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Identifying Musculoskeletal Injury from Movement Time Series using a Sinusoidal Representation Network.

Building the Analytical Foundation for Wearable Musculoskeletal Injury Biomarkers

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Disclaimer

The views expressed in this abstract are those of the authors and do not reflect the official policy or position of the U.S. Army Medical Department, Department of the Army, DoW, or the U.S. Government.

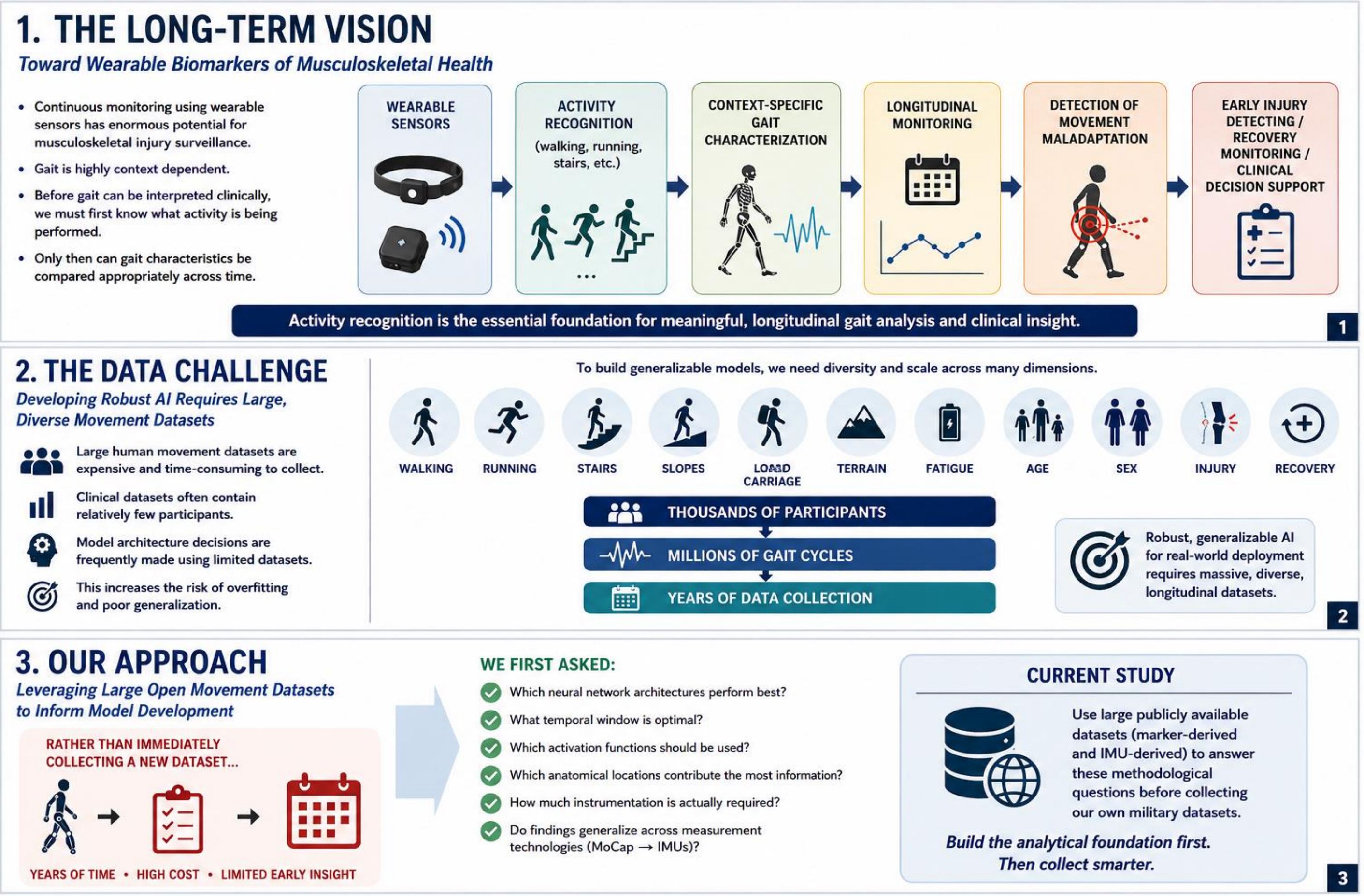
Learning Objectives

1. Outline considerations for designing human subject data collection protocols for developing classifiers.
2. Describe novel machine learning method for dimensionality reduction of movement data.
3. Broaden understanding of movement markers for clinical decision making.

The Road Map to Wearable Derived Biomarkers of Musculoskeletal Health

- Context Matters
  - Premise
  - Collecting Data ‘in the wild’

- Clinical Need
- The Challenge
- Our Strategy
- Translation



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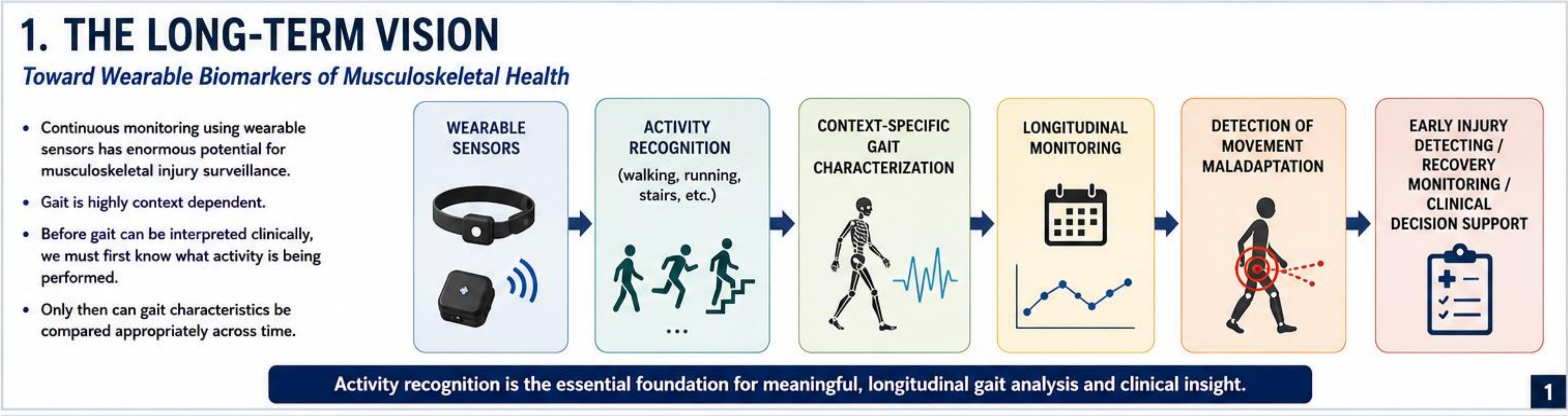
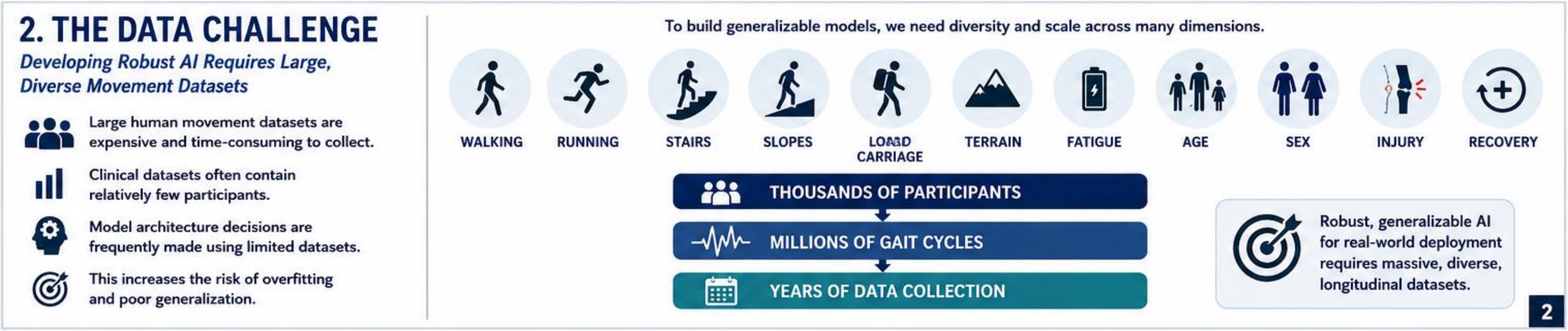
Long Term Vision - From Wearable Sensors to Clinical Decision Support



The Challenge - Building Robust AI Requires Large-Scale Movement Datasets



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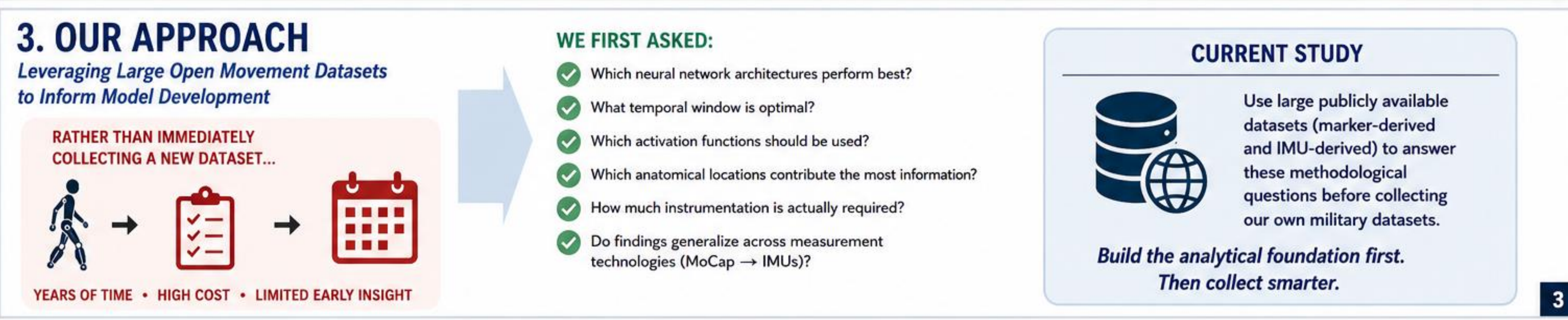
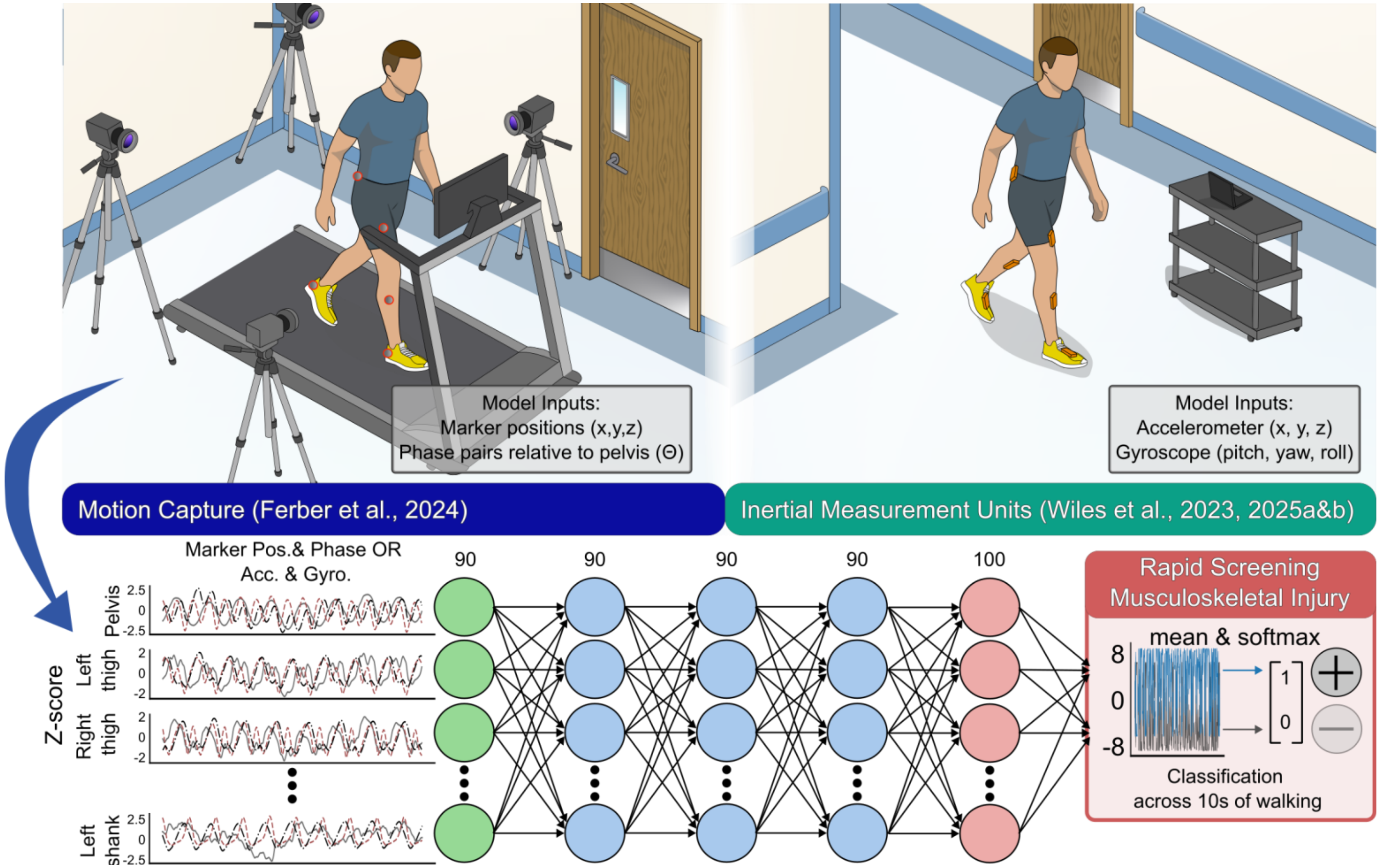
Our Approach - Learning from Big Data Before Collecting New Data



Our Approach - Develop the Flexible Analytics First: Collect Smarter Later

- Large Public Gait Datasets Accelerate Method Development
  - Different measurement methods
  - Different contexts (treadmill vs overground walking)
  - Different musculoskeletal injuries



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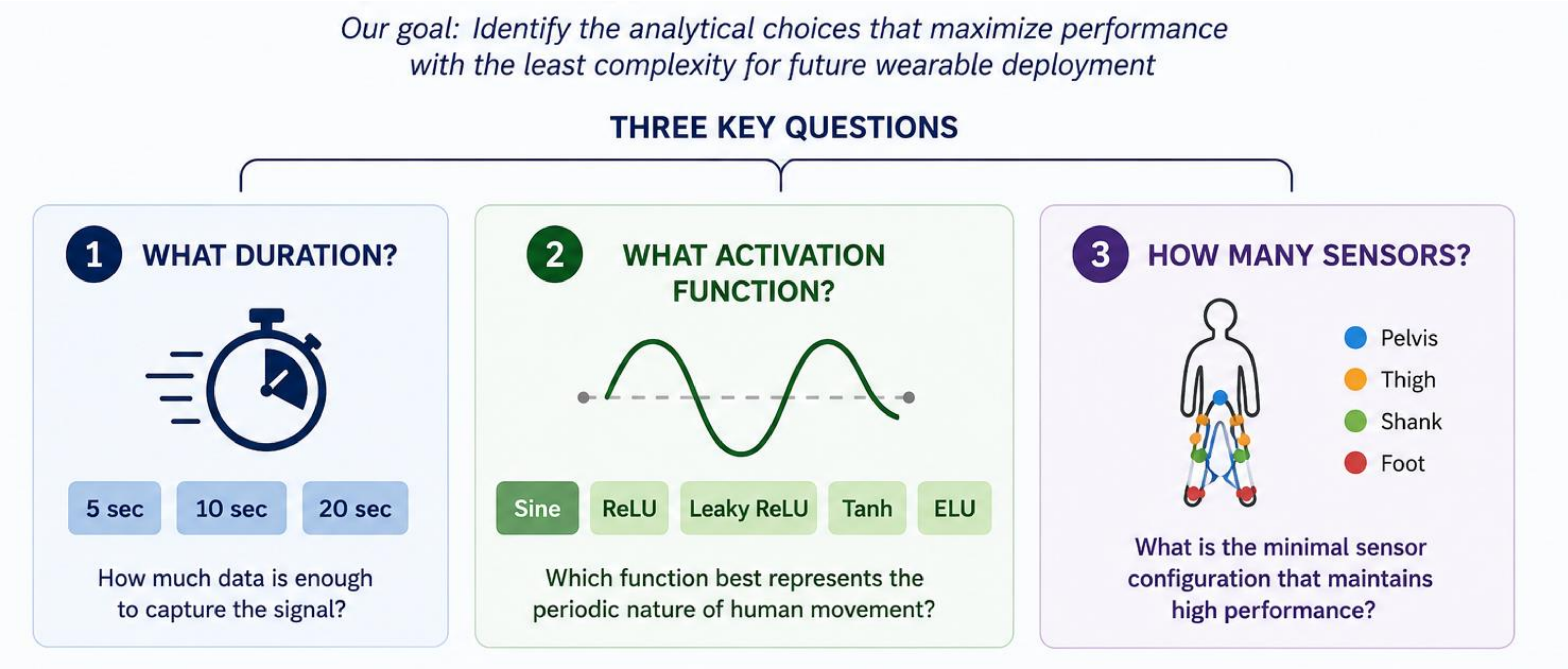
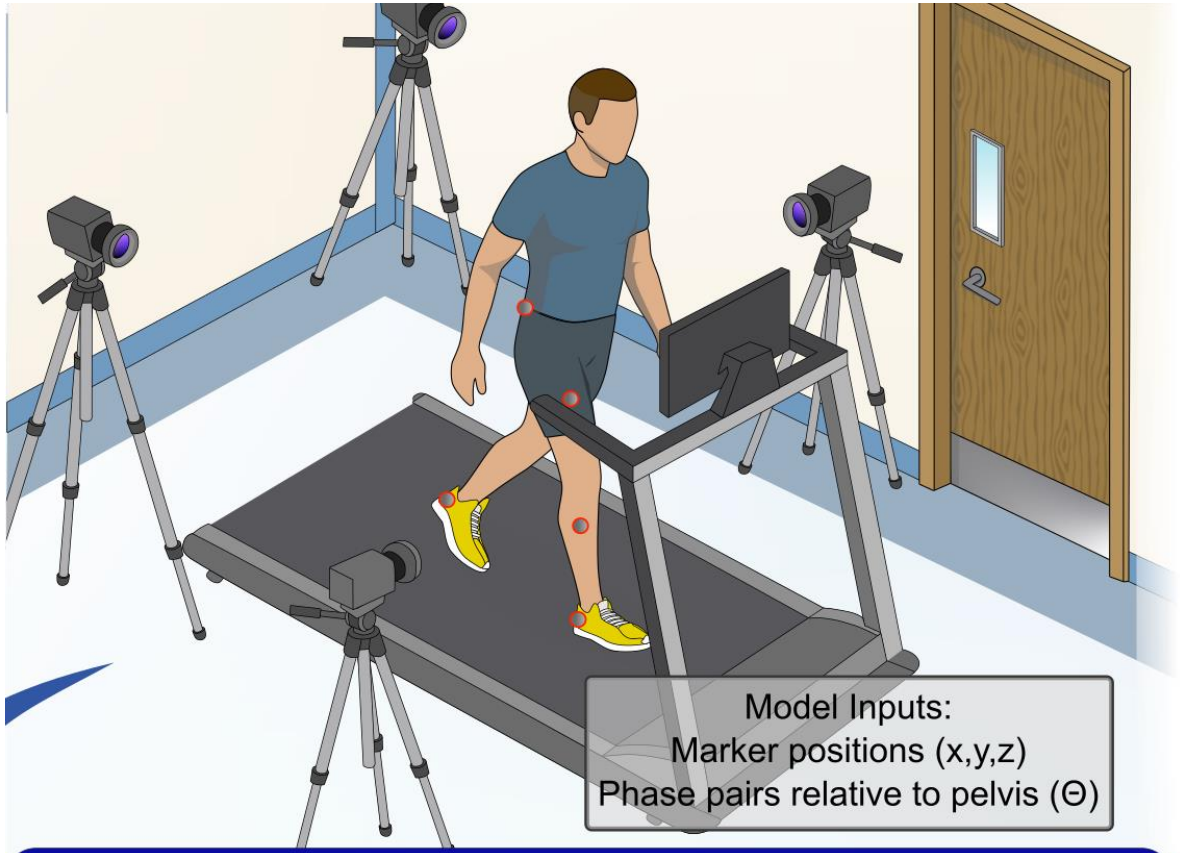
Optimizing Model Architecture



Ferber et al., 2024 Study Details

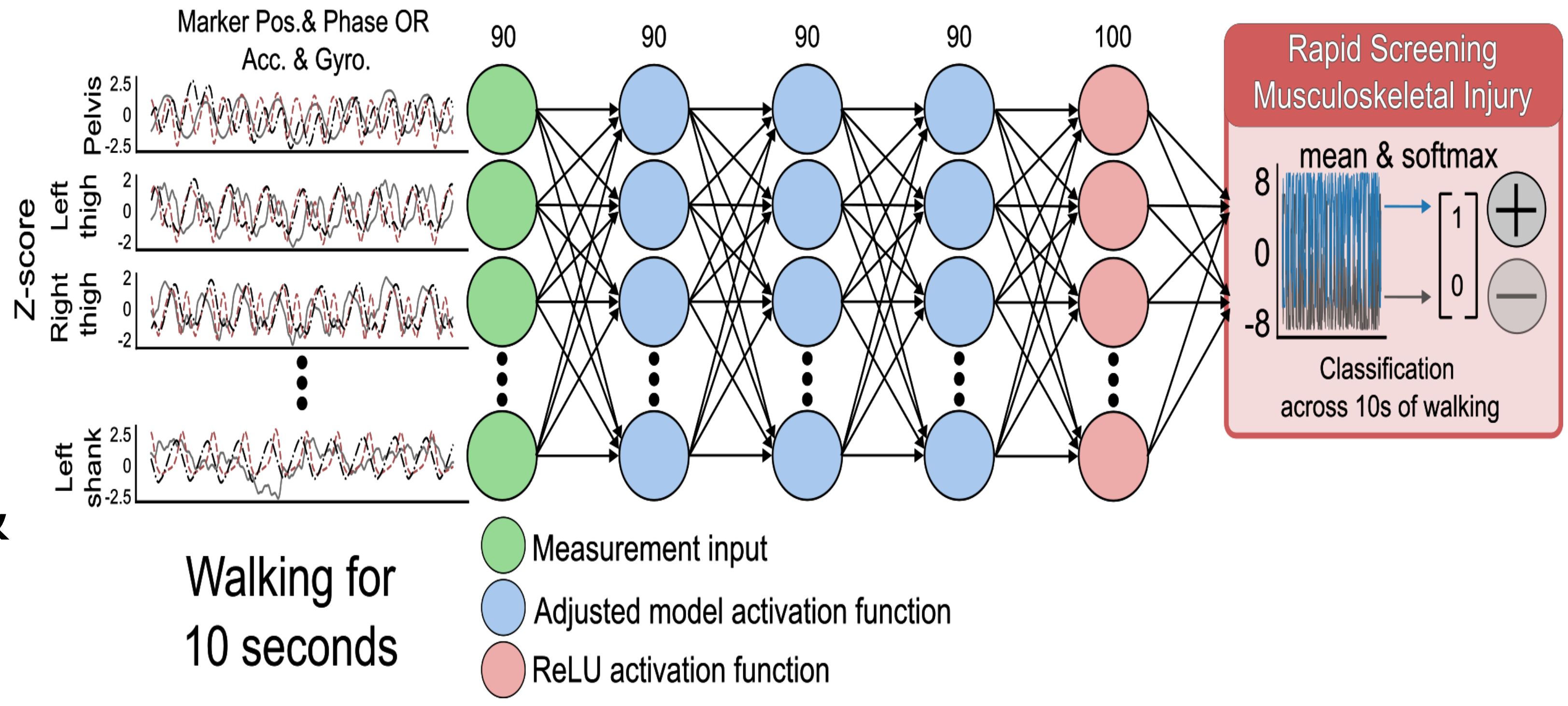
- 1686 subjects (after close inspection)
- 53 different injury labels
- Filtered marker position (x, y, z) and “angle” calculations
- Velocity and acceleration derivatives
- Sacrum, thigh, shank, foot (not of bony landmarks often used to define joint centers).
- 90 total features/inputs



Motion Capture (Ferber et al., 2024)

Why Use Sinusoidal Representation Networks?

- Periodic
- Prevents exploding/vanishing gradients
- Simple to implement & reasonably efficient training time



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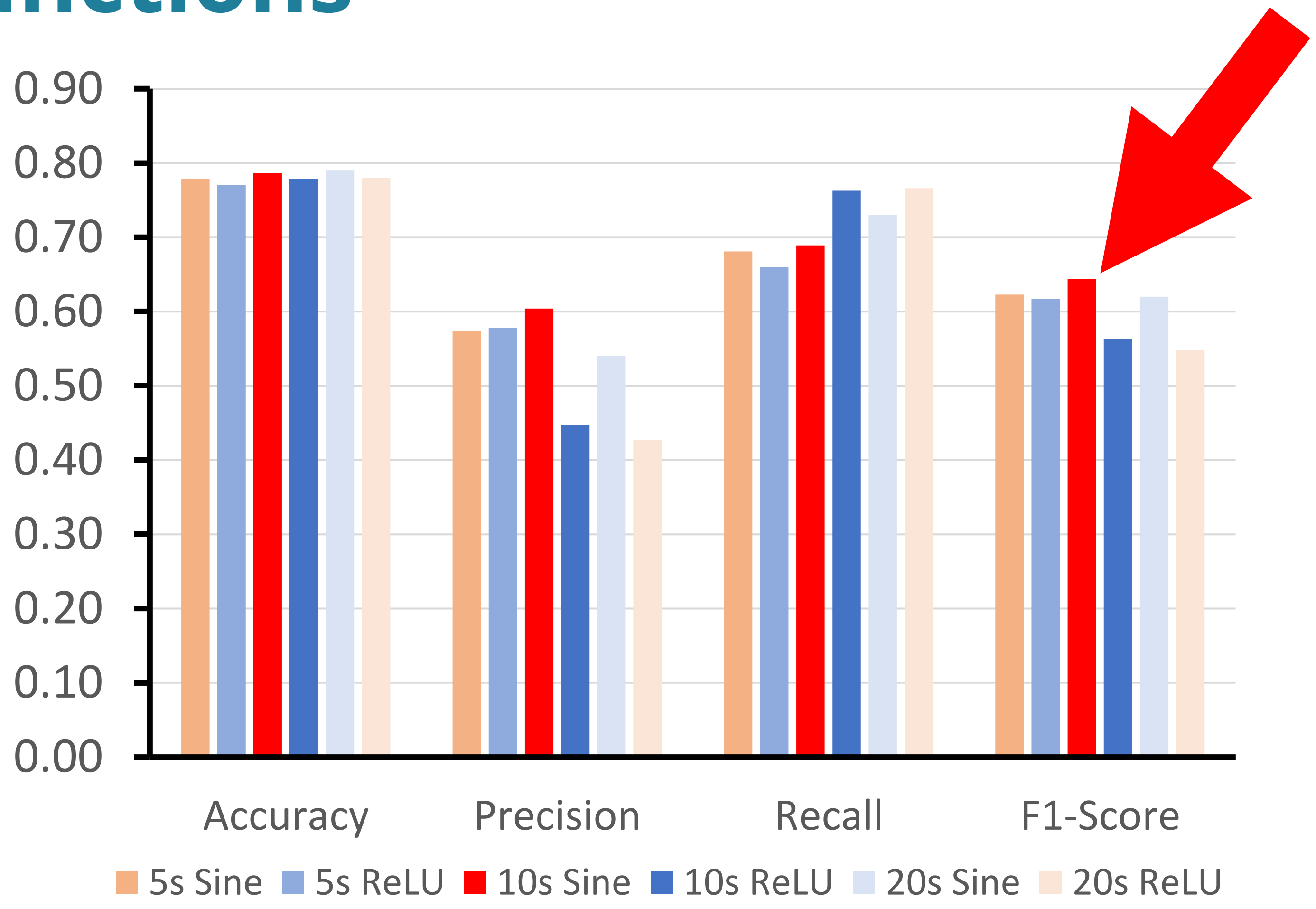
SIREN Outperformed Conventional Activation Functions

- Not much of a difference between durations
- SIREN (10s) performs better for Precision and F1-score.
- F1-Score is better for unbalanced datasets.



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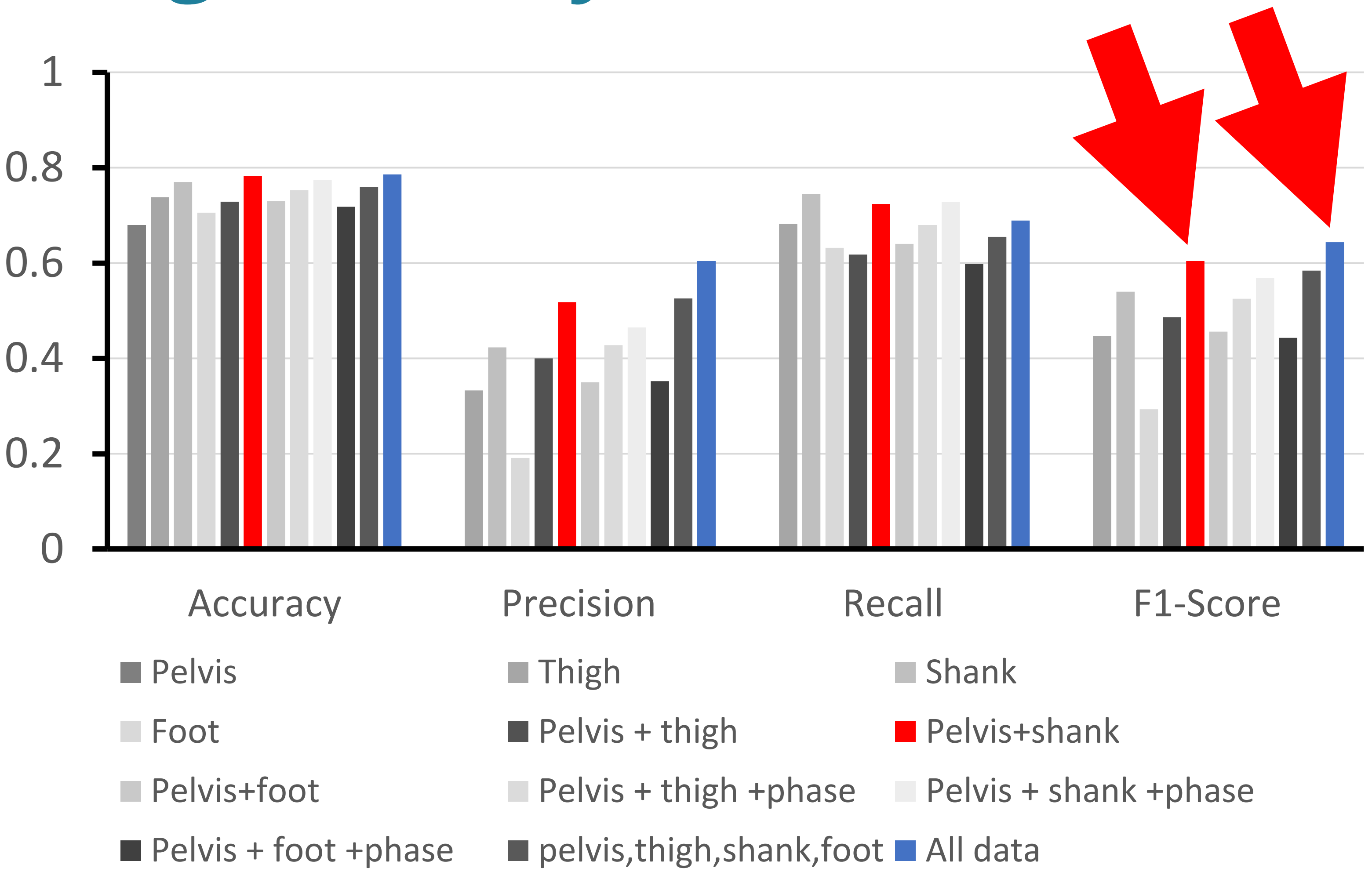
Can We Reduce Instrumentation Without Sacrificing Accuracy?

- SIREN (10s)
- Fewer Sensors May Be Enough?



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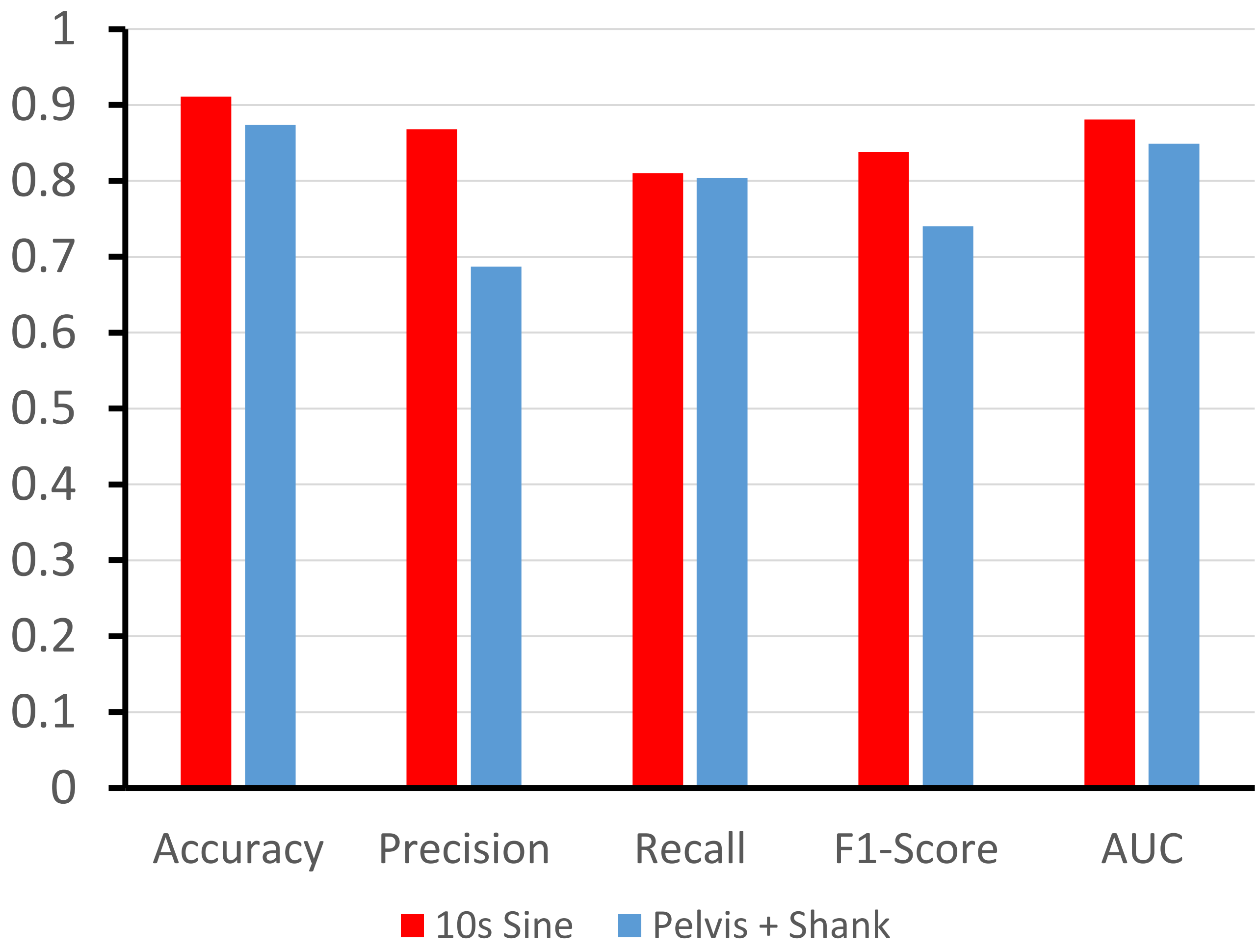
Disease-Specific Models Improve Classification Performance

- Assessed classification accuracy when narrowed to most prevalent ‘injury’ (n=393) - OA

- Performance improved
  - F1-score all injuries = 0.64
  - F1-Score OA = 0.84
  - F1-score OA (data subset) = 0.74

- While Pelvis + Shank instrumentation performed similarly to all data for classifying all injuries, for OA only, it performed worse



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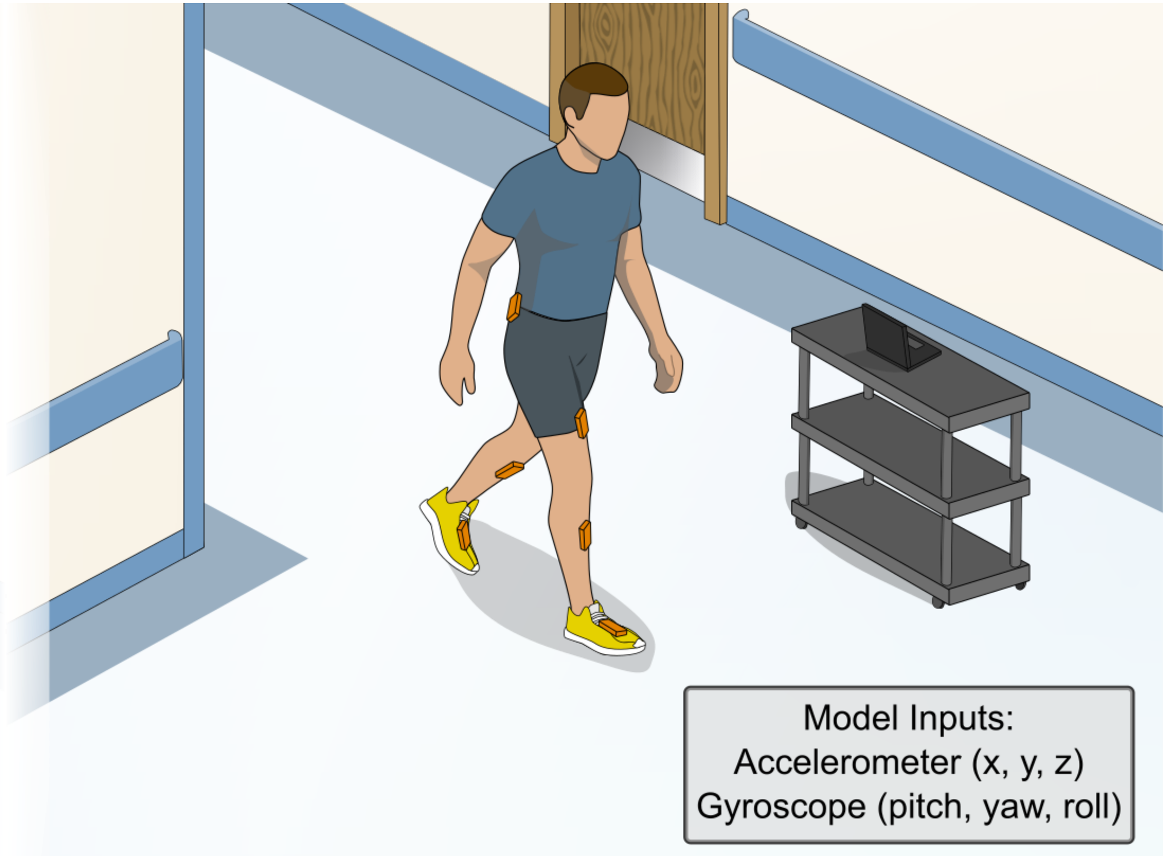
Key Findings

- Fast, easy instrumentation of markers
- Short walking period
- SIREN classification performance is similar to rapid diagnostic testing (e.g., nasal swab)
  - 62.3% for influenza
  - 80% for respiratory syncytial virus (RSV)
  - 91.84% for COVID-19
  - Each have specificities greater than 98%.
- SIREN all injuries: Sensitivity (Recall) = 0.69, Specificity = 0.87
- SIREN OA, all data: Sensitivity (Recall) = 0.87, Specificity = 0.88
- Data subsets may not generalize

Wiles et al., 2023, 2025a, 2025b: Study Details

- Three age groups
  - ‘Young’ 19-35 years (n= 35)
  - ‘Middle aged’ 36-55 years (n=50)
  - ‘Older’ over 56 years (n= 41)
- Self-selected overground walking on a 200-meter looping indoor track
- 18 x 4-min walking bouts evenly split between two sessions
- IMUs were placed pelvis, thighs, shanks, and feet
  - Accelerations and gyroscope for 42 features total



Inertial Measurement Units (Wiles et al., 2023, 2025a&b)

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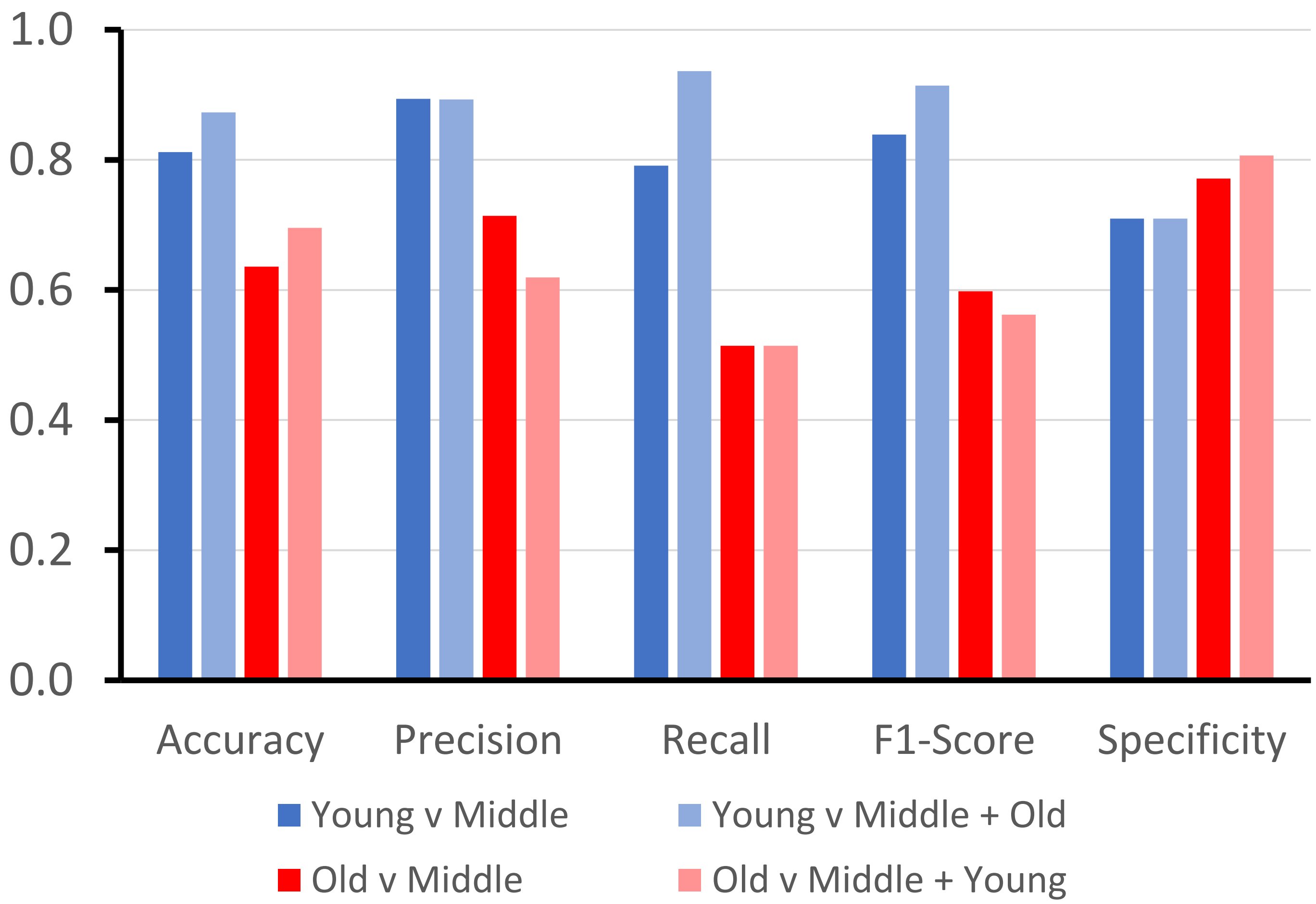
Can Models Generalize Beyond Their Training Population?

- Train on Young v Middle
- Train on Middle v Old
- Compare/Examine if generalized to remaining group

- Middle - Generalized to Old but not Young.

- Moreover, SIREN had weaker performance distinguishing walking between middle-aged and older adults.



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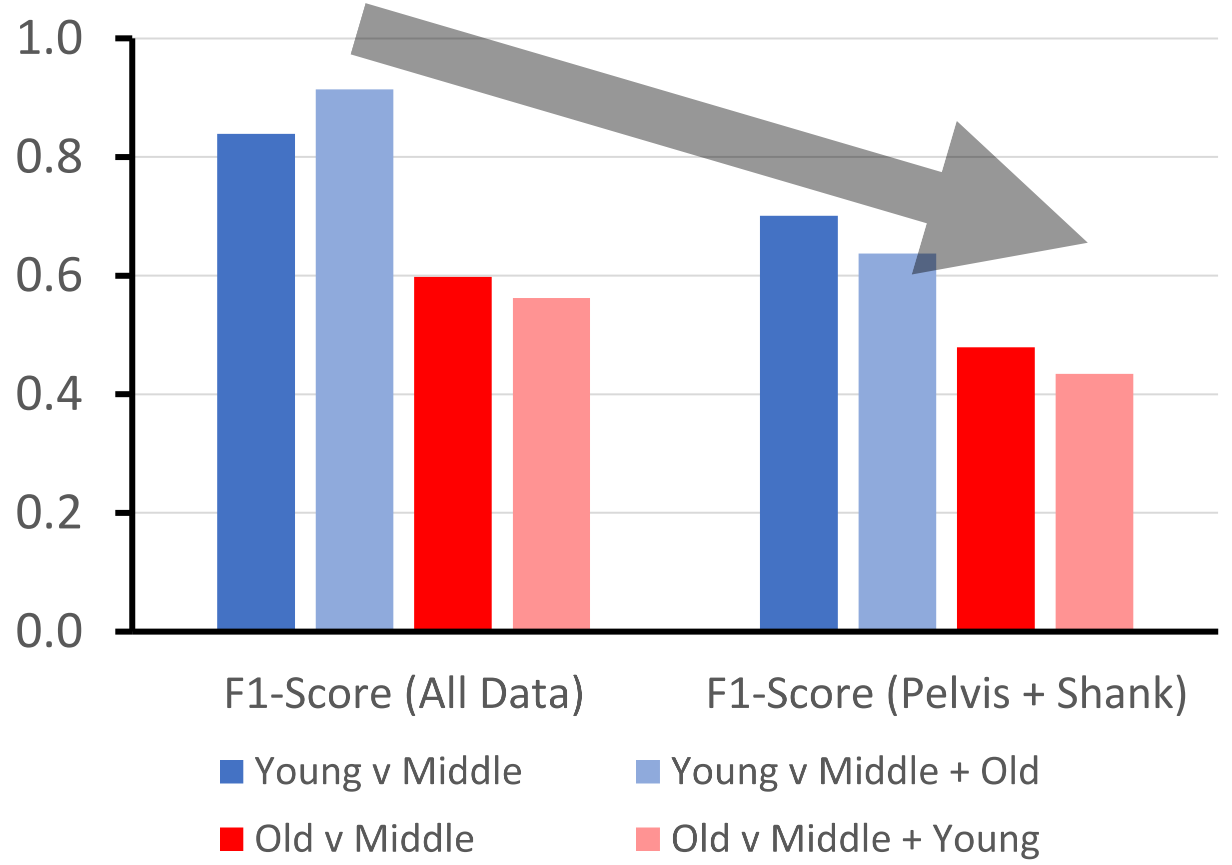
Can Instrumentation Strategies Generalize Beyond Their Training Population?

- Maybe not.
- Unlike for markers, only Pelvis+Shank IMUs performed worse.



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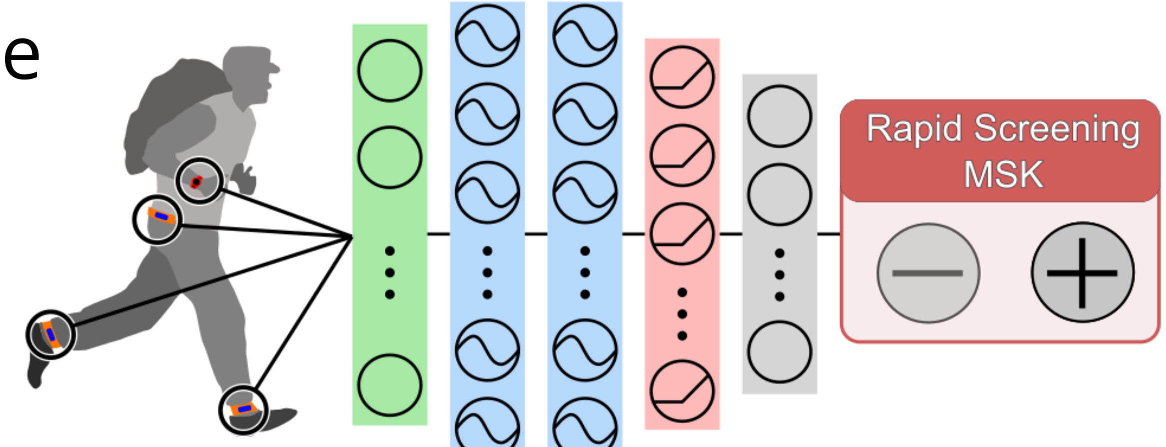
What Have We Learned?

✓ 10 seconds is more than enough
✓ SIREN consistently outperforms ReLU
✓ Disease-specific models perform best
X Instrumentation may not generalize
✓ Model architecture generalizes



✓ This work represents an analytical foundation—not the final destination.

✓ Much more work left to do!

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