BIOMECHANICS AND ARTIFICIAL INTELLIGENCE

Prof. Dr. Nick Stergiou

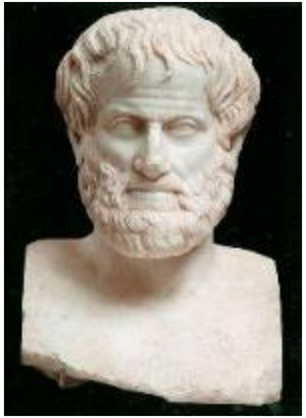
Associate Dean of the College of Education, Health, and Human Sciences, University of Nebraska at Omaha (UNO), USA

Director of the Division of Biomechanics and Research Development, UNO, USA

Professor and Founding Chair of the Department of Biomechanics, UNO, USA

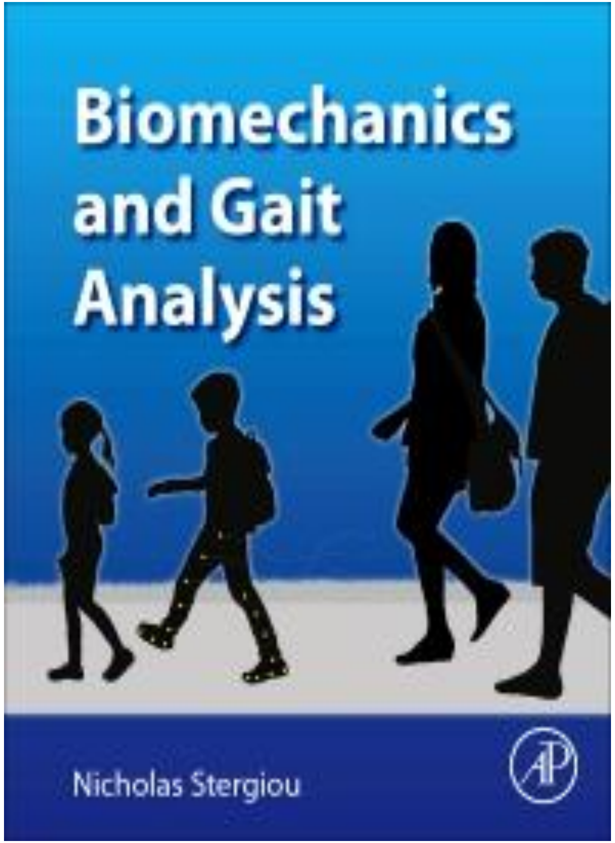
Director of the Center for Research in Human Movement Variability, UNO, USA

Professor of Biomechanics, Department of Physical Education and Sports Sciences, Aristotle University of Thessaloniki, Greece

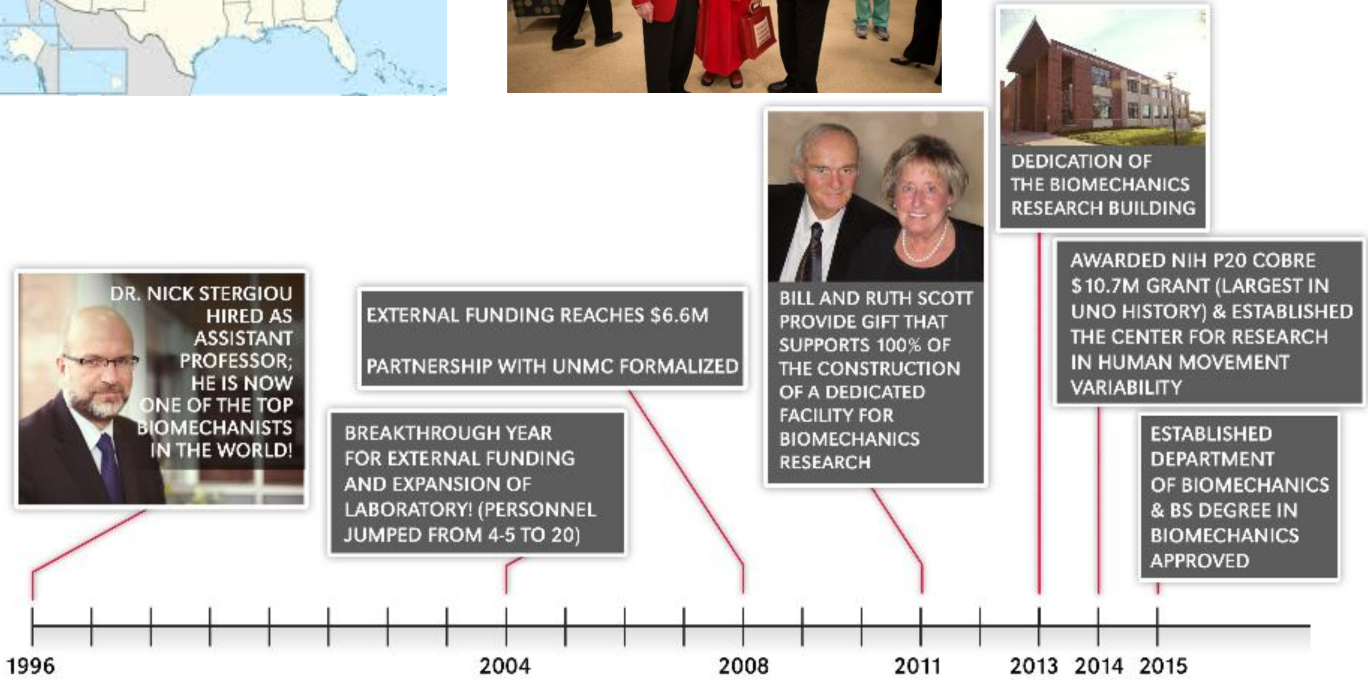


1. On the Gait of Animals
2. On the Motion of Animals
Author: Aristotle

- Biomechanics is the study of forces that apply on a body and the effects that they produce.
- Biomechanics uses anatomy and physiology and principles from mathematics and physics to understand human movement.



AUTH Biomechanics



Highlight: A study conducted by Stanford Research Institute (SRI) International in 2013 provided a comprehensive report for the Biomedical Technology capabilities in Nebraska. In this report, SRI International stated that "You are home to world-class research in biomechanics." UNO Biomechanics was ranked as No. 7 (tied with Northwestern University and University of Pittsburgh) in the United States.

AUTH Biomechanics

- 2025: The Department of Biomechanics has 18 tenure-track/tenured faculty and we continue to grow
- Sixty percent of faculty are PIs on federal grants. Two Science journal covers.
- Since its inception in 2016, the Department of Biomechanics faculty secured >$50mil of federal funding. **1/3 of the external funding that is awarded to our university.**
- **Our Equipment is almost 100% grant funded and our facilities 100% privately funded!**

<u>Division of Biomechanics and Research Development (Director: Stergiou) includes</u>:

1. Biomechanics Research Building (opened in 2013)
2. Center for Research in Human Movement Variability (MOVCENTR – established in 2014)
3. <u>Department of Biomechanics (established in 2016)</u>
   I. BS in Biomechanics (about 40 students)
   II. MS in Biomechanics (about 20 students)
   III. PhD in Biomechanics (about 40 students)
      - First Research Oriented Department at our university.
      - First such academic Department in the world.
4. <u>Center for Research in Cardiovascular Biomechanics (CRiB – established in 2024)</u>

2014: The Center for Research in Human Movement Variability (the MOVCENTR) is created. **First with this theme in the world.**

An Economic Impact evaluation of the MOVCENTR since 2019 was estimated to be $27.5 million impact on the Omaha metropolitan community.

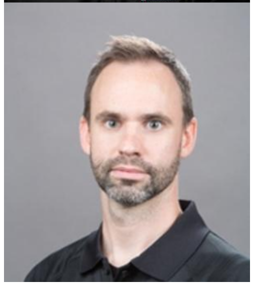
NIH P20 Centers of Biomedical Research Excellence (COBRE)

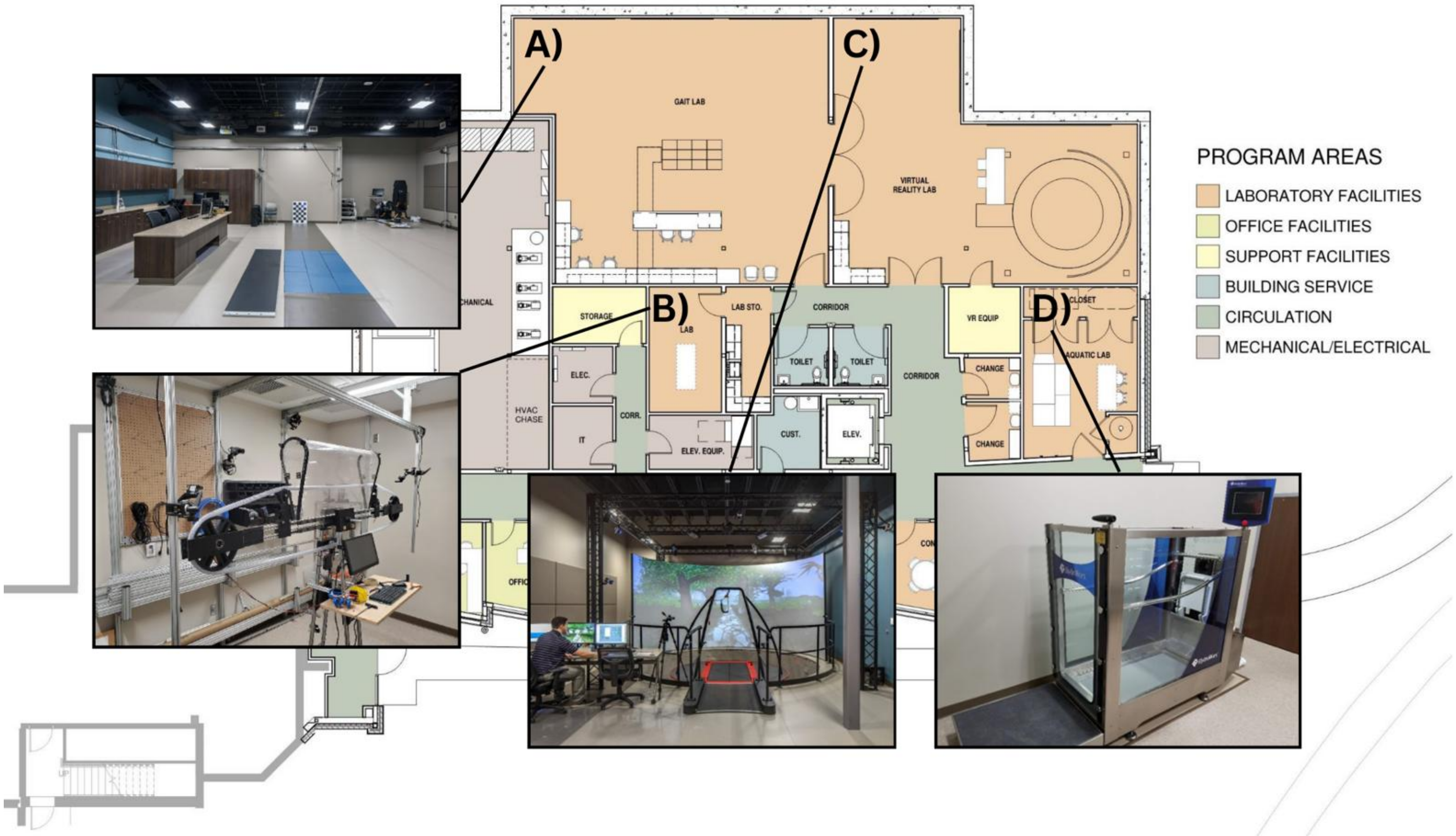
- Phase I: Developing research infrastructure, mentoring junior investigators, $10.4 million dollars in funding, largest research grant in the history of my institution
  - 2014-2019
- Phase II: Further strengthen research infrastructure developed in Phase I, $10.9 million dollars in funding, surpassed the previous record
  - 2019-2025
- Phase III: Just awarded. The center will transition to independent status, $6 million dollars in funding
  - 2025-2030

MOVCENTR Cores

- **Movement Analysis Core (Director: Dr. David Kingston)**
  - To provide biomechanical testing and support for research within the center and the community
- **Quantitative Analysis Core (Director: Dr. Aaron Likens)**
  - To provide analysis and interpretation of data in addition to instruction of nonlinear methods
- **Machining and Prototyping Core (Director: Dr. Brian Knarr)**
  - To provide design, consultation, manufacturing, and prototyping services to the center and the community






A)
B)
C)
D)
GAIT LAB
VIRTUAL REALITY LAB
STORAGE
LAB
LAB STO.
CORRIDOR
TOILET
TOILET
CORRIDOR
VR EQUIP
CLOSET
AQUATIC LAB
CHANGE
CHANGE
ELEC.
IT
CORR.
HVAC CHASE
ELEV. EQUIP.
CUST.
ELEV.
PROGRAM AREAS
LABORATORY FACILITIES
OFFICE FACILITIES
SUPPORT FACILITIES
BUILDING SERVICE
CIRCULATION
MECHANICAL/ELECTRICAL

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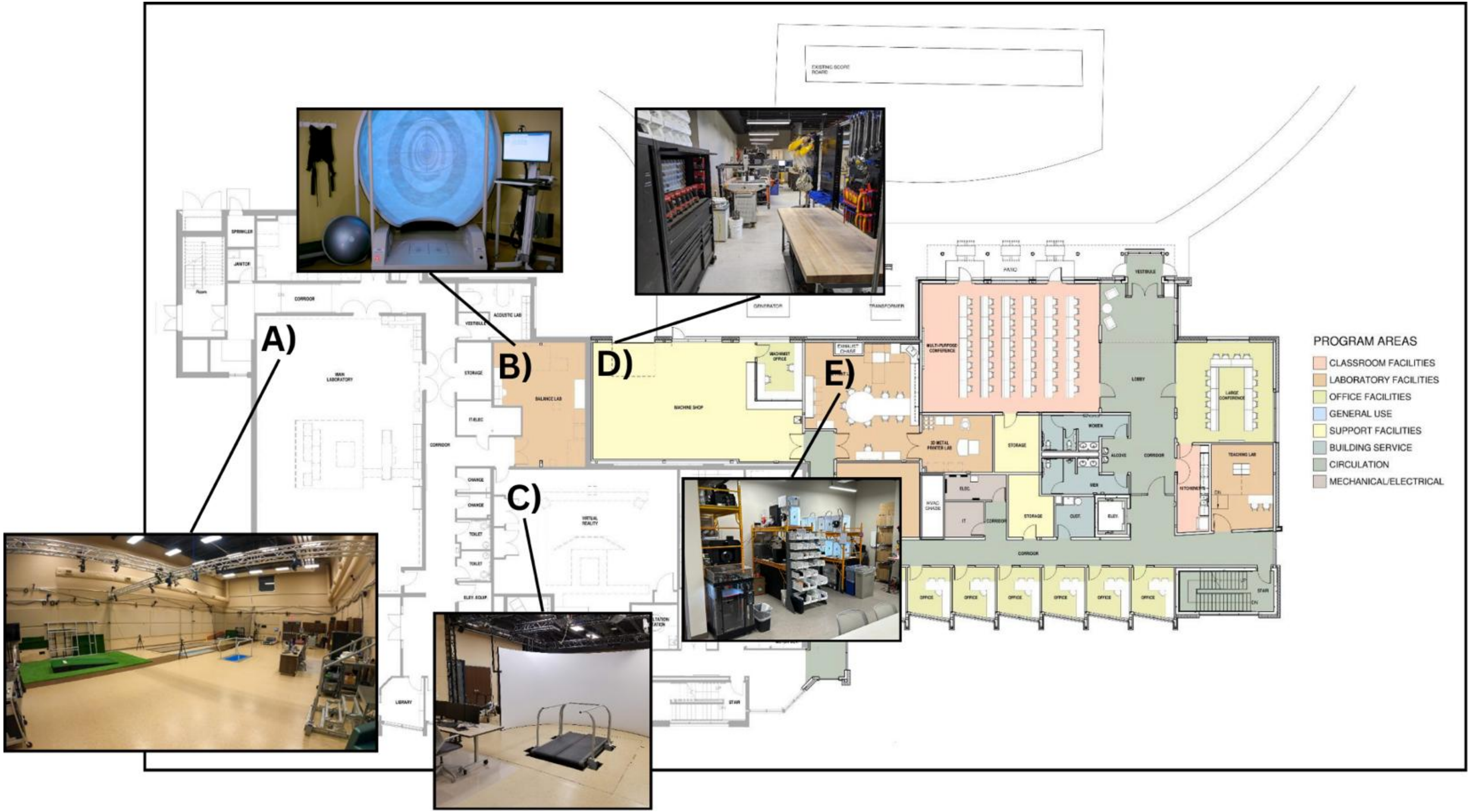
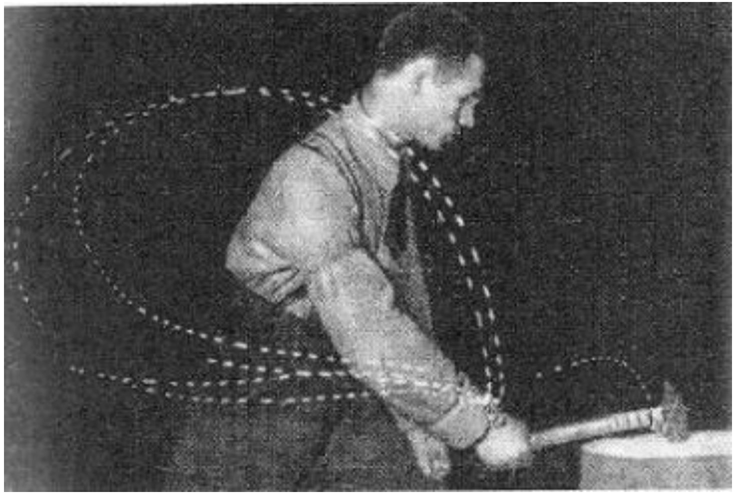


AUTH Biomechanics

University of Nebraska Omaha

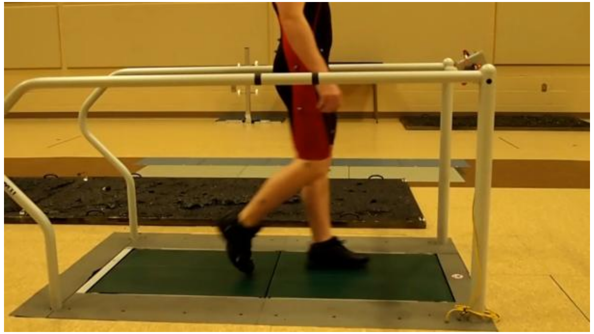
Research Focus

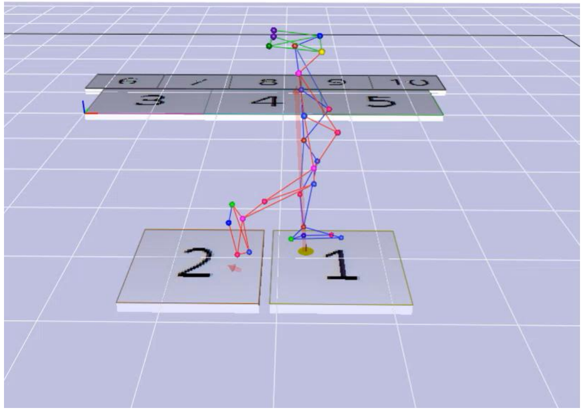
- **Personal Research Focus: Human Movement Variability.**
- Variability is a fact of life. Repetition without repetition.
- The Importance of Variation In Human Movement | Dr. Nick Stergiou | TEDxUNO
- https://www.youtube.com/watch?v=0vjViLFziV4

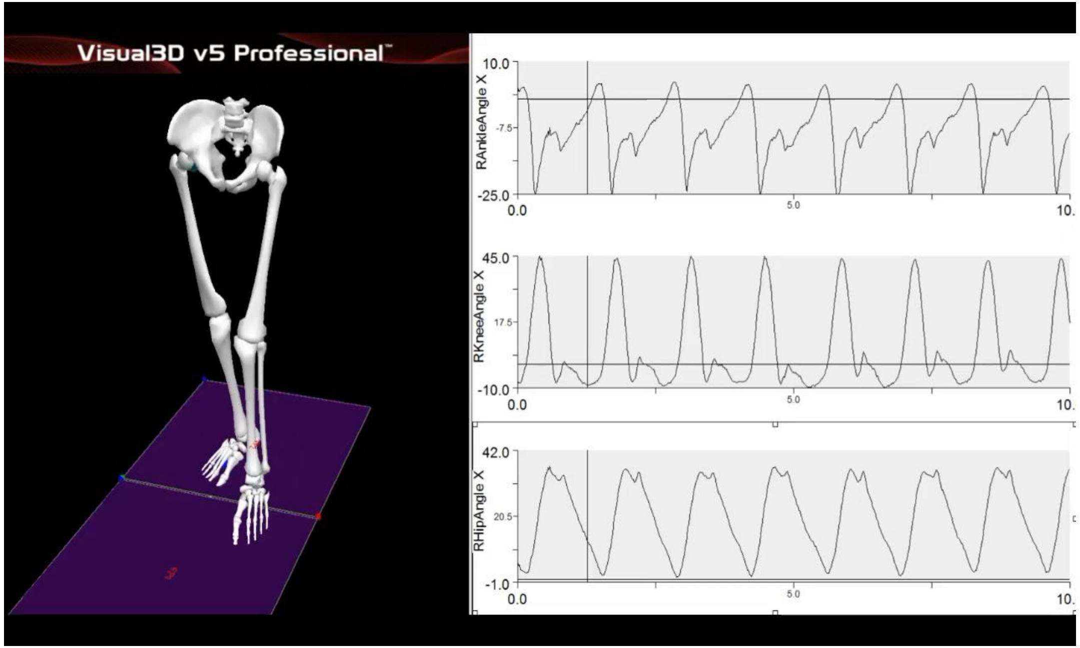


Stergiou N. (2004). Innovative Analyses of Human Movement. Human Kinetics Publ.
Stergiou N. (2017). Nonlinear Analysis for Human Movement Variability. CRC Press.

MOVEMENT UNDER THE MICROSCORE

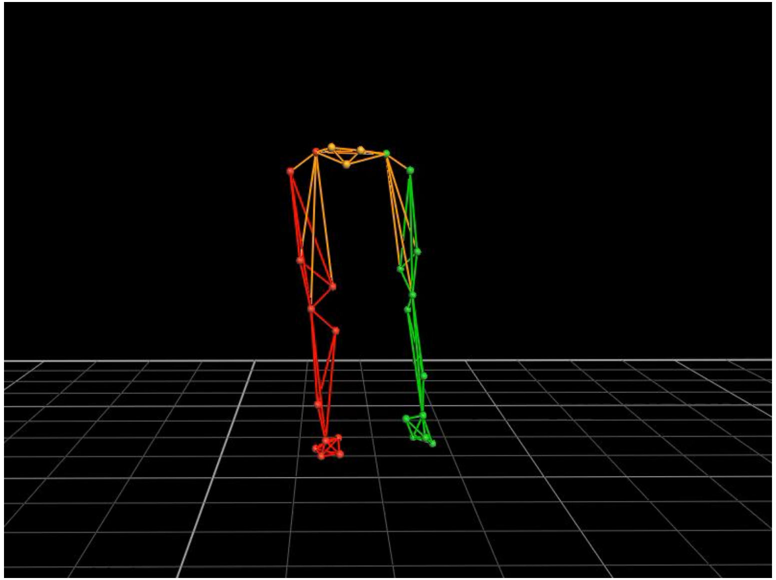






Stergiou *et al.* (2006). *J Neurol Phys Ther*, 30(3):120-129.
Harbourne & Stergiou (2009). *Phys Ther*, 89(3): 1-15.

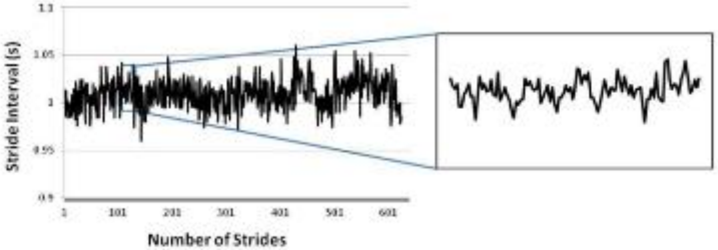
MOVEMENT UNDER THE MICROSCORE

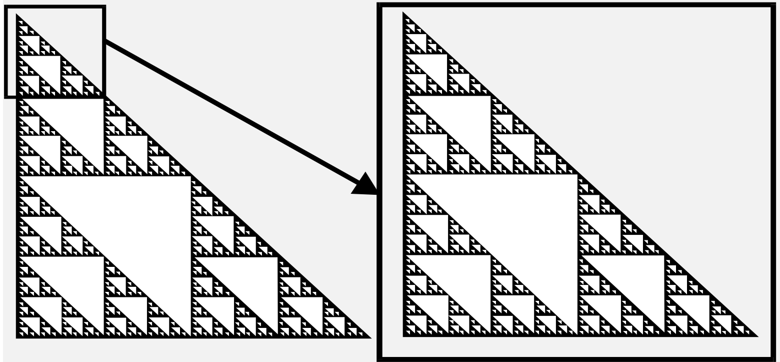


Stergiou N. (2004). Innovative Analyses of Human Movement. Human Kinetics Publ.
Stergiou N. (2017). Nonlinear Analysis for Human Movement Variability. CRC Press.

VARIABILITY IS NOT NOISE BUT HAS PATTERNS

There are a few big, many medium size, and a huge number of small size fluctuations even in most fundamental movement such as walking. Pink noise type of a process (or a distribution) with a frequency spectrum such that the power spectral density is inversely proportional to the signal's frequency. Such patterns are everywhere.





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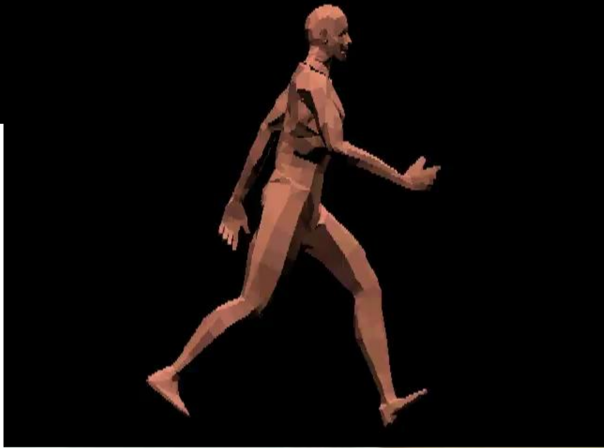


PATHOLOGY AFFECTS THESE HEALTHY PATTERNS.

On one end, we could be rigid as we see in orthopedics where you may behave like a robot due to an injury

Or at the other end, we could be very noisy like a **frail older adult**

HEALTH IS A RICH BEHAVIORAL STATE

… complex but with beautiful patterns

“Life is an aperiodic crystal, it is not random, but also is not periodic, it is something in between…” by Erwin Schrodinger: What is Life” (1944)

Variability may be the spice of life!!!

Stergiou *et al* (2006). *J Neurol Phys Ther*, 30(3):120-129.
Stergiou & Decker (2011). *Human Mov Sci*, 30(5):869-88

Εμβιομηχανικής + **Τεχνητή Νοημοσύνη (AI)** = καλύτερη κατανόηση της ανθρώπινη κίνηση, της πρόληψης τραυματισμών και της αποκατάστασης.

Η AI επιτρέπει την ανάλυση τεράστιων όγκων δεδομένων από βίντεο και αισθητήρες, καθιστώντας την εργαστηριακή ακρίβεια προσβάσιμη στην καθημερινή ζωή.

Κύριες Εφαρμογές

Ανάλυση Κίνησης χωρίς Σημάδια (Markerless Motion Capture) => OpenCap, DeepLabCut, and Vuemotion

Πρόληψη Τραυματισμών: Μοντέλα μηχανικής μάθησης (π.χ. Random Forest) μπορούν να προβλέψουν τον κίνδυνο τραυματισμών.

Εξατομικευμένη Αποκατάσταση: Digital Twins για αποτελεσματικά πλάνα φυσικοθεραπείας.

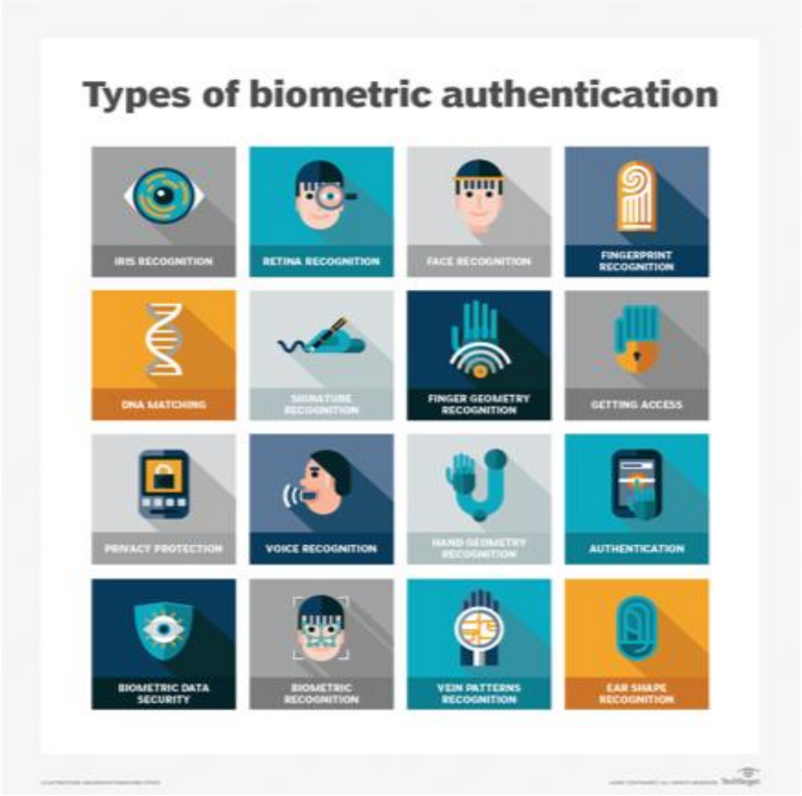
Αθλητική Απόδοση: Εξατομικευμένα προγράμματα προπόνησης σε πραγματικό χρόνο.

Ορθοπεδική και Προσθετική: Χειρουργική ακρίβεια και καλύτερα προσθετικά μελη.

Τομέας	Επίδοση / Στοιχείο
Πρόβλεψη Τραυματισμών	85% ακρίβεια σε τραυματισμούς οπίσθιων μηριαίων
Μείωση Υποτροπών	23% μείωση στα ποσοστά επανατραυματισμού
Αγορά AI Fitness	Πρόβλεψη για 4,8 δισ. δολάρια έως το 2028
Αποτελεσματικότητα AI	25% βελτίωση στην ακρίβεια των πλάνων προπόνησης

https://motion-gpt.github.io/

- **Gaitprint: "…a set of** kinematic and kinetic features measured during locomotion that uniquely identify an individual."



Tyler Wiles

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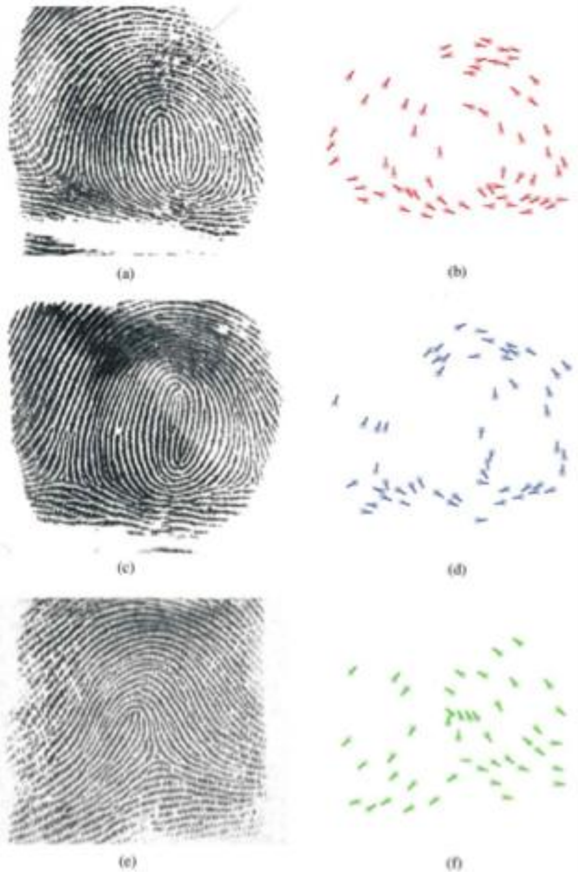
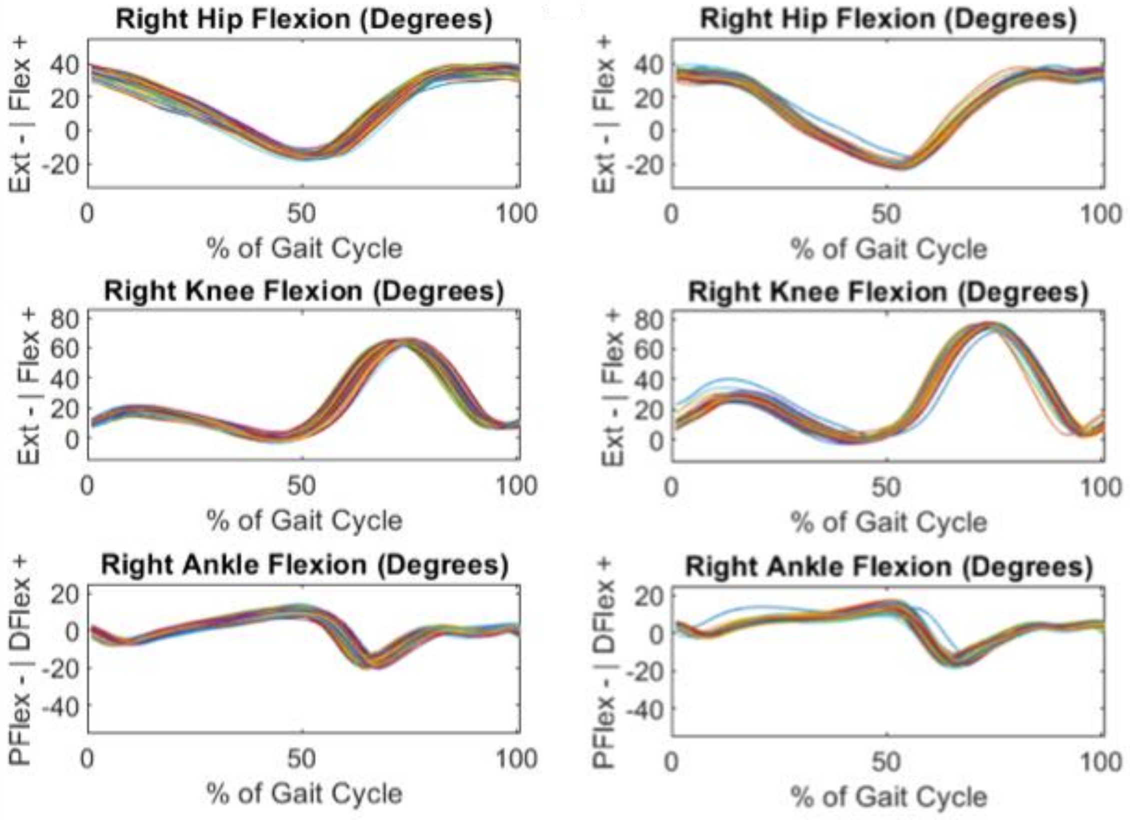
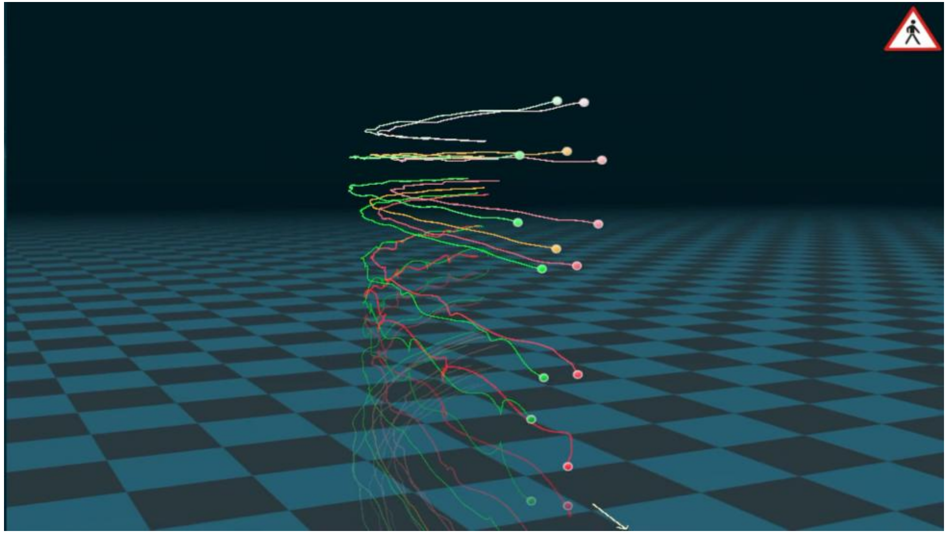
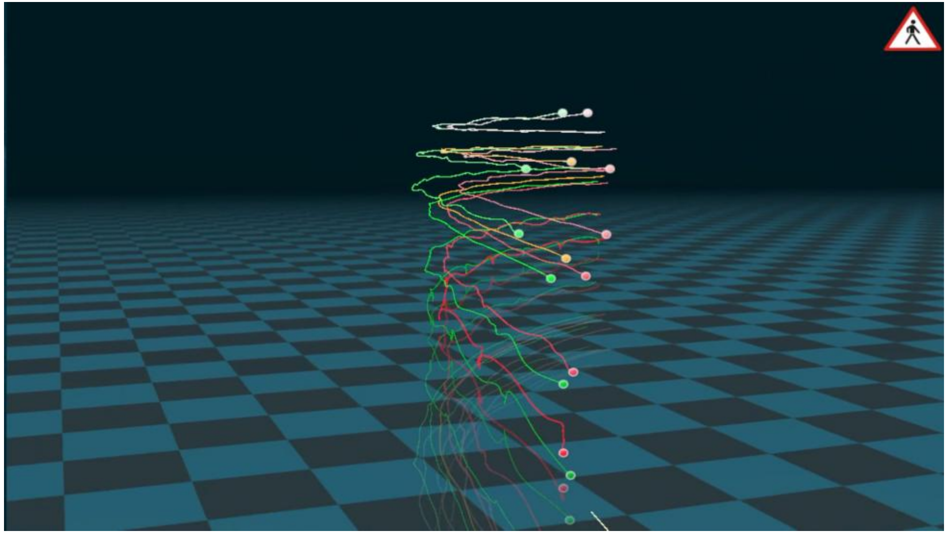
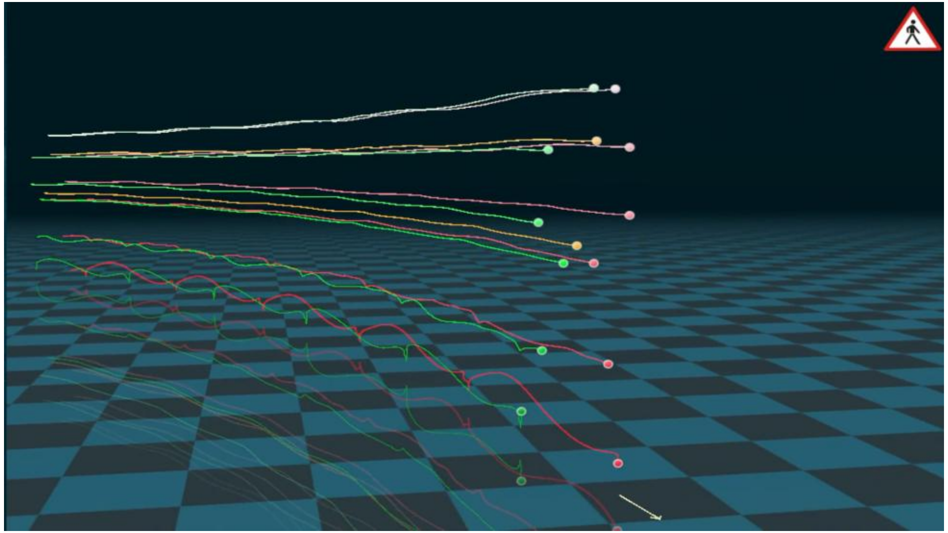
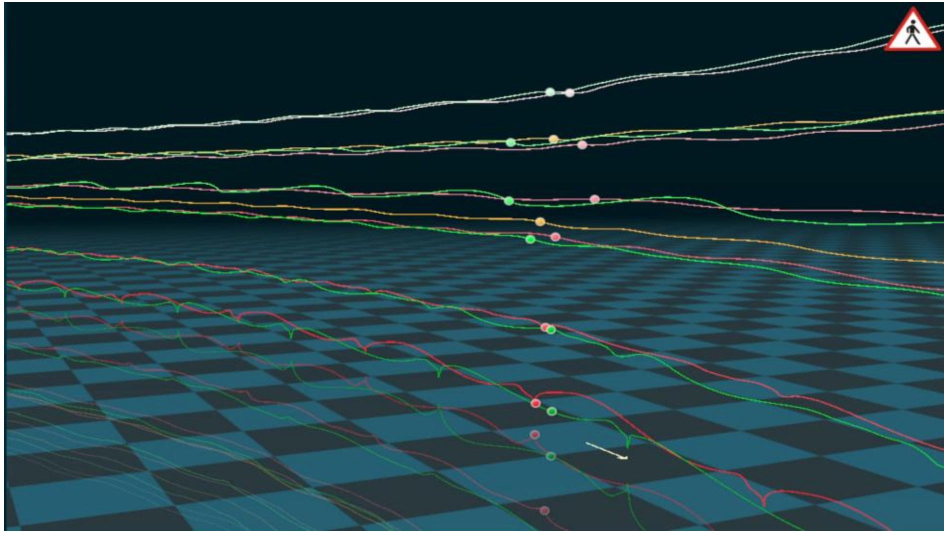




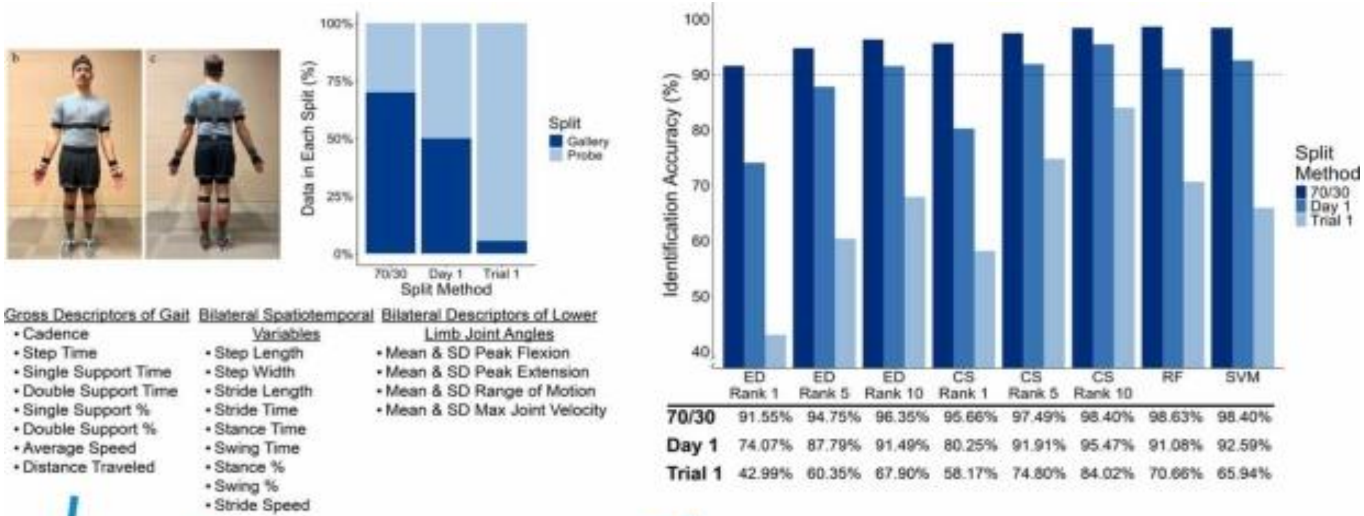




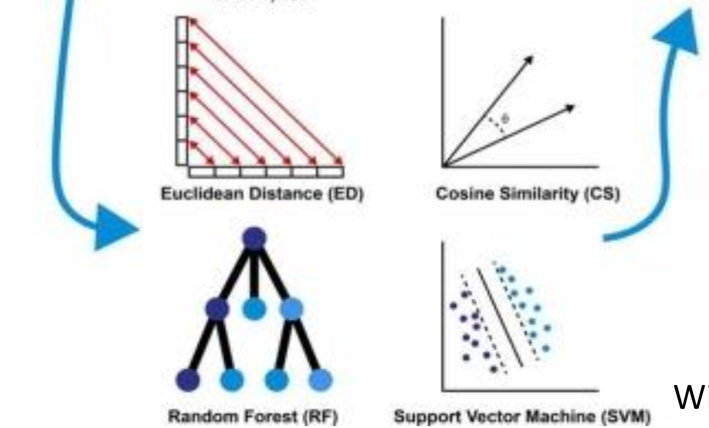




The GaitPrint



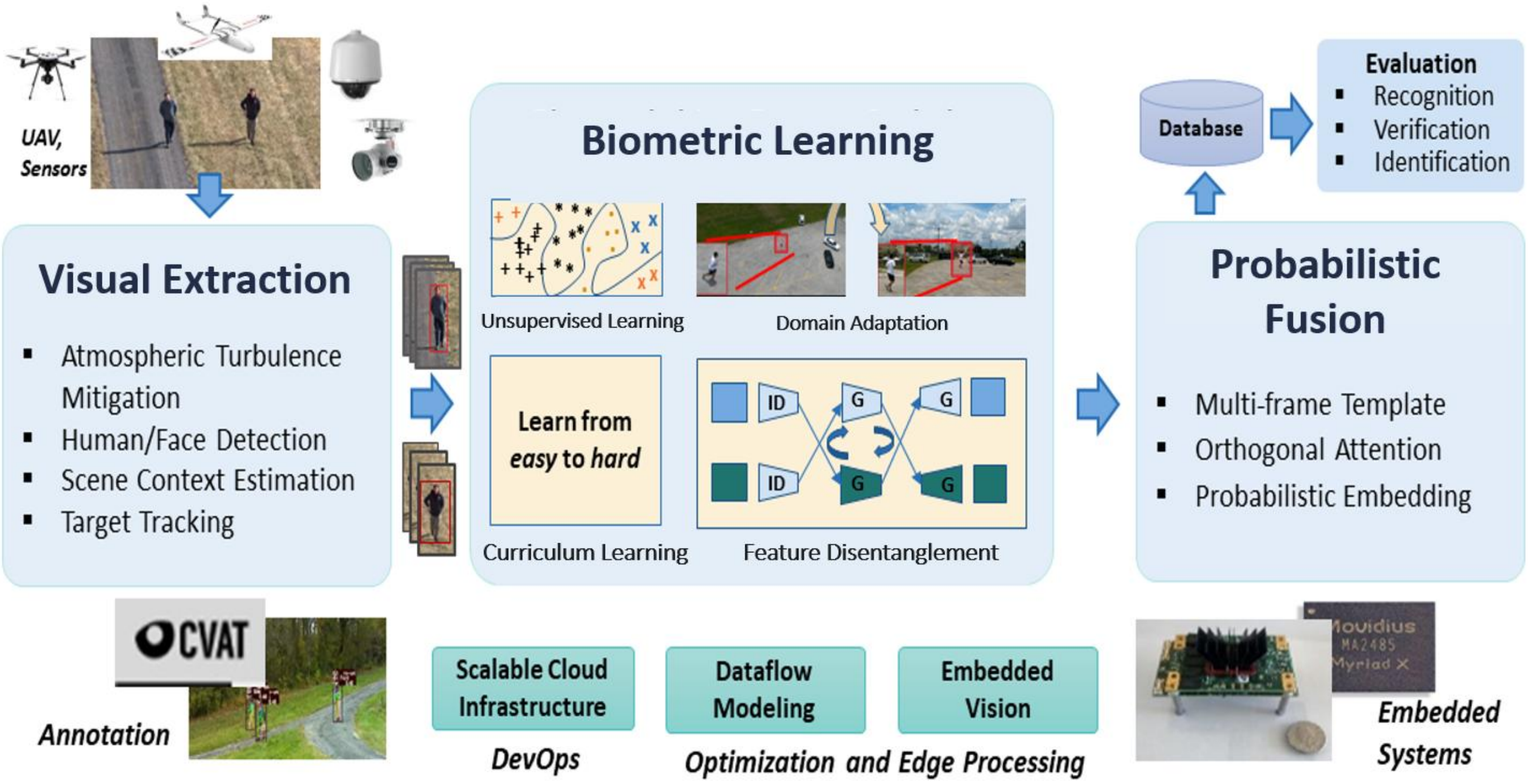
	ED Rank 1	ED Rank 5	ED Rank 10	CS Rank 1	CS Rank 5	CS Rank 10	RF	SVM
70/30	91.55%	94.75%	96.35%	95.66%	97.49%	98.40%	98.63%	98.40%
Day 1	74.07%	87.79%	91.49%	80.25%	91.91%	95.47%	91.08%	92.59%
Trial 1	42.99%	60.35%	67.90%	58.17%	74.80%	84.02%	70.66%	65.94%



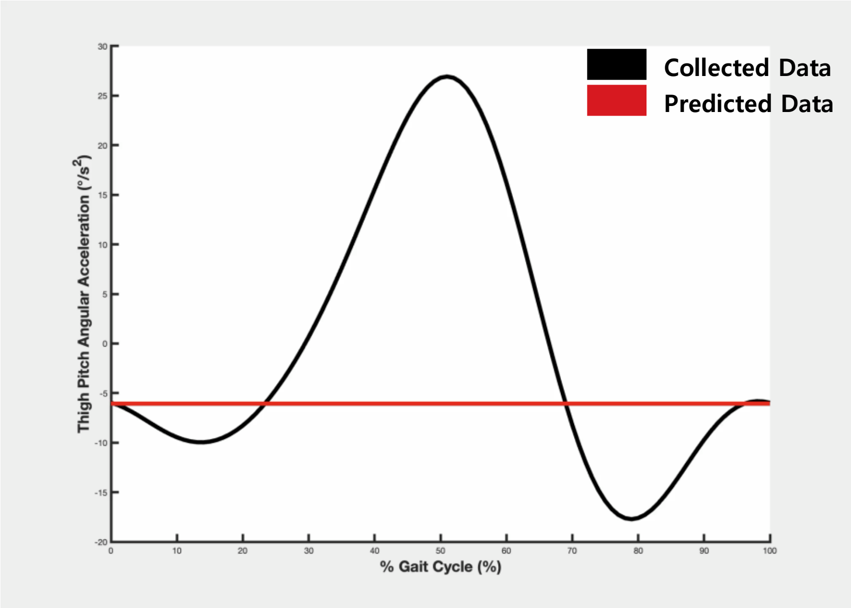
- Our results suggest the existence of a gaitprint, a persistent walking pattern with sufficient information about the individual to make them identifiable.
- Uniqueness of gait kinematics demonstrated 98.63% accuracy in 81 adults.
- Identification accuracy is maintained with reduced gallery size.
- Multi-day gait identification is feasible.

Wiles et al (2024). Comput Struct Biotechnol J Apr 12:24:281-291.

WATCH ID


UAV,
Sensors
Visual Extraction
Atmospheric Turbulence Mitigation
Human/Face Detection
Scene Context Estimation
Target Tracking
Biometric Learning
Unsupervised Learning
Domain Adaptation
Learn from easy to hard
Curriculum Learning
ID
G
Feature Disentanglement
Database
Evaluation
Recognition
Verification
Identification
Probabilistic Fusion
Multi-frame Template
Orthogonal Attention
Probabilistic Embedding
CVAT
Annotation
Scalable Cloud Infrastructure
DevOps
Dataflow Modeling
Embedded Vision
Optimization and Edge Processing
Movidius
MA2485
Myriad X
Embedded Systems

Symbolic Regression



Distilling Free-Form Natural Laws from Experimental Data

Michael Schmidt[1] and Hod Lipson[2,3]*

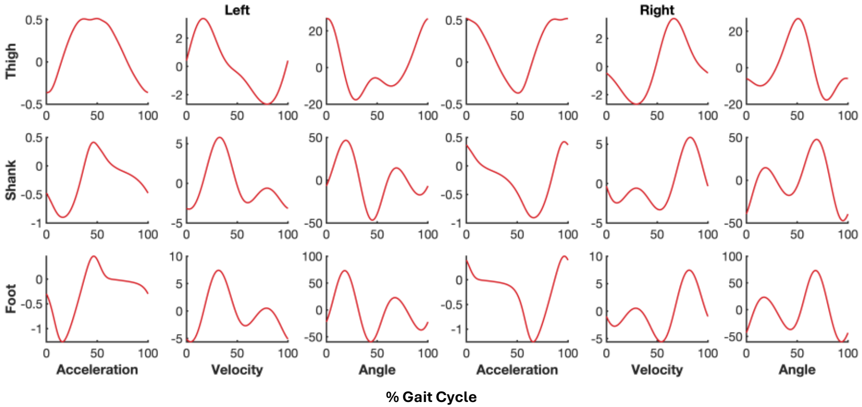
SCIENCE ADVANCES | RESEARCH ARTICLE

COMPUTER SCIENCE

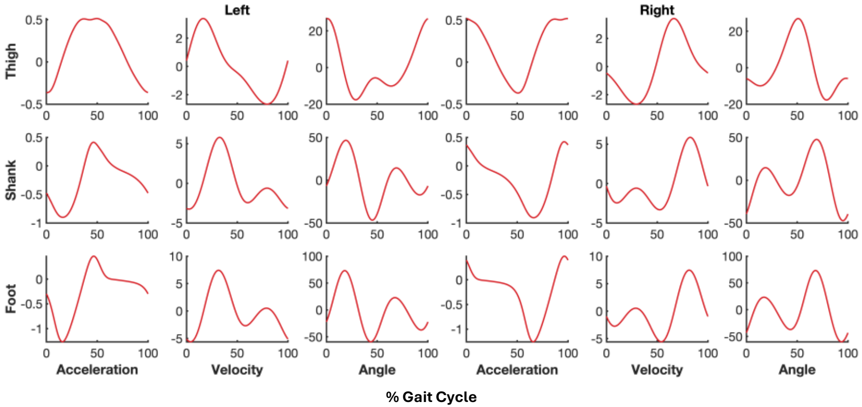
AI Feynman: A physics-inspired method for symbolic regression

Silviu-Marian Udrescu[1] and Max Tegmark[1,2]*

Distilling Laws of Human Movement

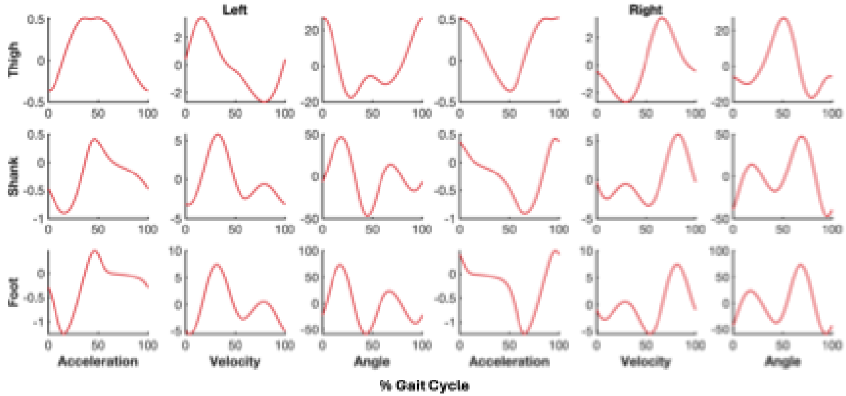


Left
Right
Thigh
Shank
Foot
Acceleration
Velocity
Angle
Acceleration
Velocity
Angle
% Gait Cycle



Symbolic Regression

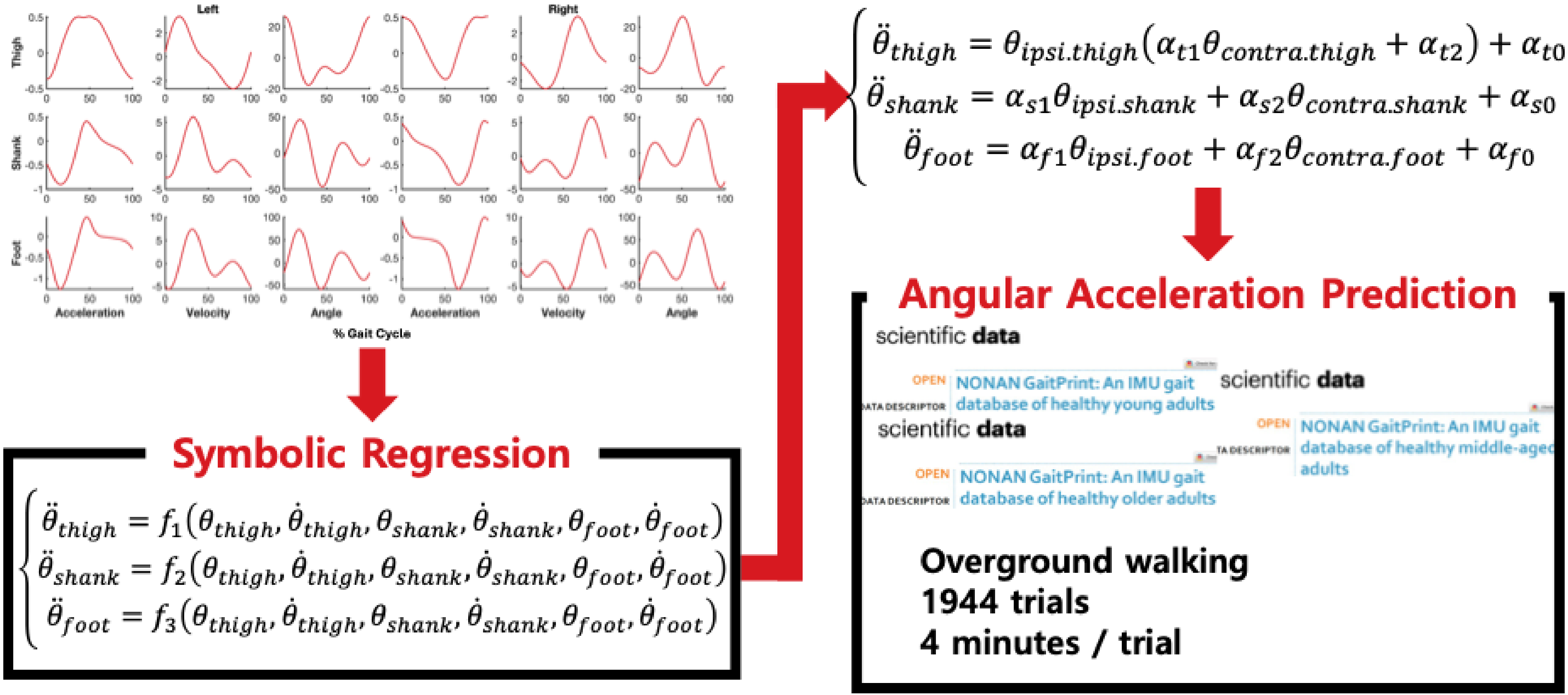
$$\begin{cases} \ddot{\theta}_{thigh} = f_1(\theta_{thigh}, \dot{\theta}_{thigh}, \theta_{shank}, \dot{\theta}_{shank}, \theta_{foot}, \dot{\theta}_{foot}) \\ \ddot{\theta}_{shank} = f_2(\theta_{thigh}, \dot{\theta}_{thigh}, \theta_{shank}, \dot{\theta}_{shank}, \theta_{foot}, \dot{\theta}_{foot}) \\ \ddot{\theta}_{foot} = f_3(\theta_{thigh}, \dot{\theta}_{thigh}, \theta_{shank}, \dot{\theta}_{shank}, \theta_{foot}, \dot{\theta}_{foot}) \end{cases}$$



Symbolic Regression

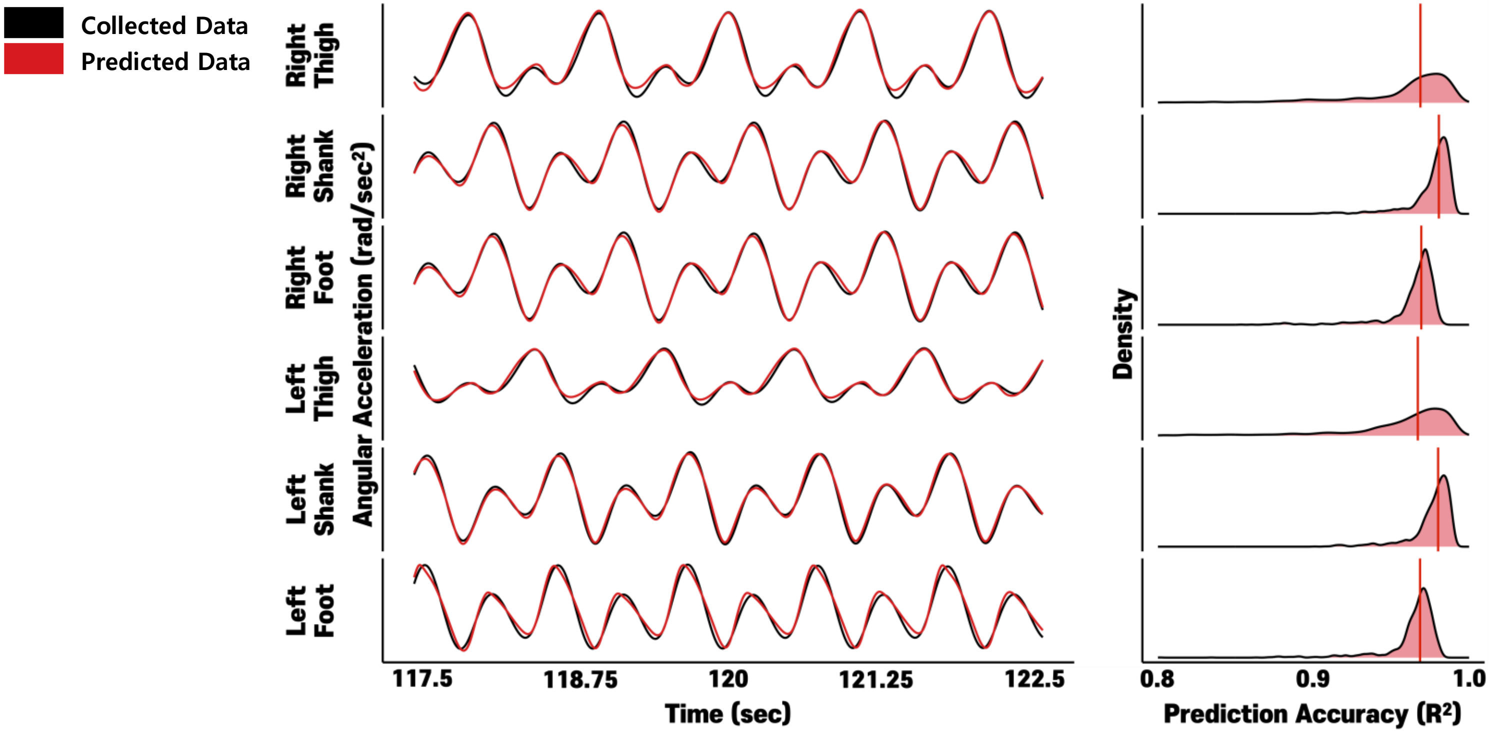
$$\begin{cases} \ddot{\theta}_{thigh} = f_1(\theta_{thigh}, \dot{\theta}_{thigh}, \theta_{shank}, \dot{\theta}_{shank}, \theta_{foot}, \dot{\theta}_{foot}) \\ \ddot{\theta}_{shank} = f_2(\theta_{thigh}, \dot{\theta}_{thigh}, \theta_{shank}, \dot{\theta}_{shank}, \theta_{foot}, \dot{\theta}_{foot}) \\ \ddot{\theta}_{foot} = f_3(\theta_{thigh}, \dot{\theta}_{thigh}, \theta_{shank}, \dot{\theta}_{shank}, \theta_{foot}, \dot{\theta}_{foot}) \end{cases}$$

$$\begin{cases} \ddot{\theta}_{thigh} = \theta_{ipsi.thigh}(\alpha_{t1}\theta_{contra.thigh} + \alpha_{t2}) + \alpha_{t0} \\ \ddot{\theta}_{shank} = \alpha_{s1}\theta_{ipsi.shank} + \alpha_{s2}\theta_{contra.shank} + \alpha_{s0} \\ \ddot{\theta}_{foot} = \alpha_{f1}\theta_{ipsi.foot} + \alpha_{f2}\theta_{contra.foot} + \alpha_{f0} \end{cases}$$

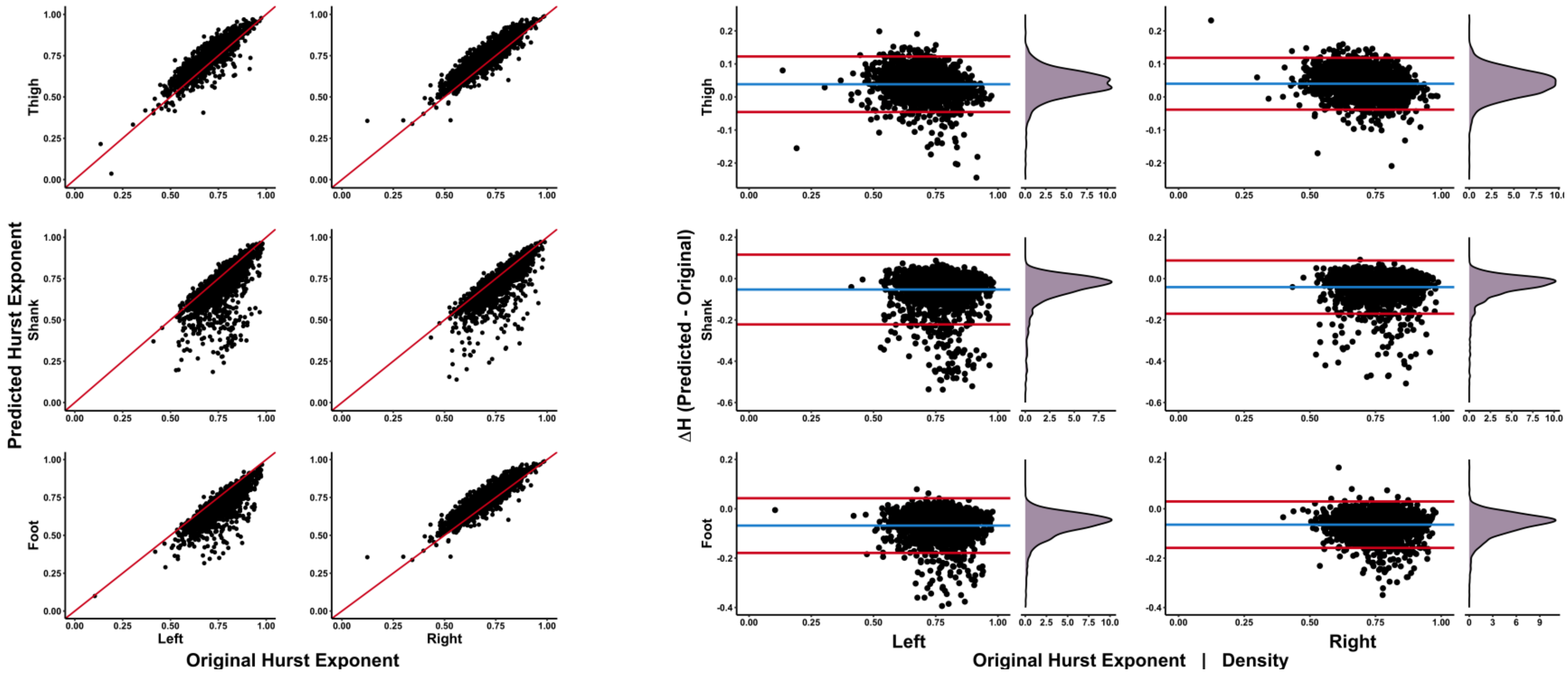


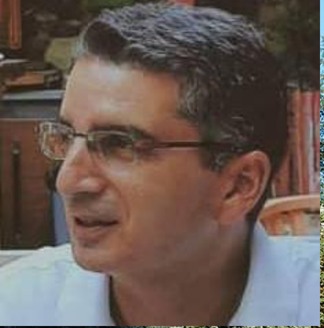
Left
Right
Thigh
Shank
Foot
Acceleration
Velocity
Angle
Acceleration
Velocity
Angle
% Gait Cycle
Symbolic Regression
$\ddot{\theta}_{thigh} = f_1(\theta_{thigh}, \dot{\theta}_{thigh}, \theta_{shank}, \dot{\theta}_{shank}, \theta_{foot}, \dot{\theta}_{foot})$
$\ddot{\theta}_{shank} = f_2(\theta_{thigh}, \dot{\theta}_{thigh}, \theta_{shank}, \dot{\theta}_{shank}, \theta_{foot}, \dot{\theta}_{foot})$
$\ddot{\theta}_{foot} = f_3(\theta_{thigh}, \dot{\theta}_{thigh}, \theta_{shank}, \dot{\theta}_{shank}, \theta_{foot}, \dot{\theta}_{foot})$
$\ddot{\theta}_{thigh} = \theta_{ipsi.thigh}(\alpha_{t1}\theta_{contra.thigh} + \alpha_{t2}) + \alpha_{t0}$
$\ddot{\theta}_{shank} = \alpha_{s1}\theta_{ipsi.shank} + \alpha_{s2}\theta_{contra.shank} + \alpha_{s0}$
$\ddot{\theta}_{foot} = \alpha_{f1}\theta_{ipsi.foot} + \alpha_{f2}\theta_{contra.foot} + \alpha_{f0}$
Angular Acceleration Prediction
scientific data
OPEN
NONAN GaitPrint: An IMU gait database of healthy young adults
scientific data
OPEN
NONAN GaitPrint: An IMU gait database of healthy middle-aged adults
scientific data
OPEN
NONAN GaitPrint: An IMU gait database of healthy older adults
Overground walking
1944 trials
4 minutes / trial

Prediction Accuracy



Preservation of Gait Variability





THANK YOU!