A Distributed Wearable Ultrasound Platform for Neuromuscular Monitoring: Applications for Military Operational Readiness

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Disclosure

Dr. King is affiliated with a commercial enterprise, Myokinetics, INC, for wearable ultrasound technology

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Impact of Musculoskeletal Injuries on Military Readiness

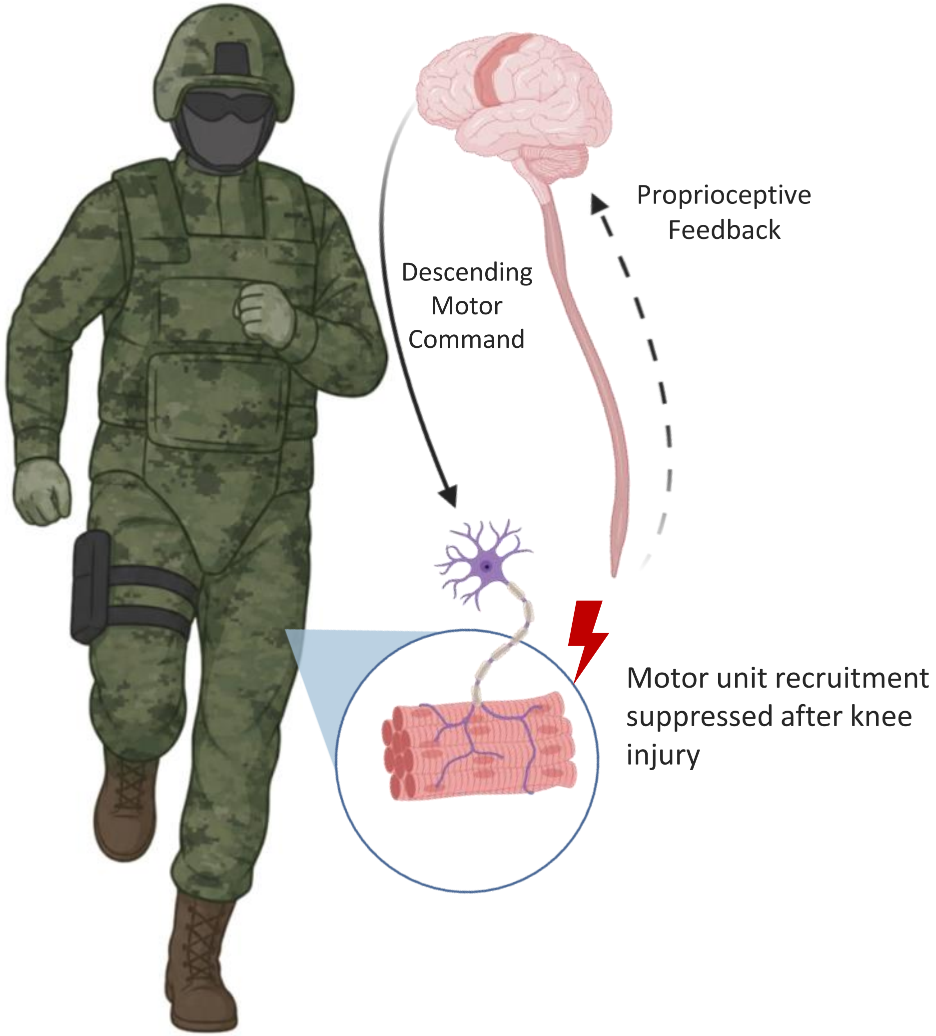
Musculoskeletal Injury Burden

- 70% of all injuries reported at basic training are classified as musculoskeletal
- *Highest Injury Ares:* Knee and Ankle

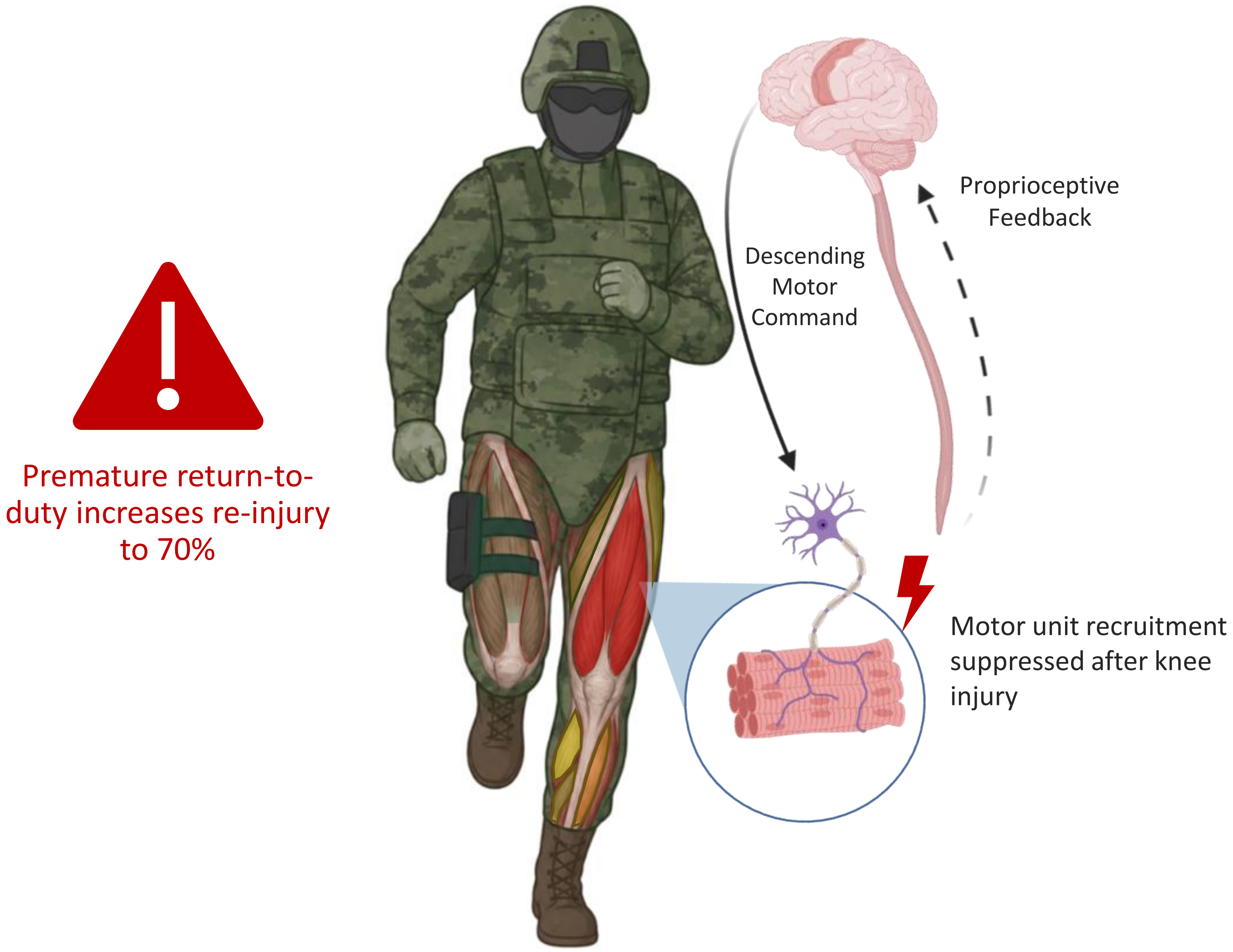
Cost to Readiness

- 4M+ lost duty days DoD-wide (2019)
  - 10.7M days limited in the Army alone (2017)
- Leading cause of non-deployability (~65% of medically non-deployable soldiers)

What happens to the warfighters who suffer a musculoskeletal injury?



What happens to the warfighters who suffer a musculoskeletal injury?



Current Rehabilitation Monitoring Tools

Clinical Assessments


Wearable Ultrasound Systems for Guiding Training and Recovery from Musculoskeletal Injury
Page 1

Short Musculoskeletal Function Assessment (SMFA) Scored

Record ID

PLEASE STATE INJURY AND INJURY LOCATION:

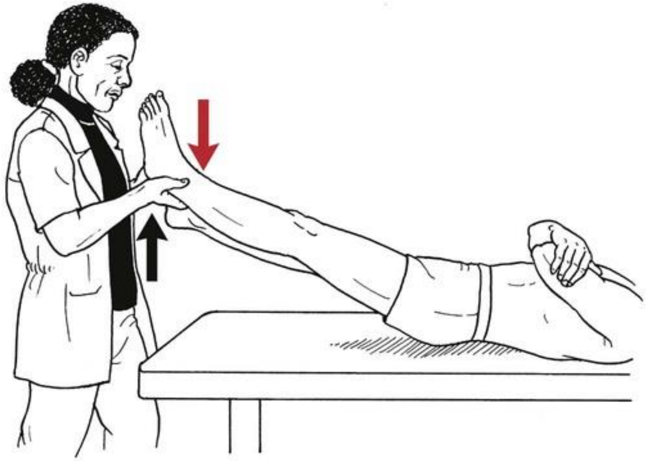
PLEASE STATE WHEN YOUR INJURY WAS DIAGNOSED:

IF YOU HAVE BEEN GOING THROUGH REHABILITATION FOR THIS INJURY, PLEASE LIST ALL CURRENT EXERCISES THAT YOU PERFORM:

These questions are about how much difficulty you may have been having with your daily activities since your injury diagnosis. Please answer each question by selecting the choice that best describes you.

	Not at All Difficult	A Little Difficult	Moderately Difficult	Very Difficult	Unable to Do
1. HOW DIFFICULT IS IT FOR YOU TO WALK?	○	○	○	○	○
2. HOW DIFFICULT IS IT FOR YOU TO ASCEND STAIRS?	○	○	○	○	○
3. HOW DIFFICULT IS IT FOR YOU TO DESCEND STAIRS?	○	○	○	○	○
4. HOW DIFFICULT IS IT FOR YOU TO BEND OR KNEEL DOWN ON YOUR UNINJURED LIMB?	○	○	○	○	○
5. HOW DIFFICULT IS IT FOR YOU TO BEND OR KNEEL DOWN ON YOUR INJURED LIMB?	○	○	○	○	○
6. HOW DIFFICULT IS IT FOR YOU TO SQUAT DOWN?	○	○	○	○	○
7. HOW DIFFICULT IS IT FOR YOU TO PIVOT/TURN?	○	○	○	○	○
8. HOW DIFFICULT IS IT FOR YOU TO DO PHYSICAL ACTIVITY, SUCH AS BIKING, JOGGING, OR PLAYING SPORTS?	○	○	○	○	○
9. HOW DIFFICULT IS IT FOR YOU TO JUMP?	○	○	○	○	○

Manual Muscle Testing



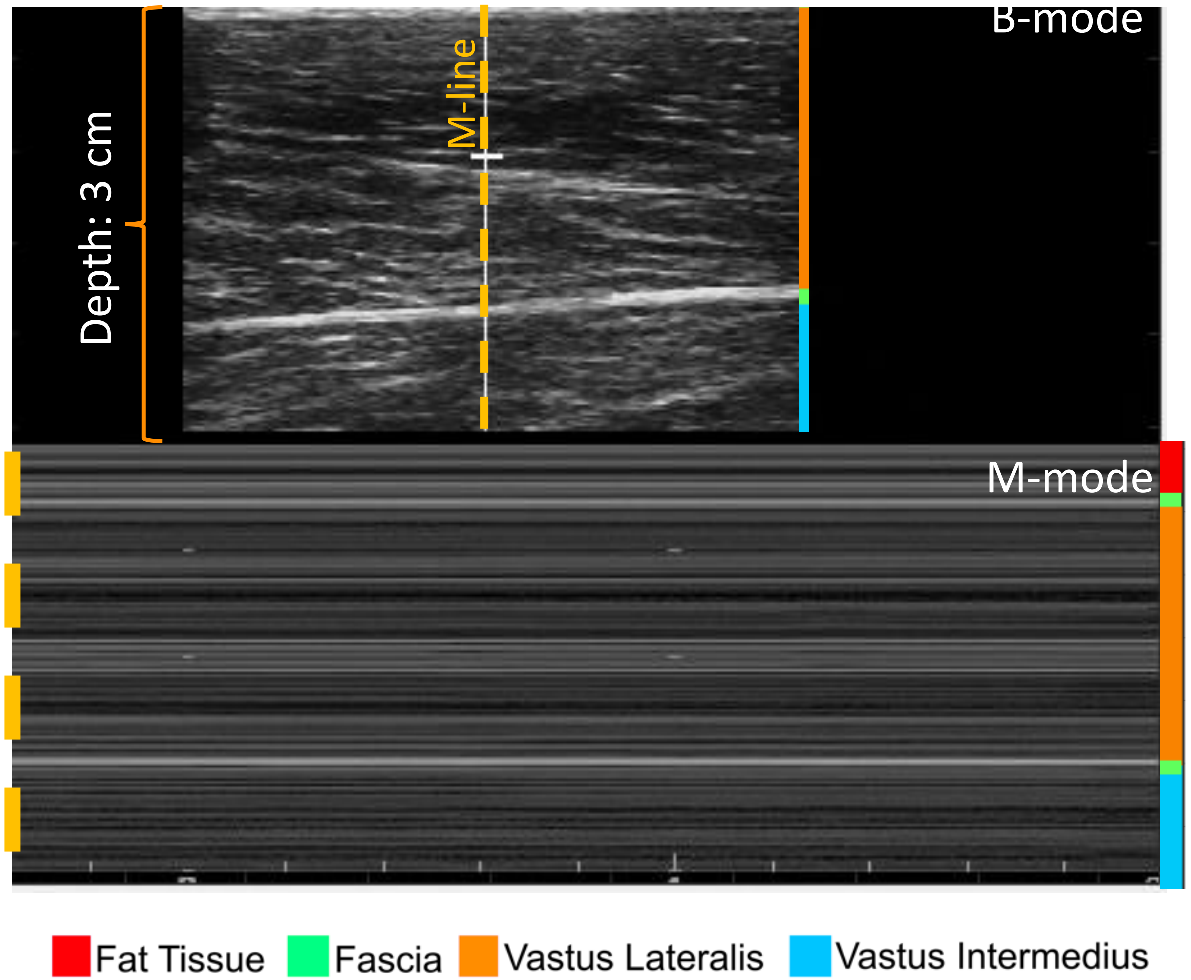
Laboratory Assessments

Isokinetic Strength Testing

Current tools lack objective tissue specific metrics

Bohannon, 2005, Taborri et al., 2020

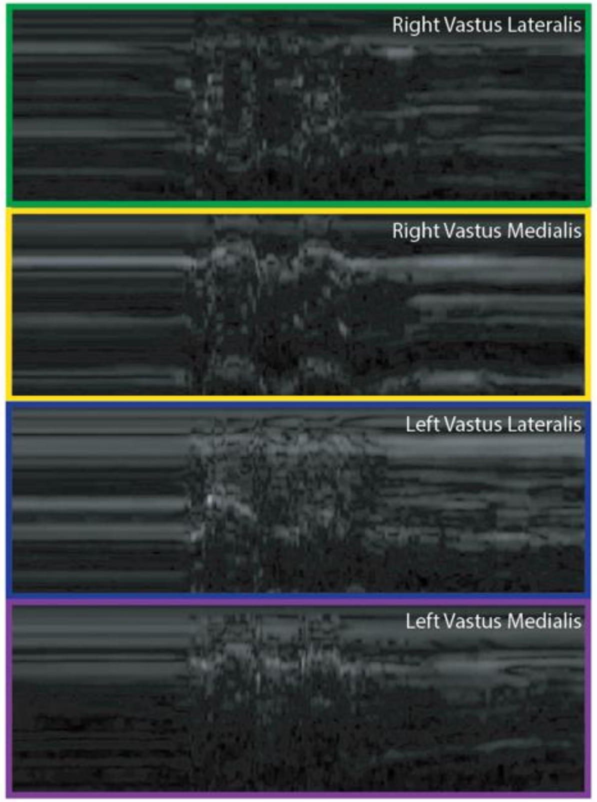
Ultrasound can provide tissue specific metrics



Ultrasound can provide tissue specific metrics

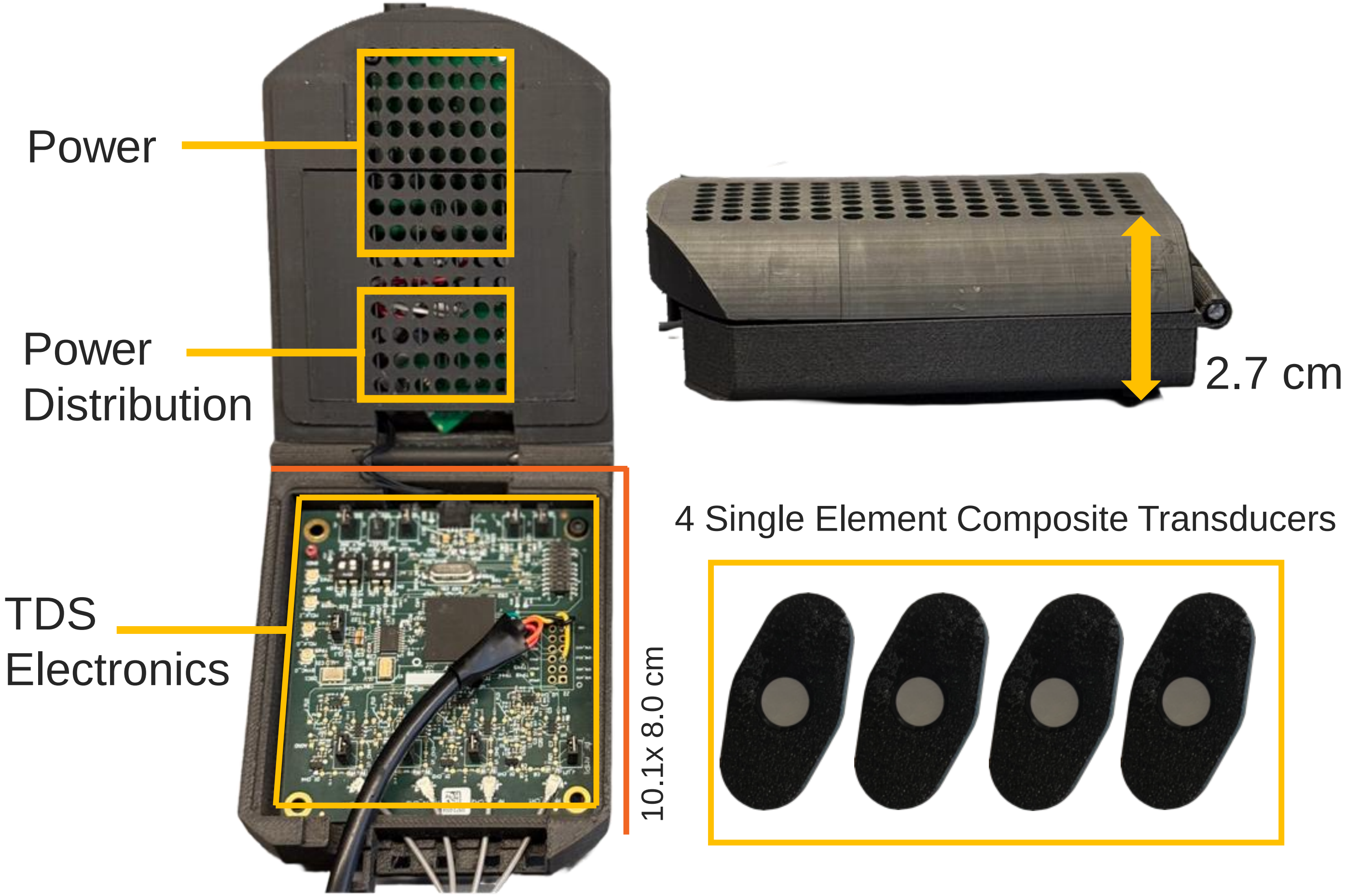
Clinical Ultrasound

Distributed Wearable Ultrasound



SonoTrak - Time Delay Spectrometry

- Time Delay Spectrometry
  - Low voltage, long duration transmit chirps
  - Time delay encoded in frequency
  - Signal processing to extract depth
- Benefits:
  - Lower sampling rates (kHz)
  - Simpler wearable design 4-channel M-mode design
  - ***Multi-Site Imaging during complex movements***



Techniques to Extract Muscle Mechanics

Different extraction techniques can be used depending on the research question

1. Normalized Pixel Difference + TKEO Filter

Movement type

Controlled, single-joint (isokinetic plantarflexion)

What it does

Converts M-mode video to a 1-D motion trace, isolates onset via an energy operator

Extracts

Precise activation timing (ms)

Question it answers:

“When did each muscle activate?”

2. Composite Factorization with PCA

Movement type

Dynamic, multi-joint, bilateral (jump / landing)

What it does

Factorizes M-mode data (W x H) into temporal components (residual-based factor selection)

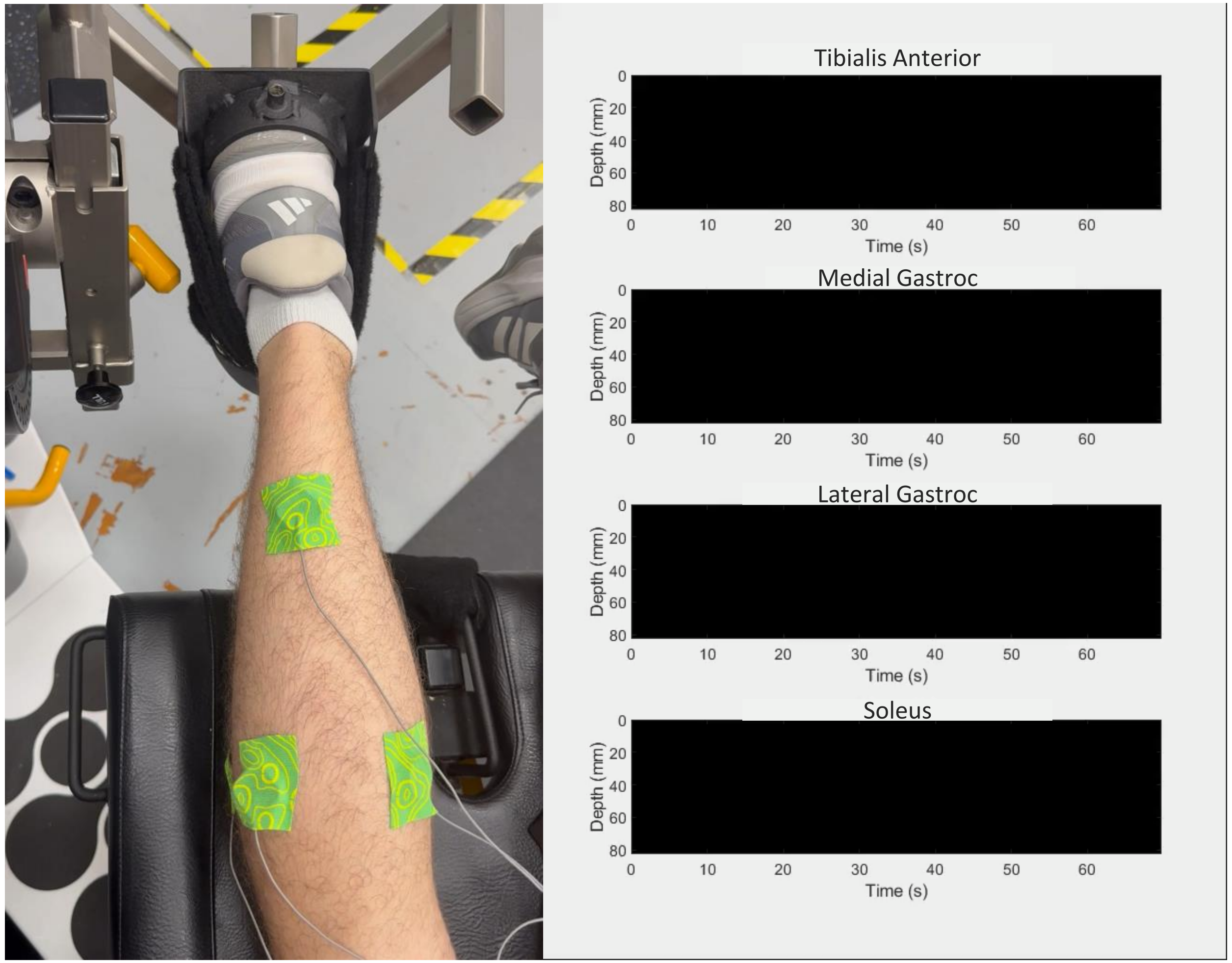
Extracts

Symmetry indices for contraction and overall timing

Question it answers:

“How do muscles compare to each other?”

Wearable Ultrasound and Muscle Activation Patterns



Participants:

- Four participants (27.75 ± 5.7 years) completed plantarflexion testing using their right (dominant) leg.

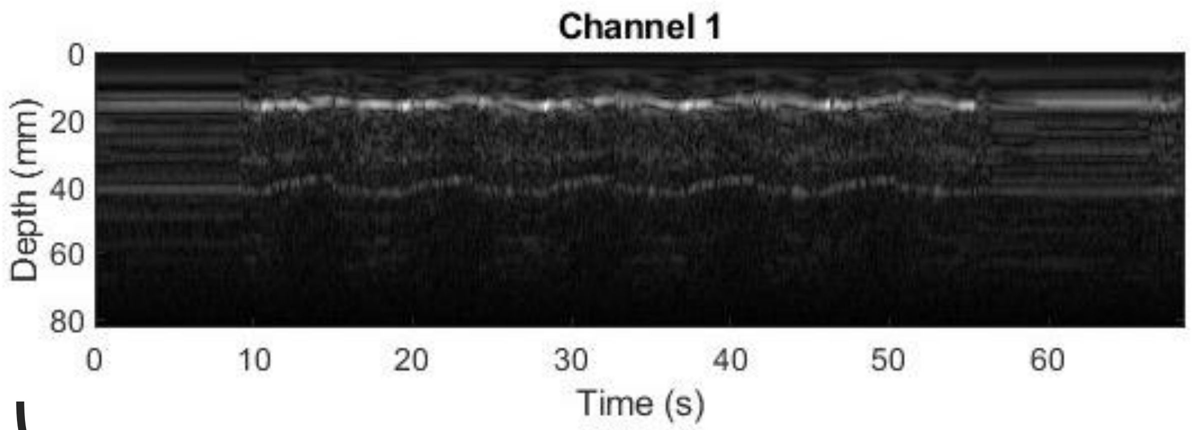
Task:

- Torque and ankle position were collected during 15°/s plantarflexion

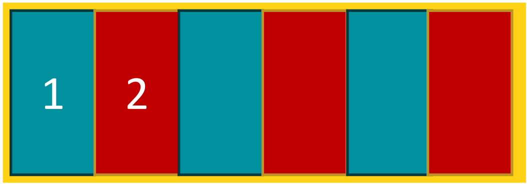
Assessment Tools:

- SonoTrak over the tibialis anterior (TA), medial gastrocnemius (MG), lateral gastrocnemius (LG), and soleus
- Signal Processing: ***Normalized Pixel Difference***

Signal Processing: Normalized Pixel Difference + TKEO Filter



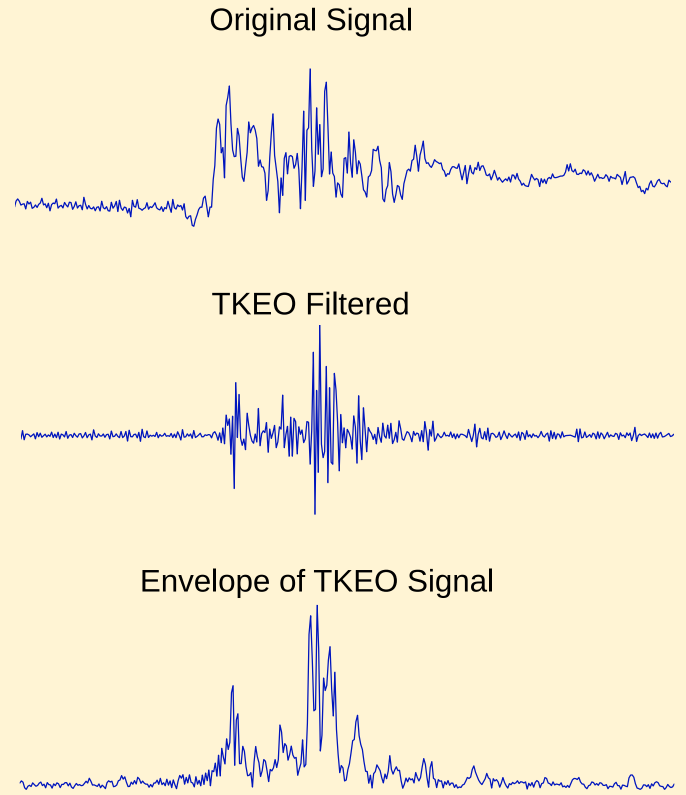
Individual M-lines



$$NPD(i) = \frac{\sum_{n=1}^{M\times N} |frame\,2 - frame\,1|}{M \times N}$$

1D signal over time

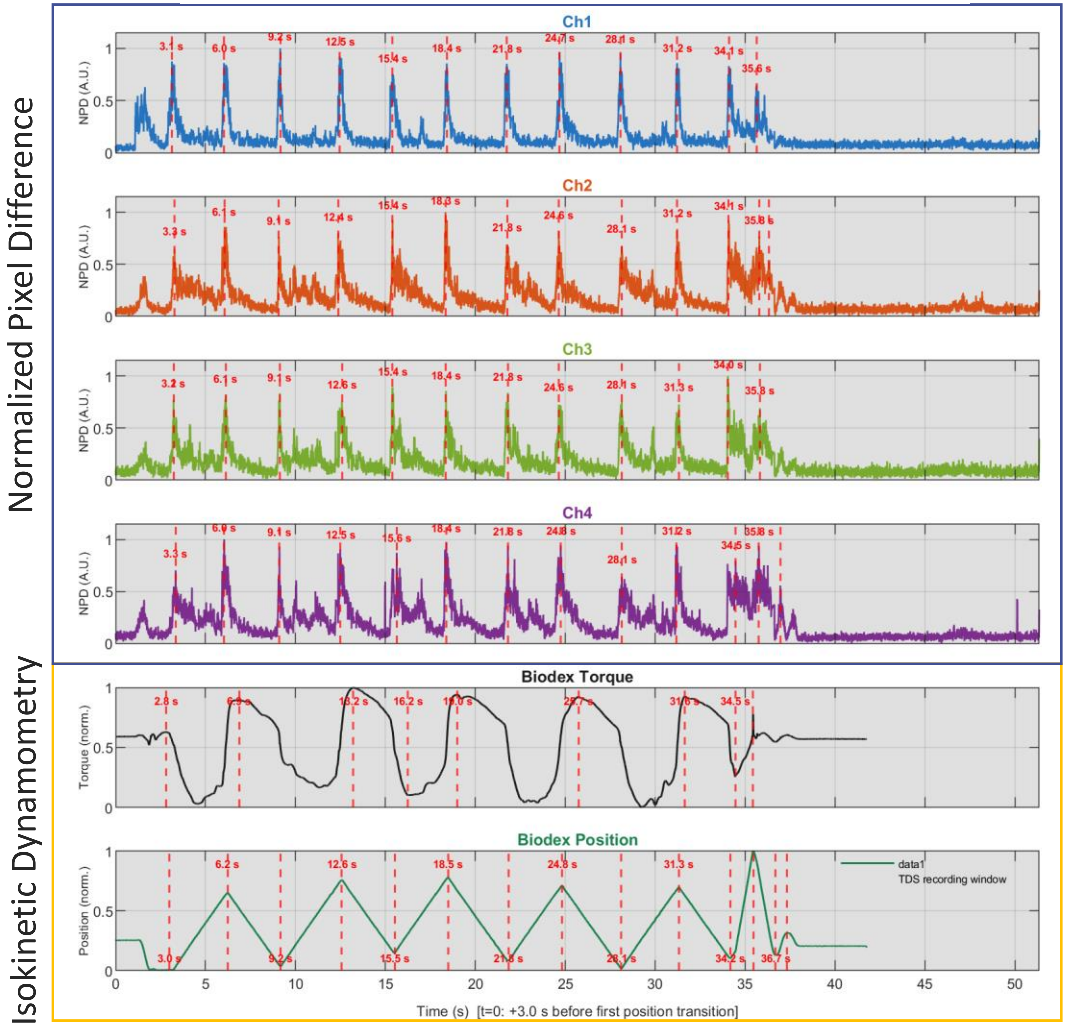
<u>Teager-Kaiser Energy Operator (TKEO):</u>



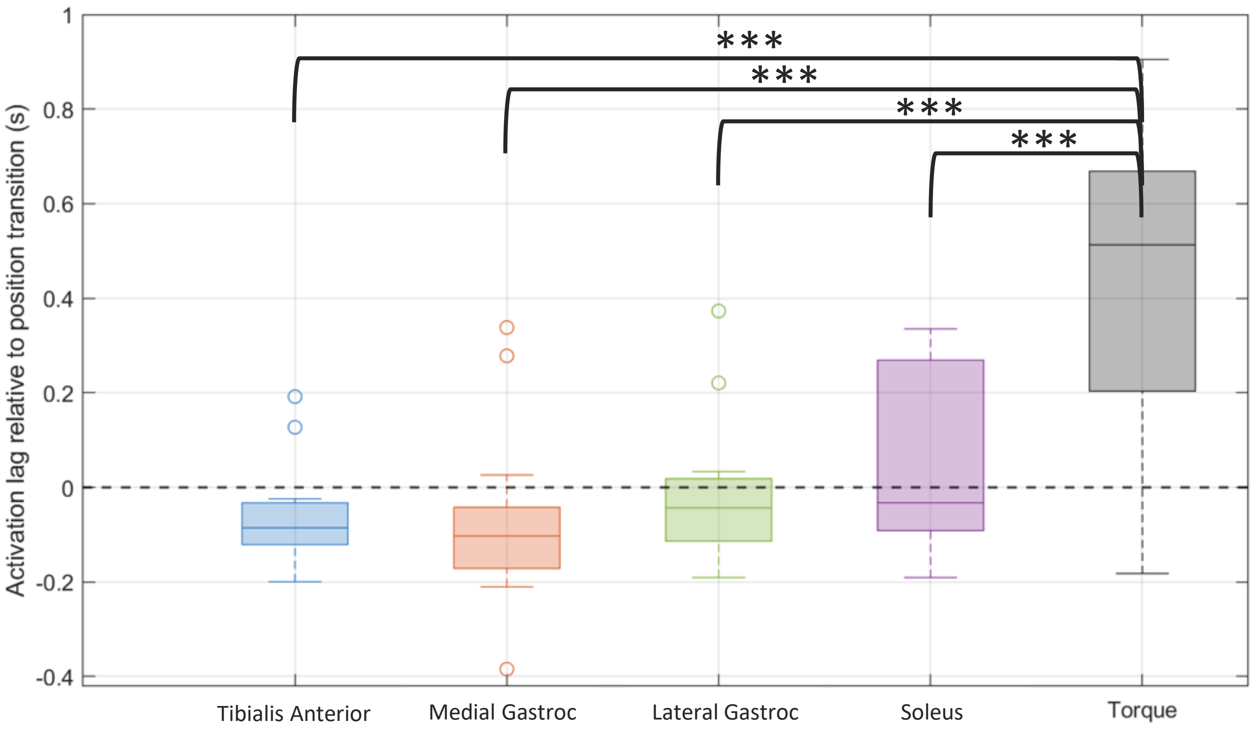
$$TKEO = \; x^2(n) - x(n-1) * x(n+1)$$

Wearable Ultrasound and Muscle Activation Patterns

Plantar Flexion @ 15 deg/sec



Activation Timing Differences Relative to Ankle Position

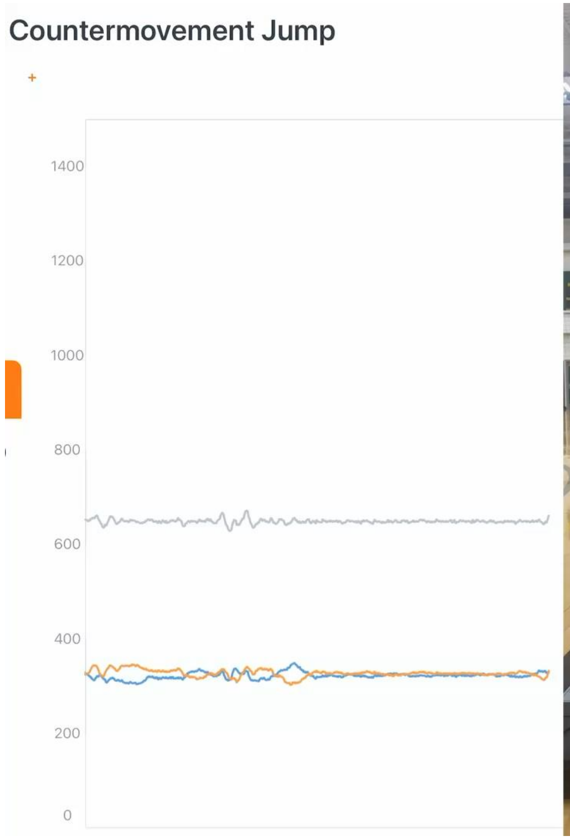


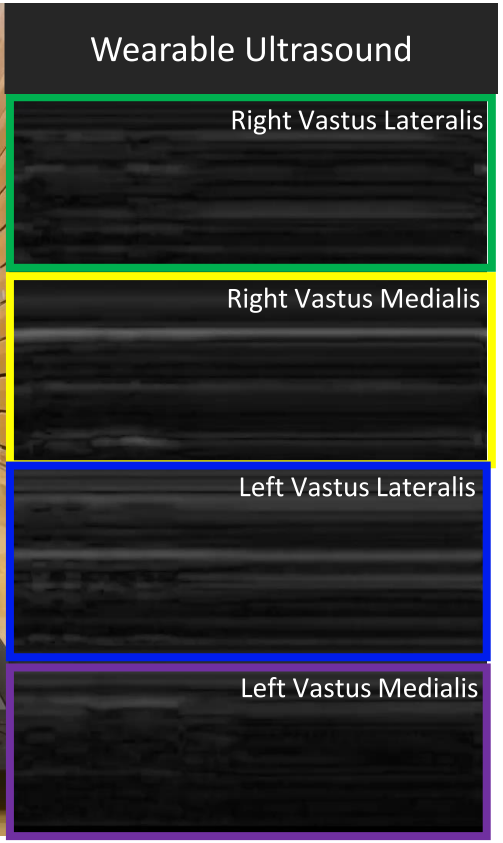
- No significant differences in activation timing among the four muscles (all $p > 0.17$)
- Peak torque occurred significantly later than all four muscle activation peaks ($p < 0.001$)

*** $p < 0.001$

Wearable Ultrasound and Neuromuscular Adaptations after Injury

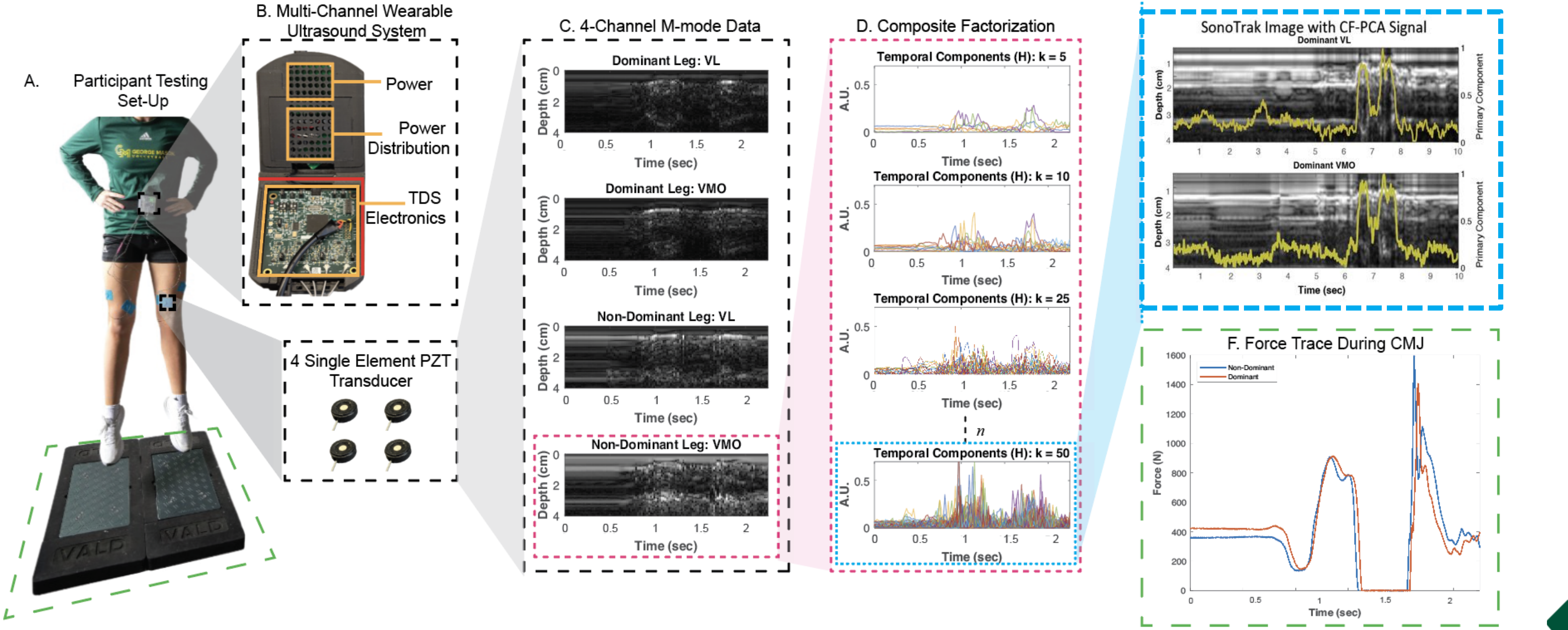
- Participants: **20 female athletes**
  - *Knee Injury within 2 years* (n = 9)
  - *No Knee Injury* (n = 11)
- Self-Reported Wellness:
  - *Short Muscle Function Assessment* (SMFA) Surveys
- 3 maximal countermovement jumps on bilateral force plates
- SonoTrak on the left and right vastus lateralis (VL) and vastus medialis oblique (VMO)
- Signal Processing: ***Composite Factorization PCA (CF-PCA)***



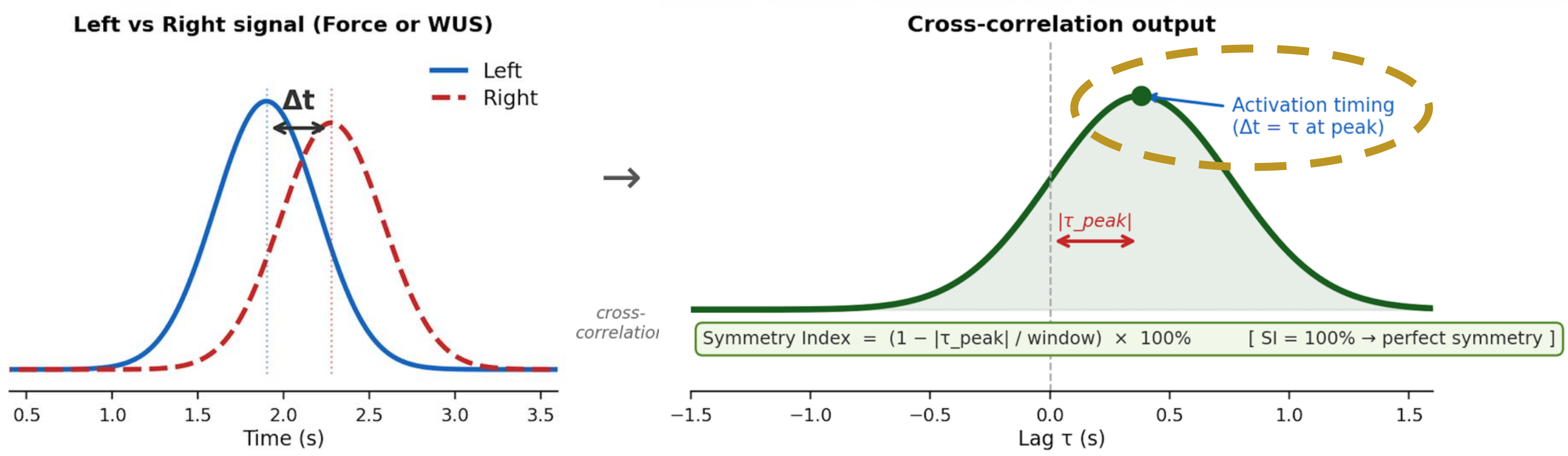


King et al., *IEEE TBME,* 2026 (under review)

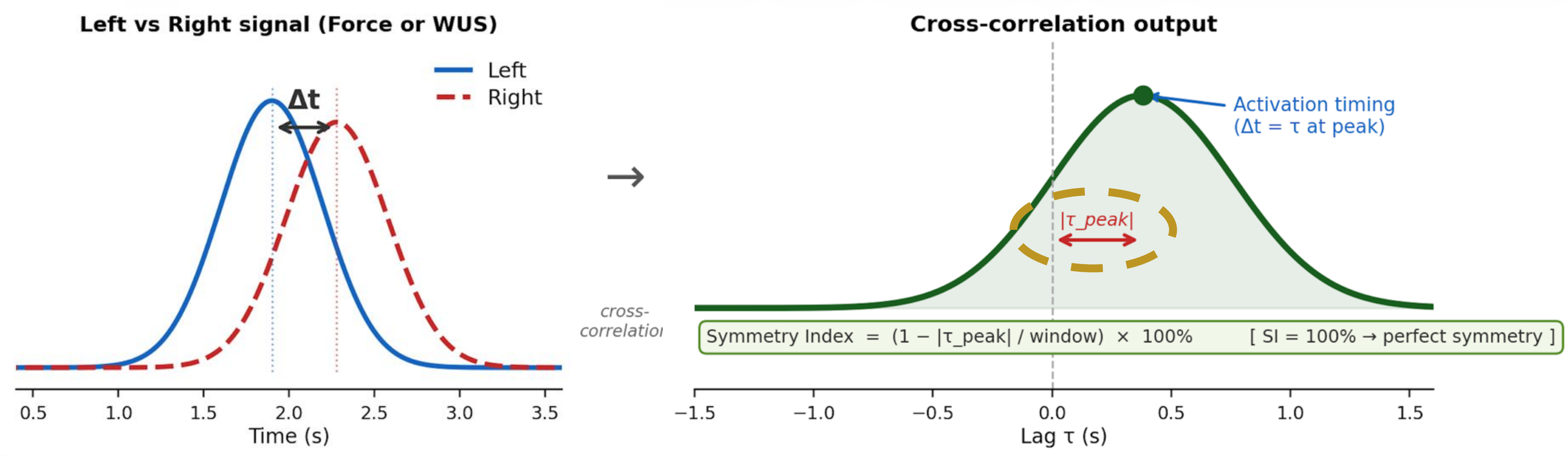
Signal Processing: Composite Factorization PCA (CF-PCA)



Signal Cross-Correlation



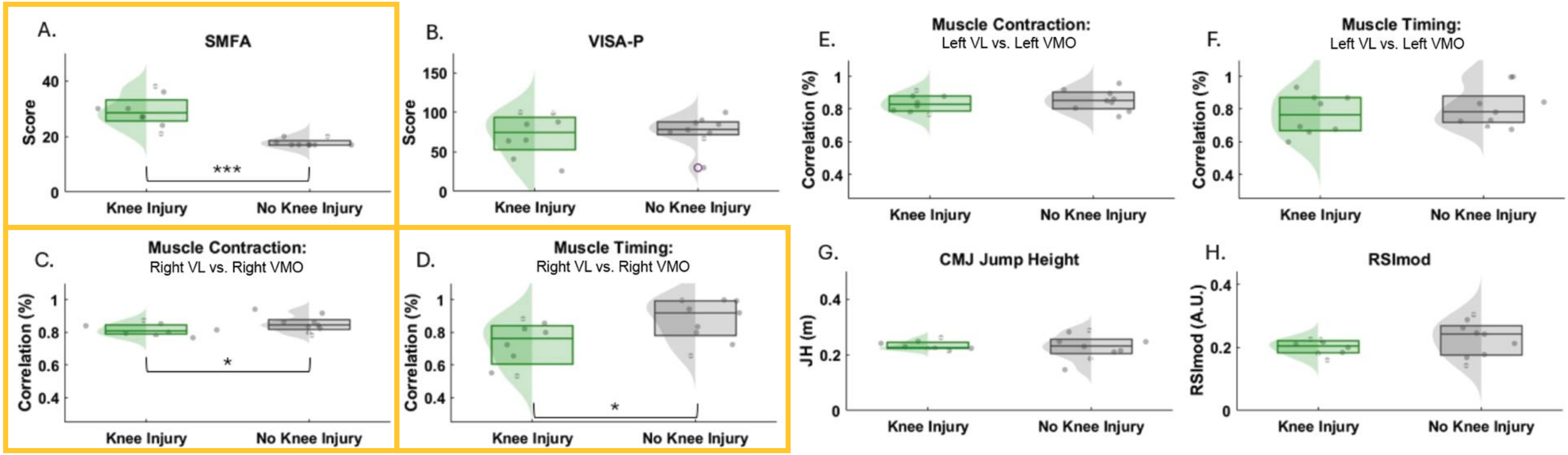
Signal Cross-Correlation



<u>Outcome Metrics</u>: **Muscle Timing** and **Muscle Contraction** Symmetry

King et al., *IEEE TBME* 2026 [UNDER REVIEW]

Wearable Ultrasound and Neuromuscular Adaptations



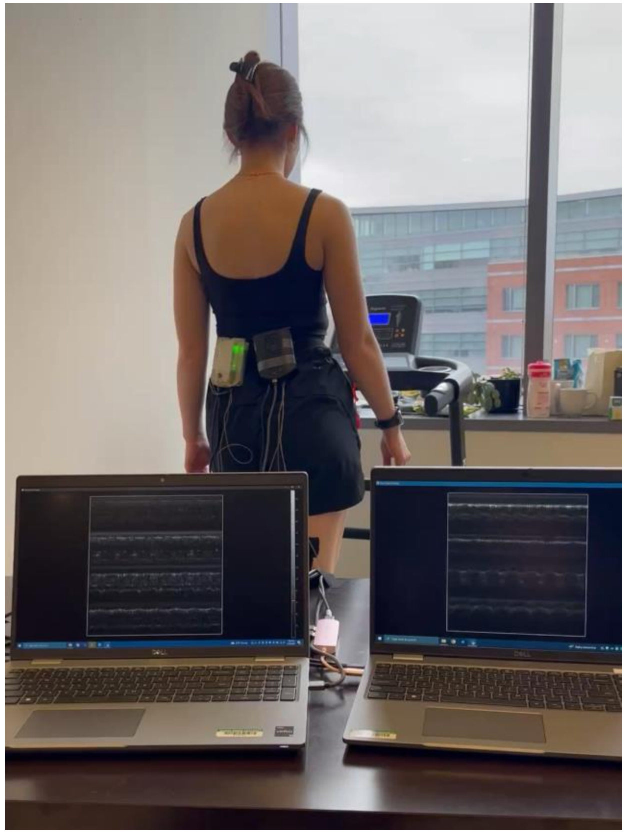
*$p < 0.05$

Conclusion

Wearable Ultrasound is A Feasible Technology to Monitor Across Joints and Injury Types

- Wearable Ultrasound can reliably extract clinically meaningful neuromuscular metrics using pipeline processing tailored to specific exercises
- Demonstrates the platform generalizes across joints, tasks, and injury types rather than being purpose-built for one condition
- Compact, wearable form factor (TRL 5) supports deployment in austere/field settings without specialized ultrasound operators

Objective tool for return-to-duty decision-making and personalized rehabilitation monitoring improving military readiness



Walking

Thank you!

Principal Investigators

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- Connor Delaney
- Morgan Lamarre
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GMU Patriot Performance Lab

- Margaret T. Jones, PhD
- Noelle Saine

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- Chris Rhea, PhD
- Ryan McCann, PhD

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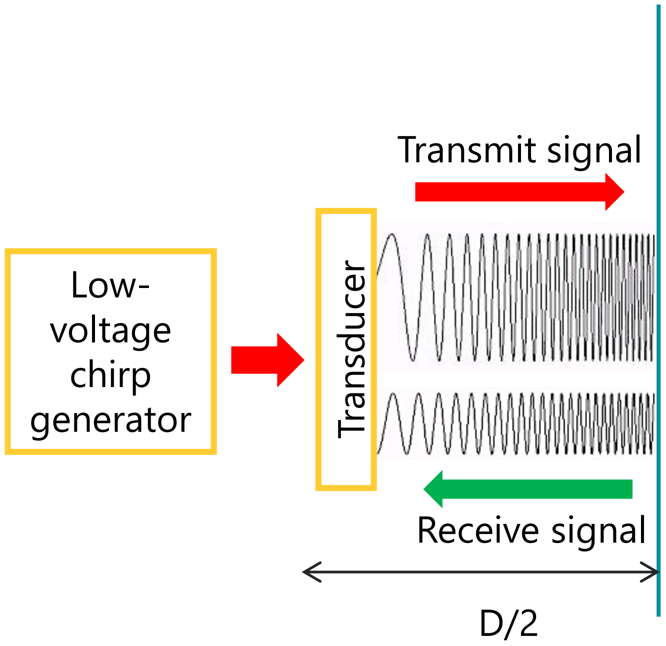
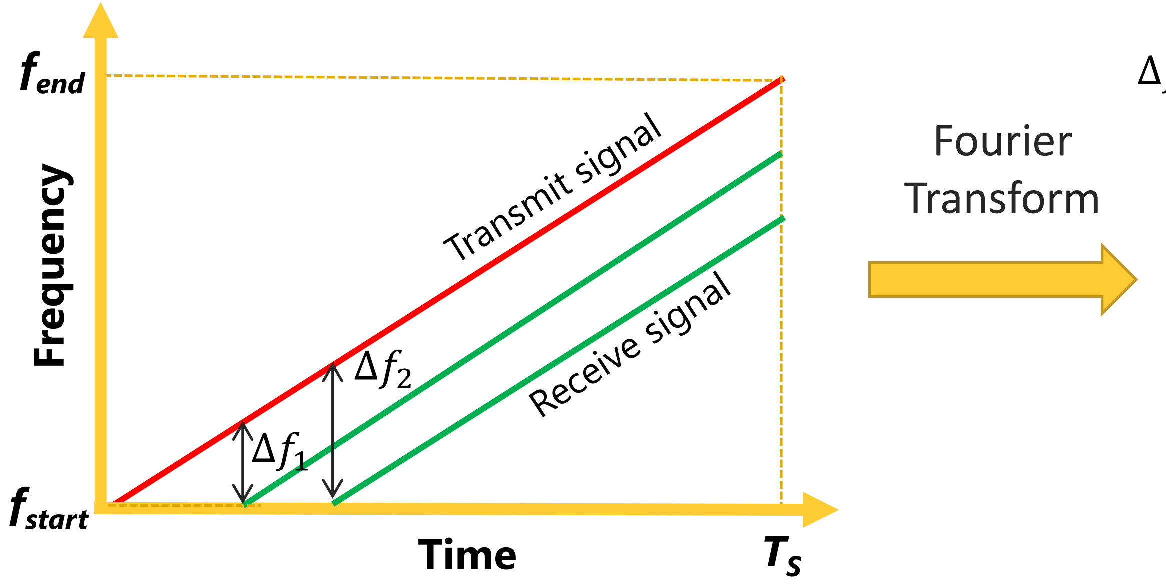
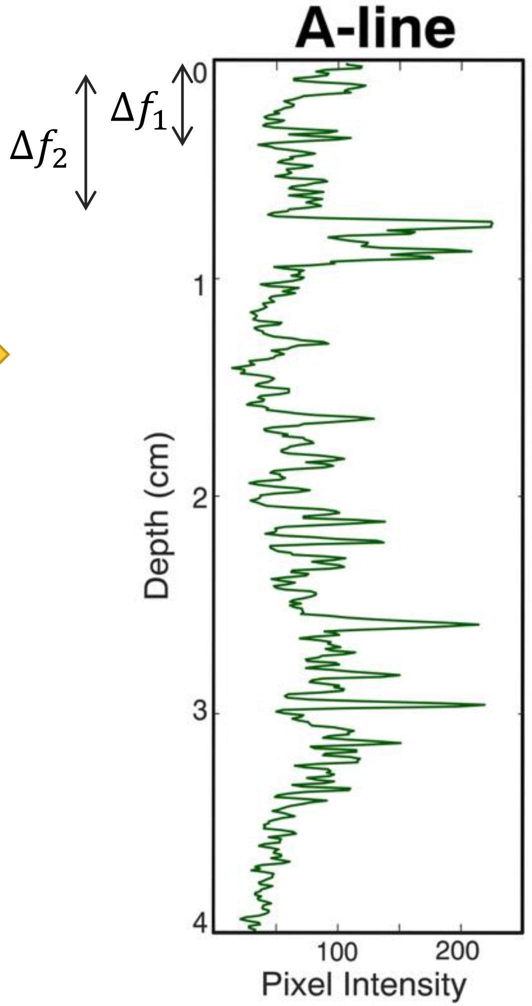
SonoTrak - Time Delay Spectrometry







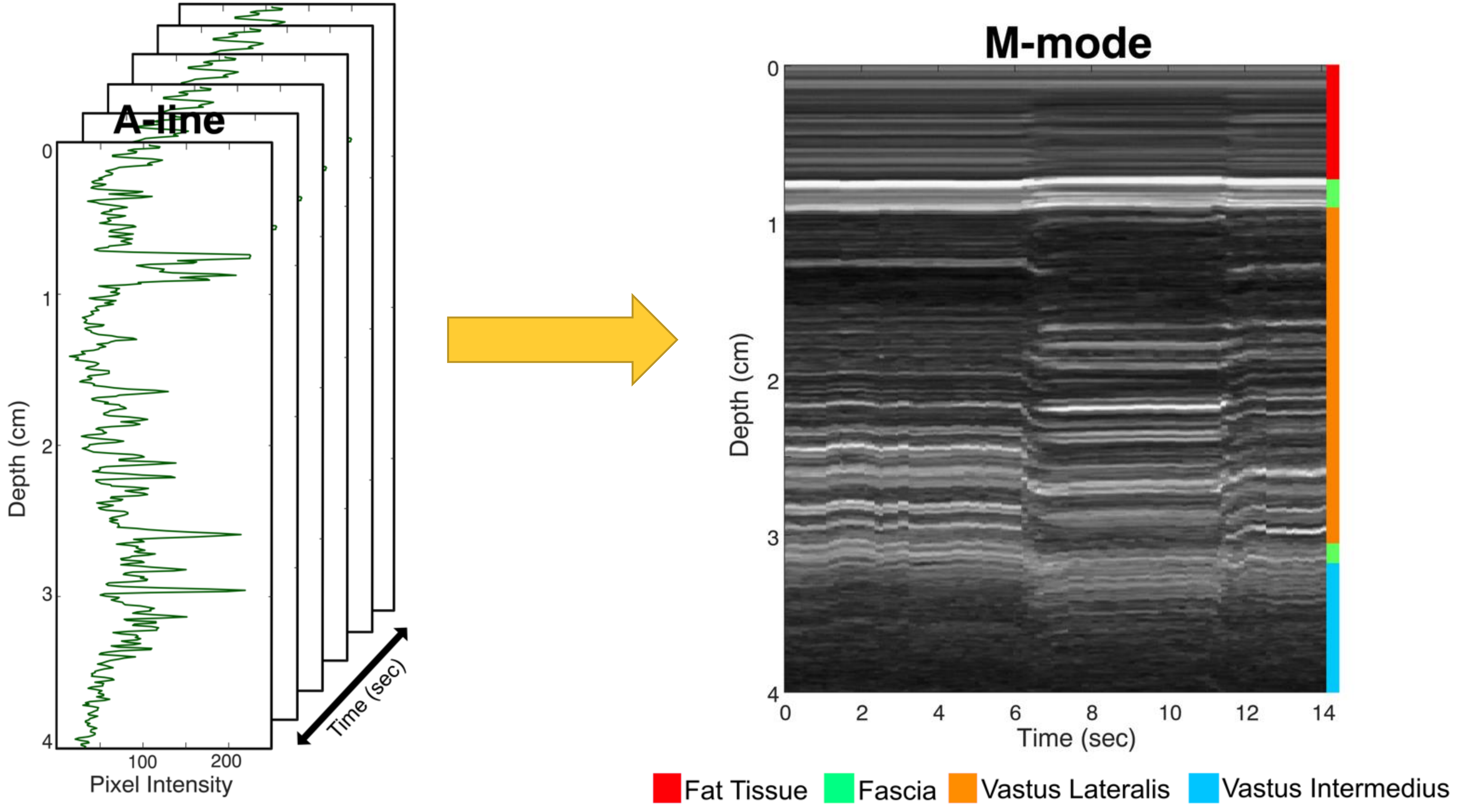
depth frequencies (Δf) is extracted mixing transmit and receive signals in hardware

Sweep Rate

$$S = \frac{|f_{end} - f_{start}|}{T_S}$$

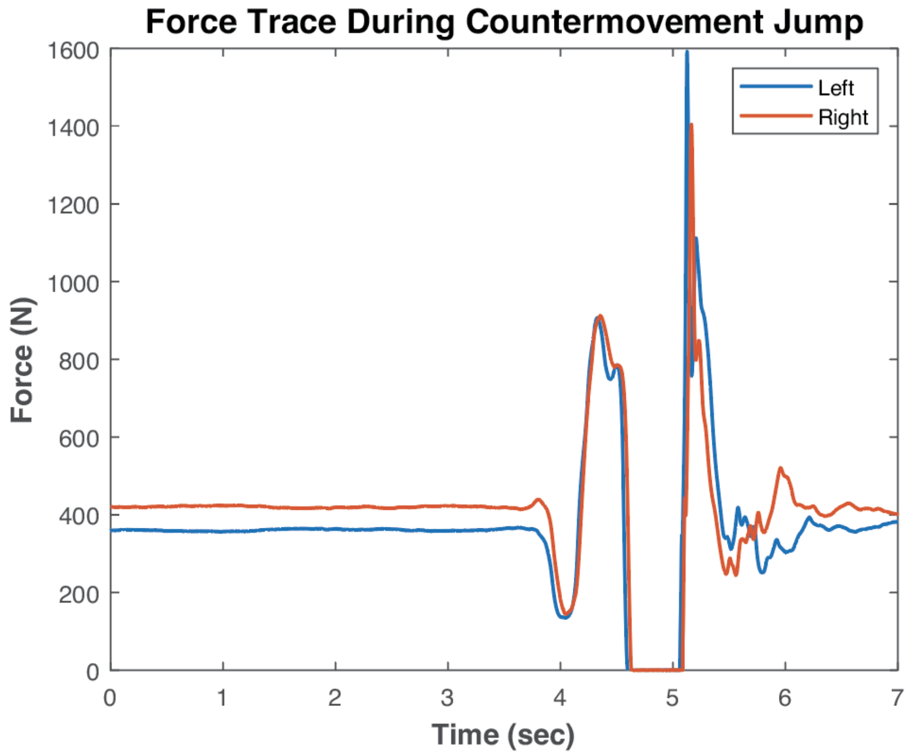
$$Depth = \frac{\Delta f\ c}{2\ S}$$

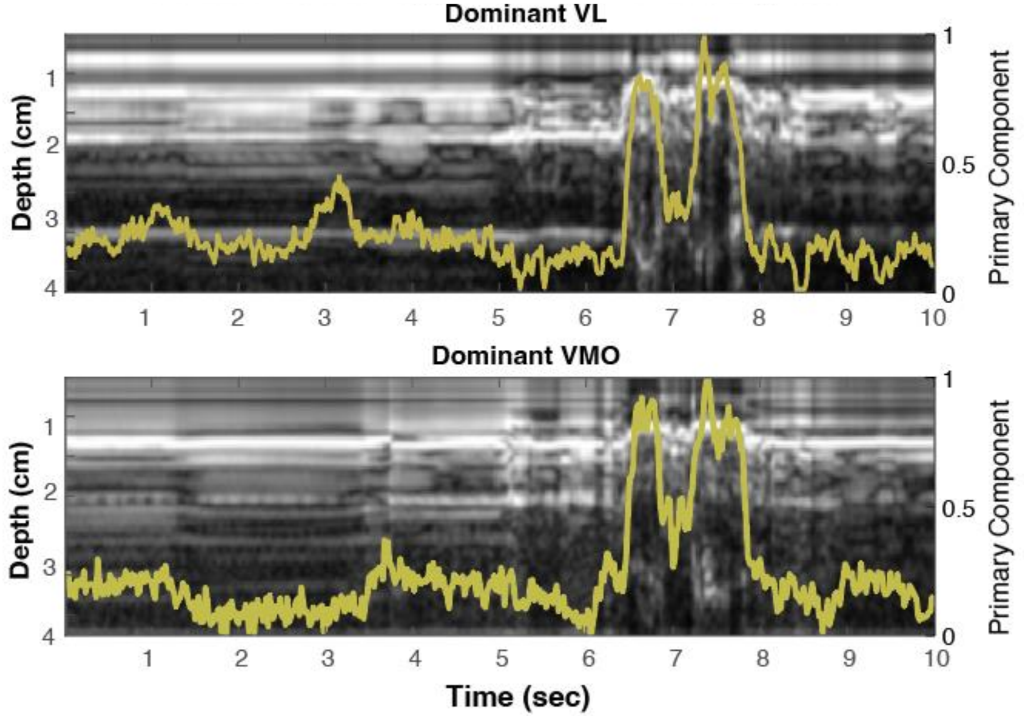
SonoTrak - Time Delay Spectrometry



(Bashatah et al., 2024)

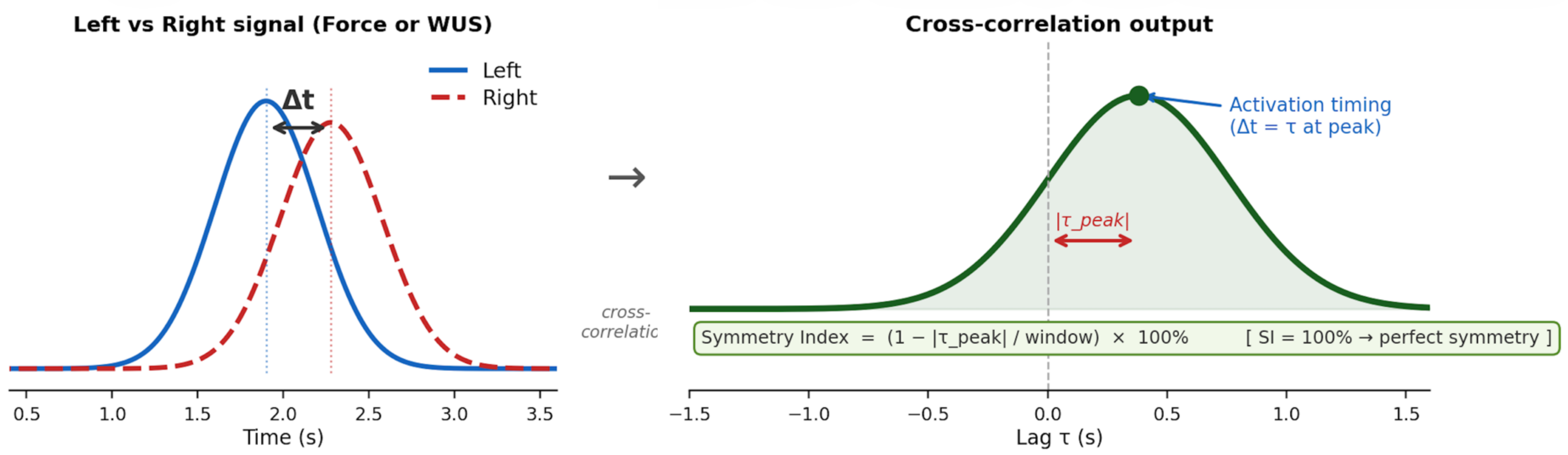
CF-PCA and Force Outputs



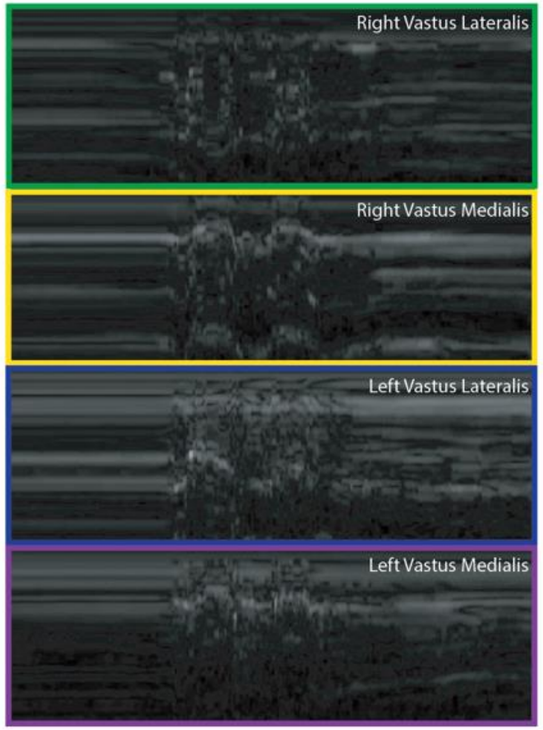


King et al., *IEEE TBME* 2026 [UNDER REVIEW]

Signal Cross-Correlation



Non-Negative Matrix Factorization



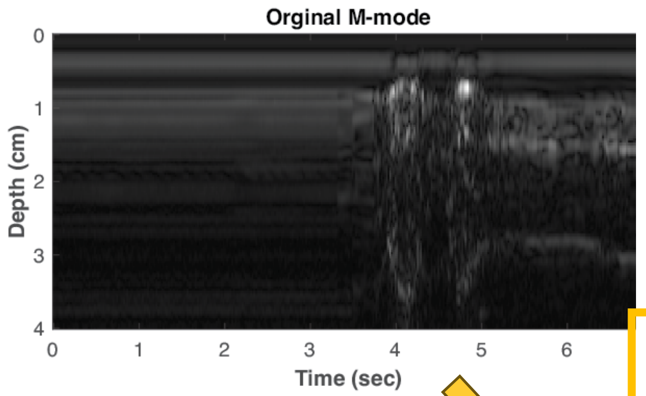
Pre-Processing

Non-Negative Matrix Factorization (NNMF)

M-mode ≈ W × H

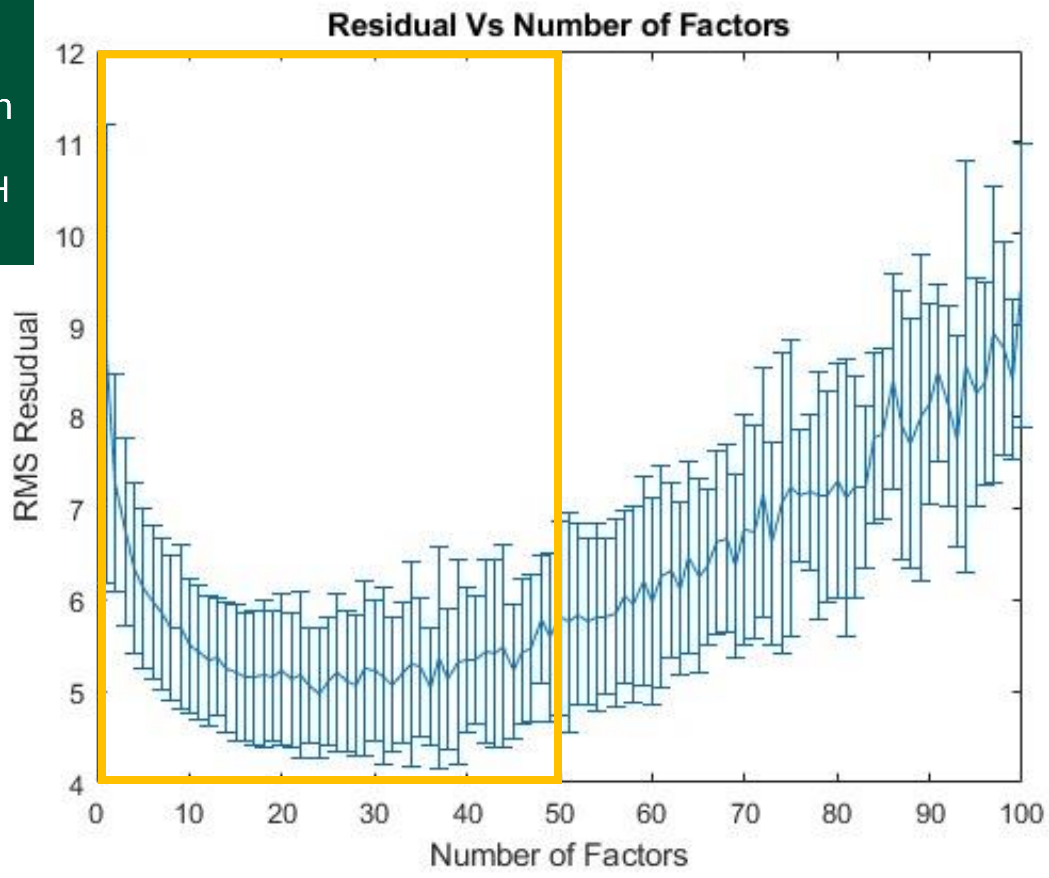
Non-Negative Matrix Factorization

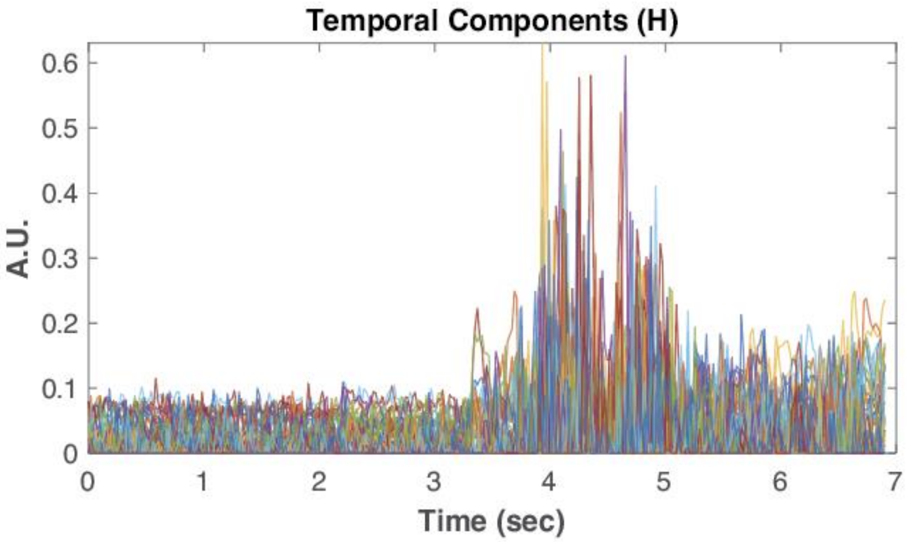
Non-Negative
Matrix Factorization
(NNMF)
M-mode ≈ W × H



NNMF: Number of Factors Selection

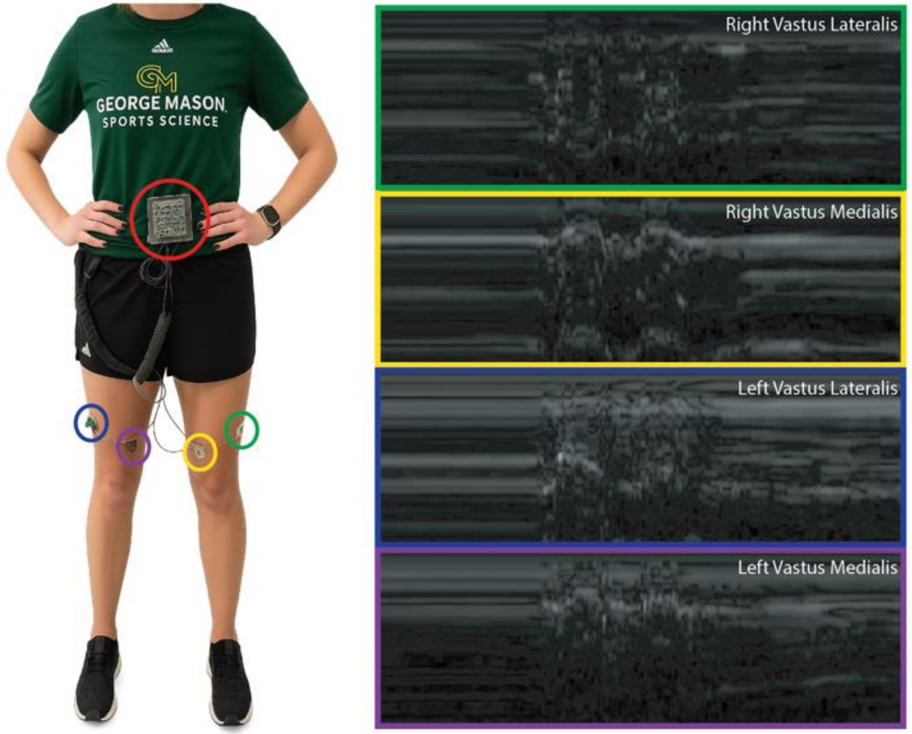
Non-Negative Matrix Factorization (NNMF)
M-mode ≈ W × H





New Temporal Matrix = 1245 x m

Composite Factorization PCA (CF-PCA)



Pre-Processing → Non-Negative Matrix Factorization (NNMF) M-mode ≈ W × H → Principle Component Analysis (PCA)

Composite Factorization PCA (CF-PCA)