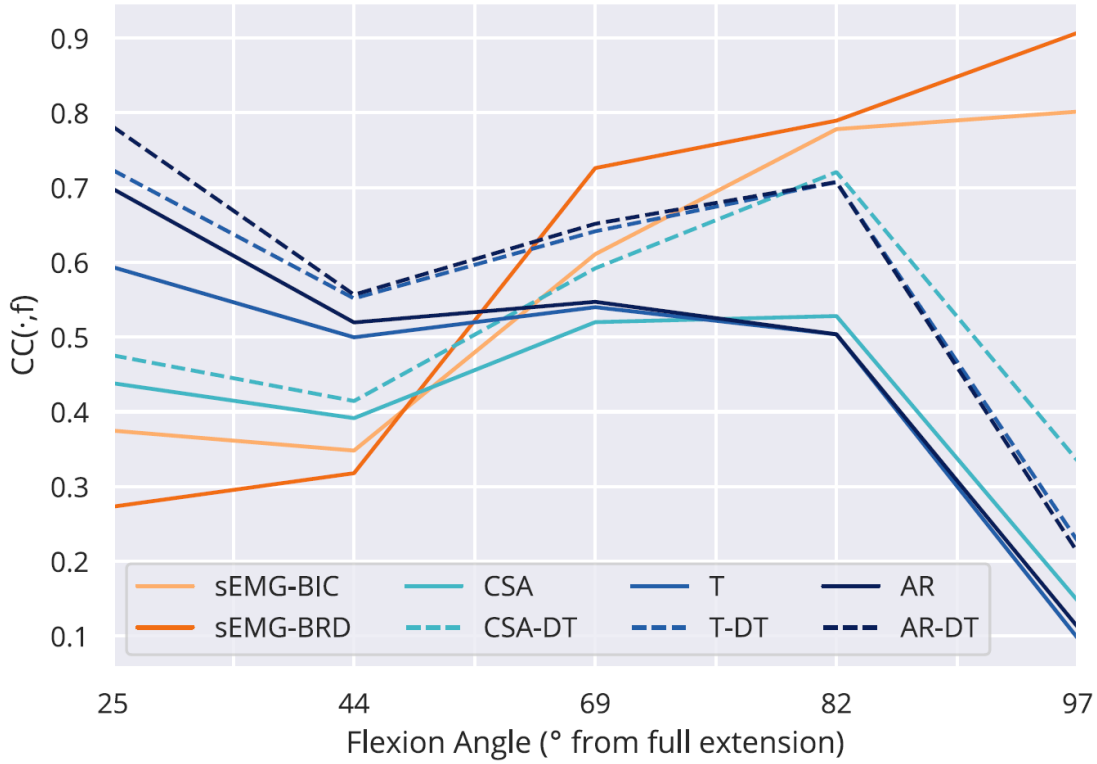
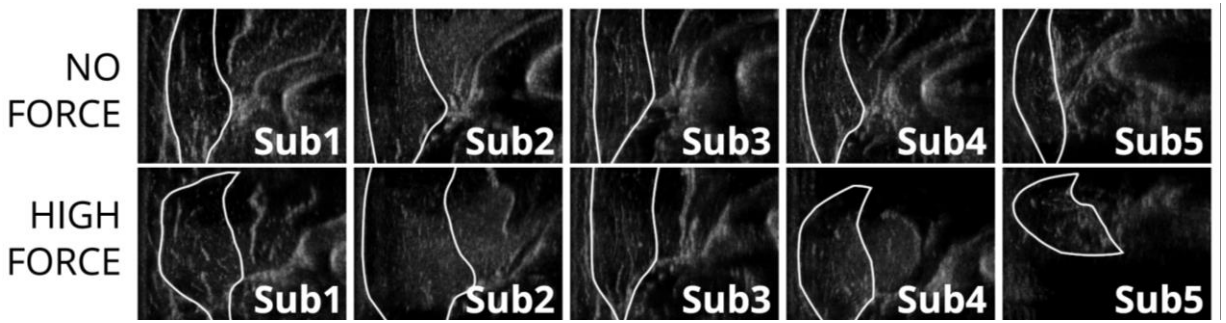


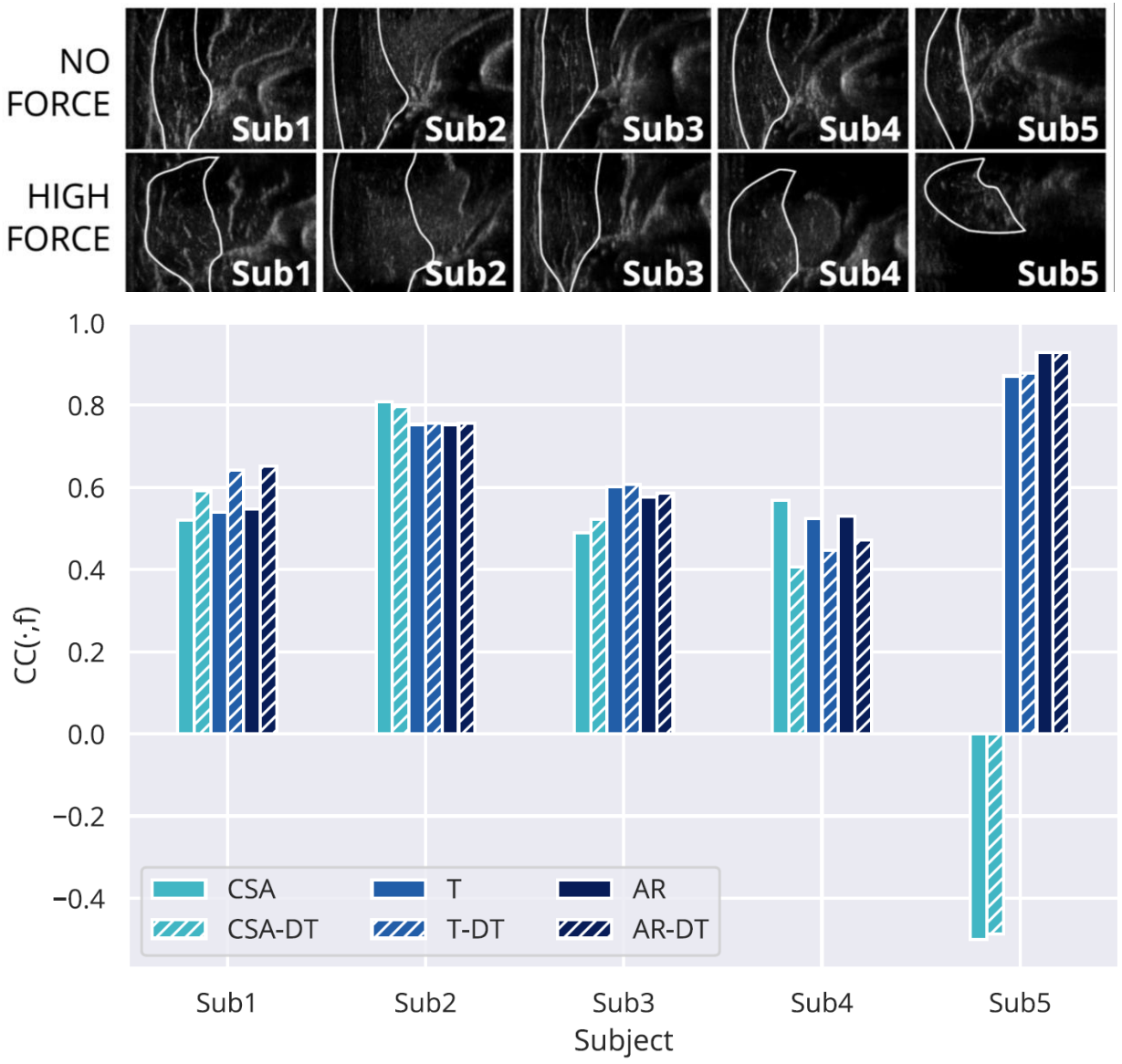




Correlation Analysis: Subjects



Correlation Analysis: Subjects



Scaling Up: Beyond Manual Annotation

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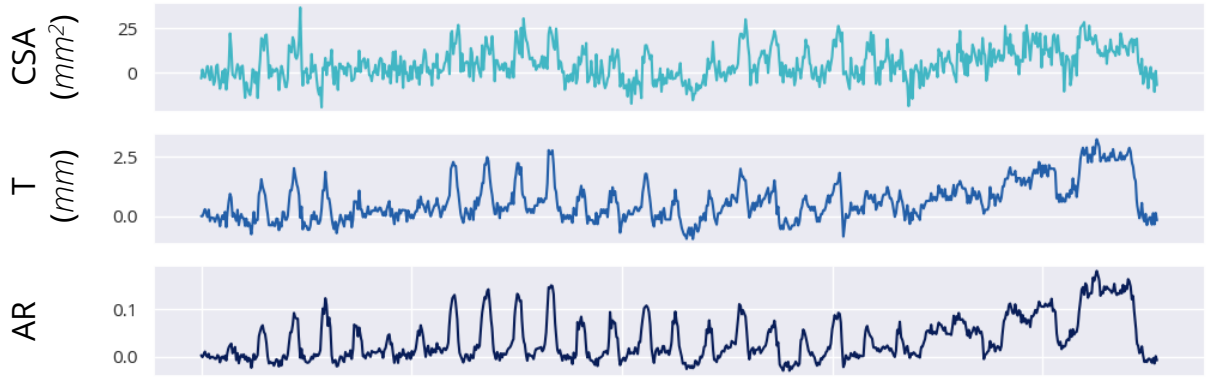

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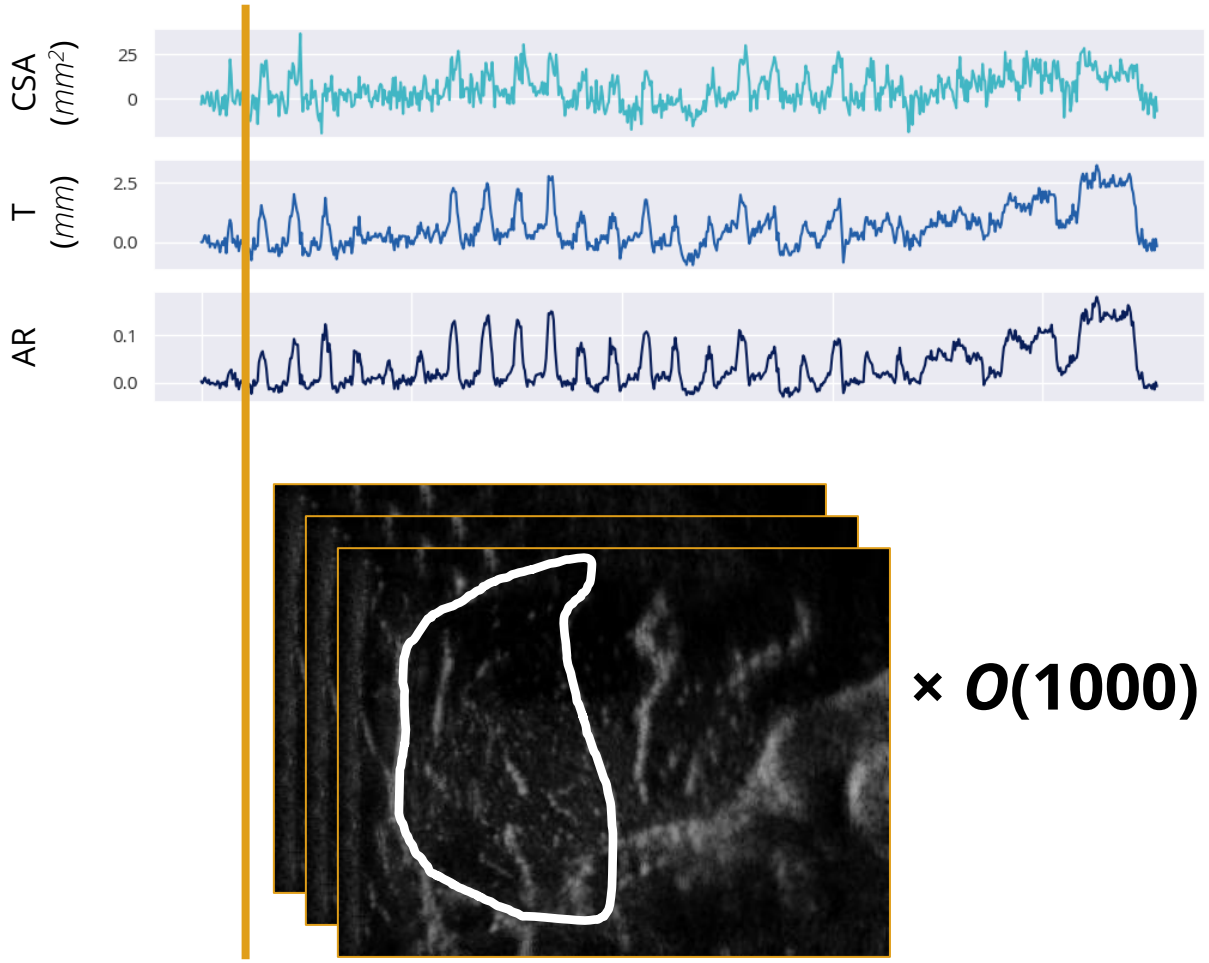

× *O*(1000)

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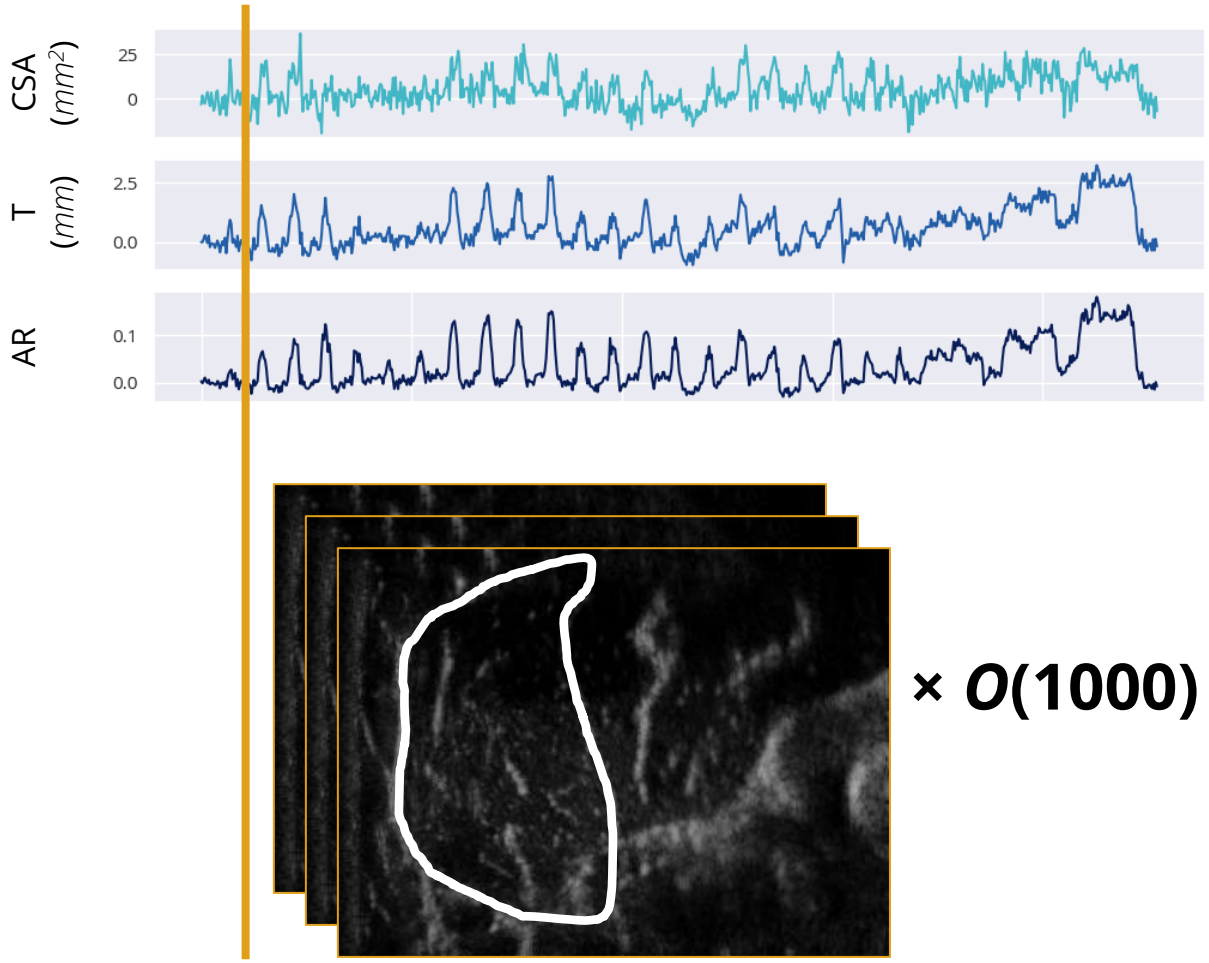

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Manual annotation is **prohibitively time-intensive**.

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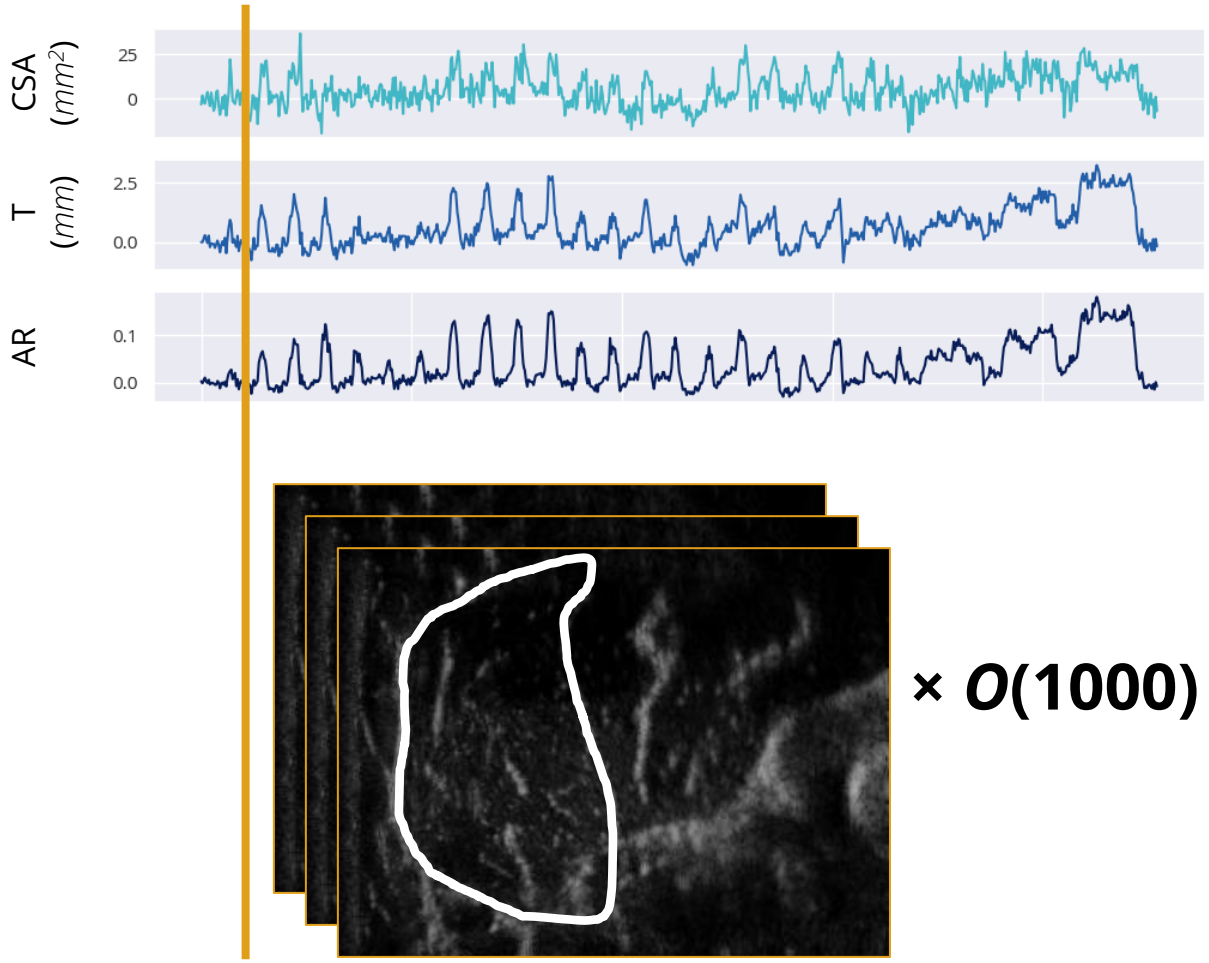
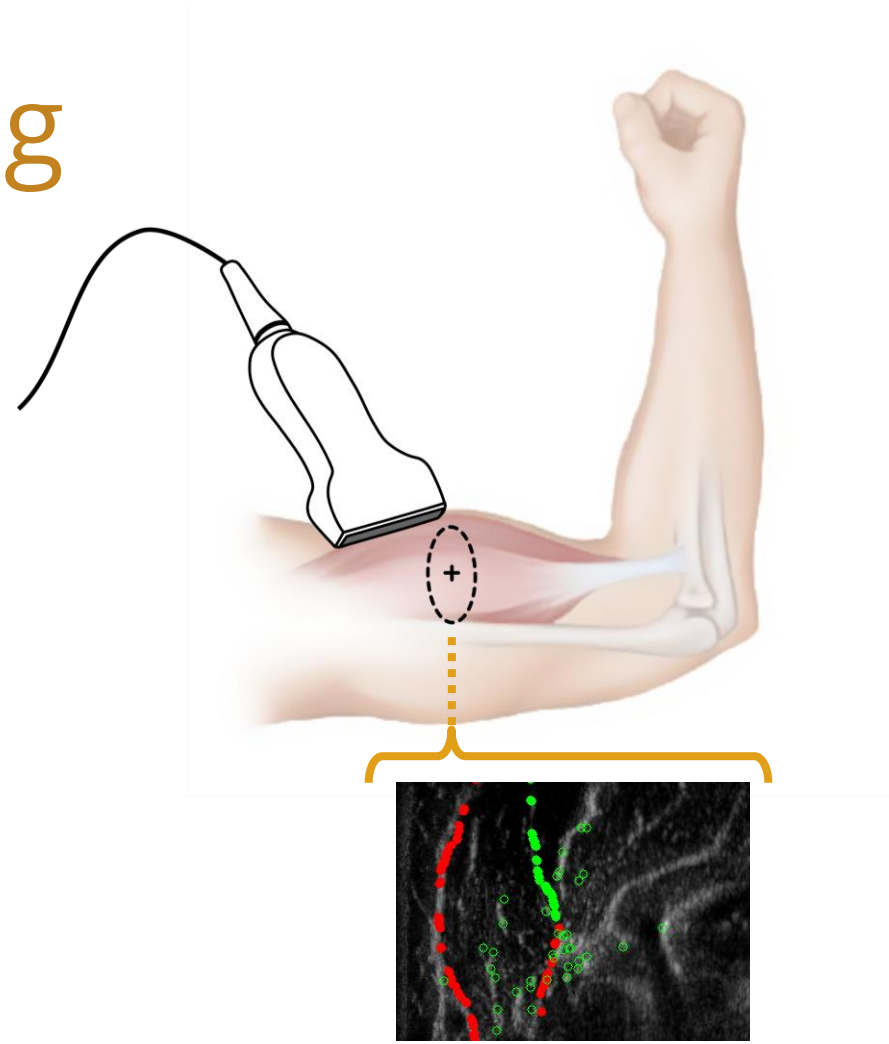


× *O*(1000)

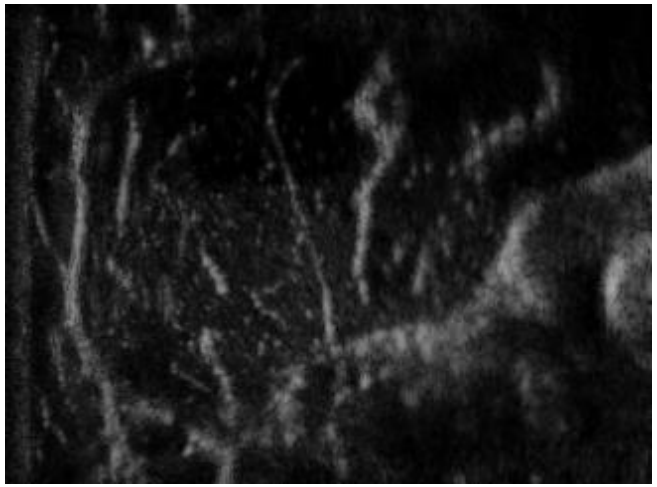
Manual annotation is **prohibitively time-intensive** and **cannot be accomplished in real time**.

CONTRIBUTION II

Muscle Cross Section Tracking

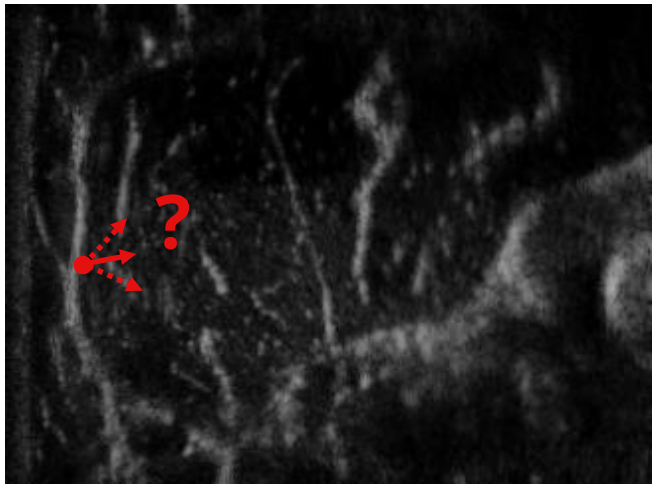


Core Algorithm: Lucas–Kanade Optical Flow



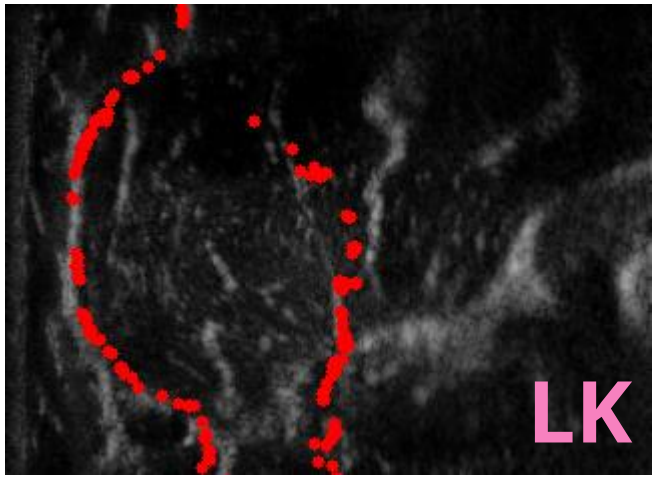
[Lucas & Kanade, 1981]

Core Algorithm: Lucas–Kanade Optical Flow



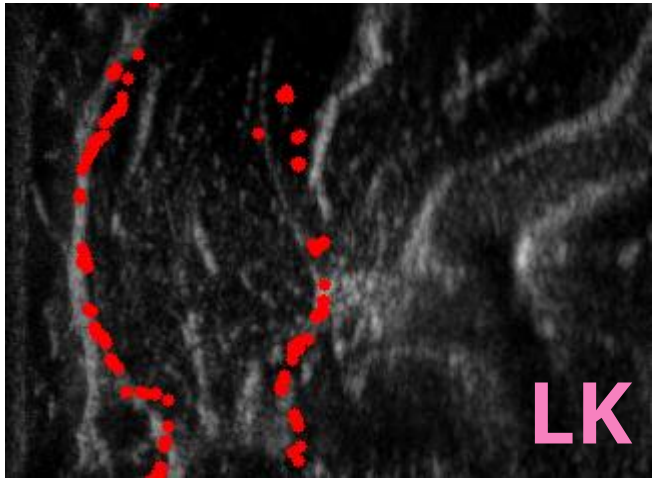
[Lucas & Kanade, 1981]

Candidate Tracking Algorithms



(Naive Lucas–Kanade)

Candidate Tracking Algorithms



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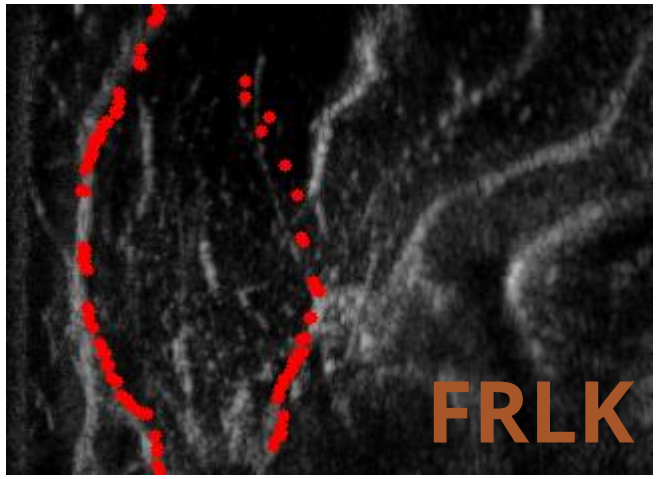
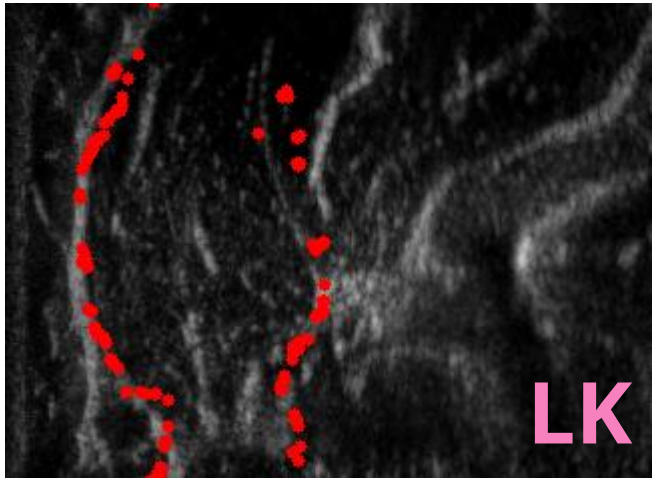


(Feature-Refined Lucas–Kanade)

Candidate Tracking Algorithms



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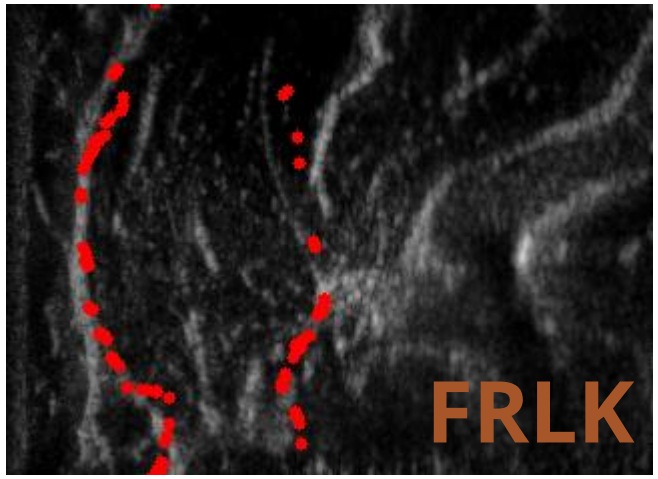

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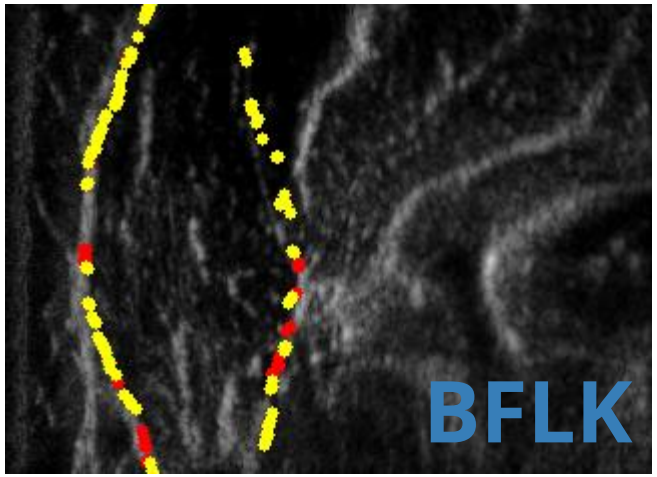
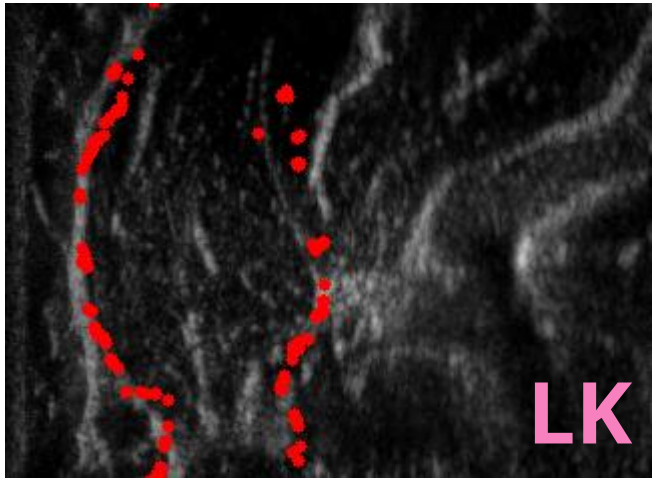


(Bilaterally-Filtered Lucas–Kanade)

Candidate Tracking Algorithms



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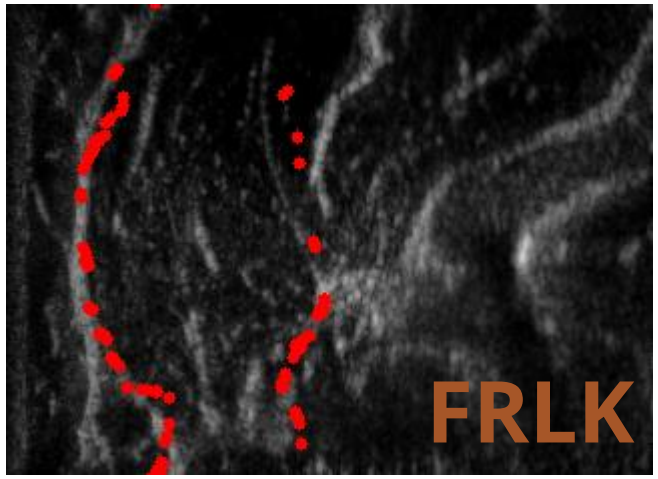

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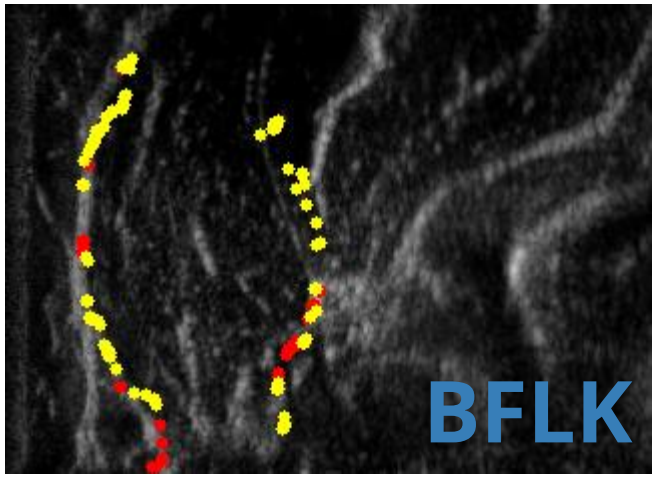

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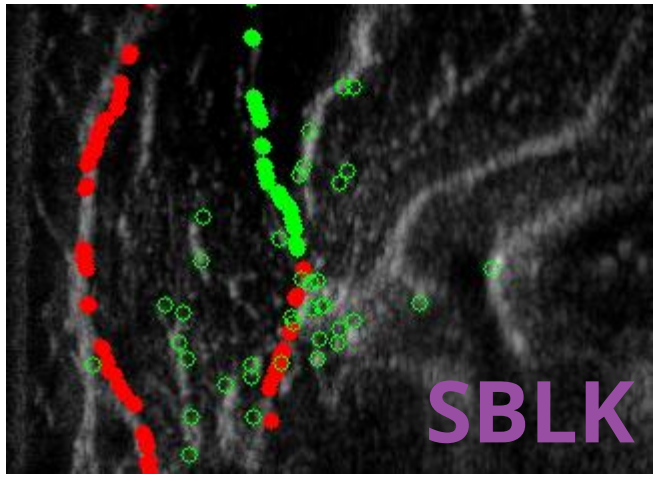
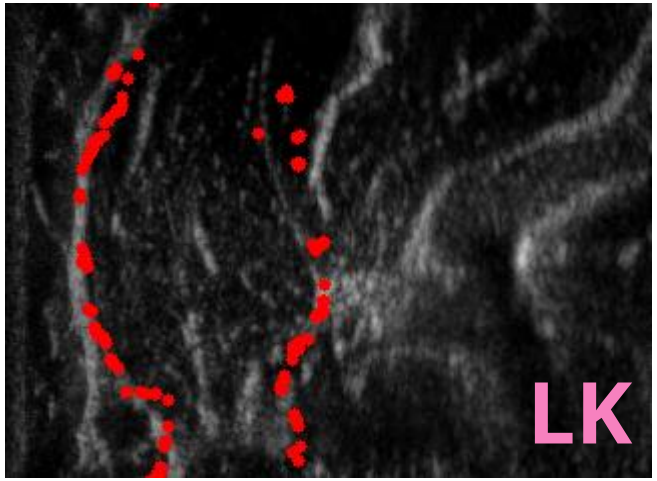


(Supporter-Based Lucas–Kanade)

Candidate Tracking Algorithms: Performance



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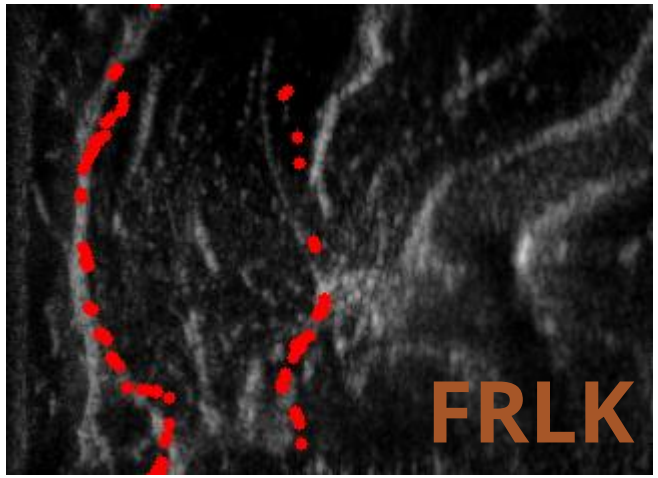

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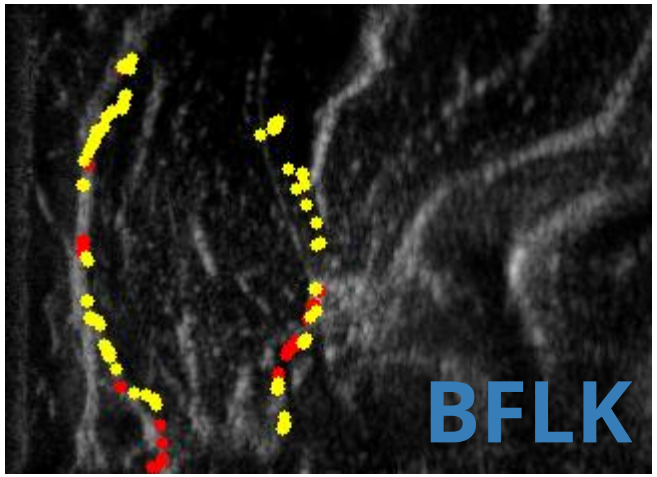

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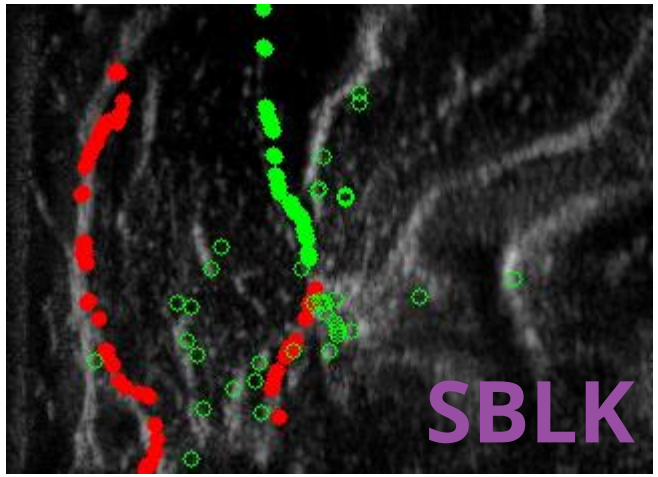
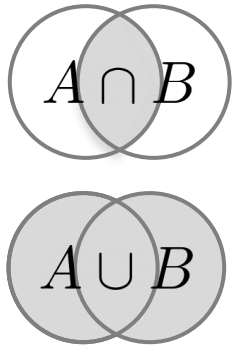


(Supporter-Based Lucas–Kanade)

Jaccard Distance:

$$1 - \frac{|A \cap B|}{|A \cup B|}$$



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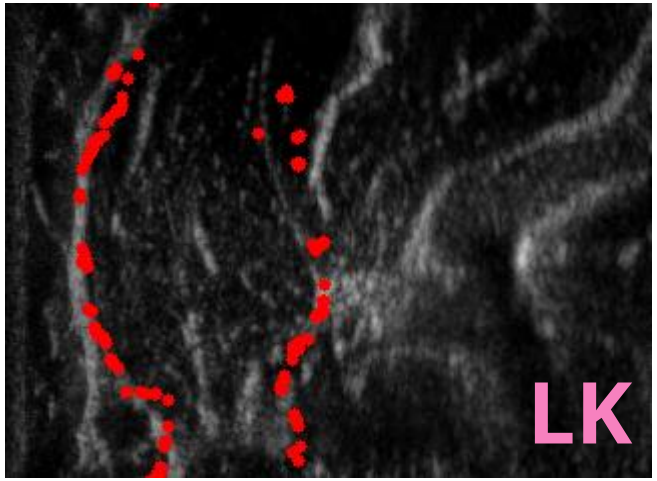

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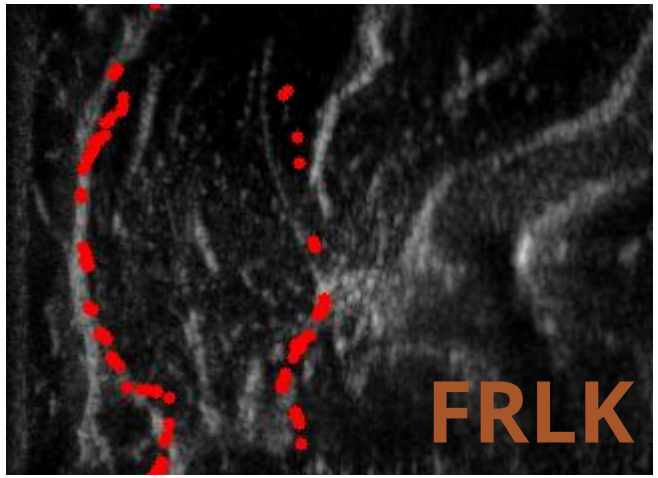

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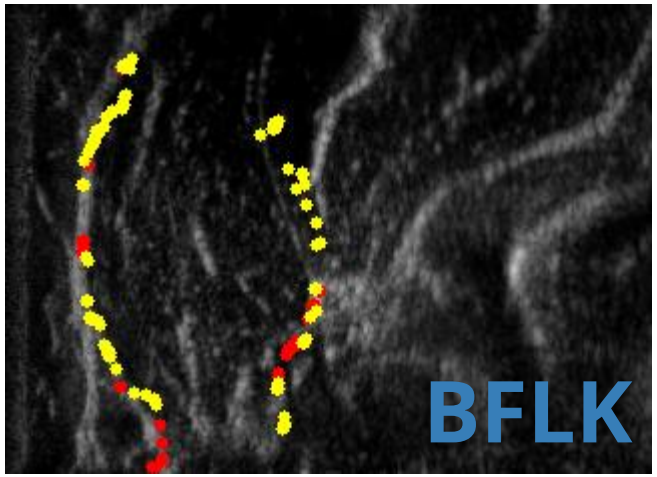

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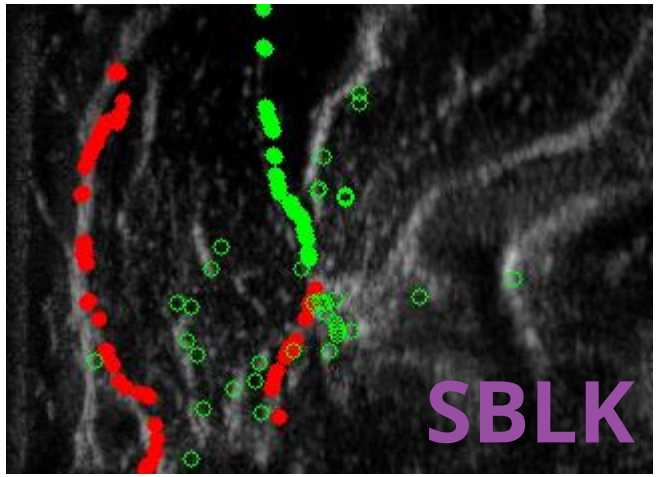

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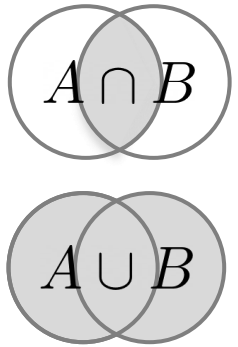

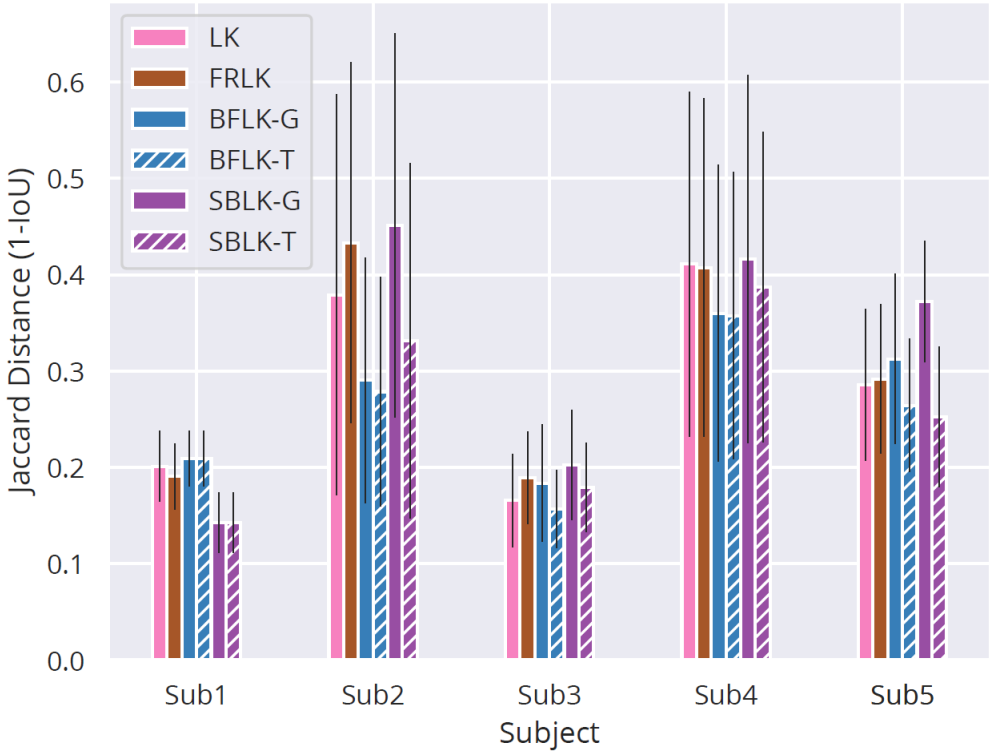

Contribution Summary & Further Resources

We have shown that:

I. Several simple **muscle deformation signals** are **correlated with output force**.
II. These signals can be **observed** and **tracked over time** via ultrasound and optical flow.

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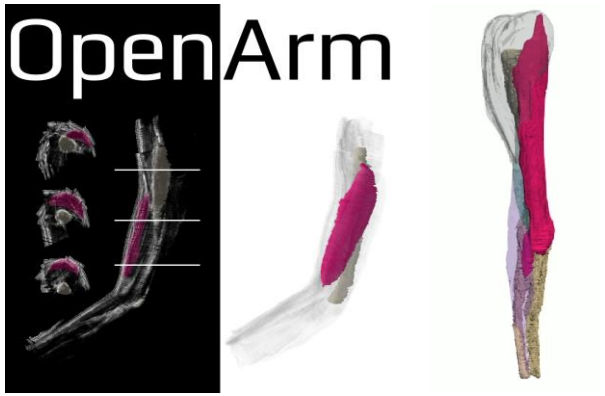

Check out our other code and data sets!
simtk.org/projects/openarm

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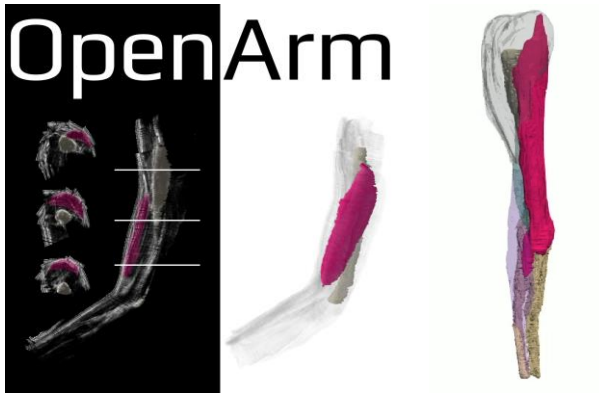

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Thanks to:

Gregorij Kurillo
Robert Matthew
Daisuke Kaneishi
Sarah Seko
Daniel Ho
Jeffrey Zhang
Ian McDonald
Sathvik Nair
Logan Howard
Yannan Tuo
Vijay Govindarajan

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