Making an impact: Where does biomechanics need to go next?

Michael A. Hunt PT, PhD
Professor – Department of Physical Therapy
University of British Columbia

For your consideration please

- How much evidence is needed to guide clinical/industry decision making and/or research questions?

- What is/are the most appropriate type(s) of evidence for this?

- Are state of the art approaches always best to acquire this evidence?

Biomechanics – historical context

- Biomechanics research (and thus applications) has long been limited by challenges in:
  - Collection of data
  - Analysis of data
  - Determining what is important to focus on
  - Interpretation of data
  - Uptake and acceptance of data

- Result = low sample sizes, minimal outcomes, minimal integration with other relevant constructs

Collecting biomechanics data ~~is~~ was hard!

- Kinematic analyses necessitates "observation" of movement, most commonly via video capture
  – Requires joints/segments/bodies to be visible
- Synchronization of different physiological constructs can be complex
- Confined to laboratory settings and generally short bursts of moderately dynamic, cyclical movement

ELSEVIER

Gait and Posture 16 (2002) 159–179

GAIT & POSTURE

www.elsevier.com/locate/gaitpost

The evolution of clinical gait analysis Part II Kinematics☆

D.H. Sutherland *

Children's Hospital San Diego, 3020 Children's Way MC 5054, San Diego, CA, USA 92123-4282

Accepted 18 December 2001

proach to kinematic analysis was to apply Geissler tubes to the limb segments, interrupt the illumination at regular intervals by a large tuning fork, and photograph the subject walking in total darkness with four cameras while the lenses were open. One camera was positioned in front of the subject, one behind, and one on each side, making their measurements tri-dimensional. The subjects were protected from electrical shock by wearing rubber suits resembling wet suits. The process of collecting data required 8 or 10 hours per subject and then it involved months of work to reduce the data and calculate kinematic measurements. This was a fantastic scientific achievement, however, because it was so time consuming, Braun and Fischer's method could only be applied in gait research.

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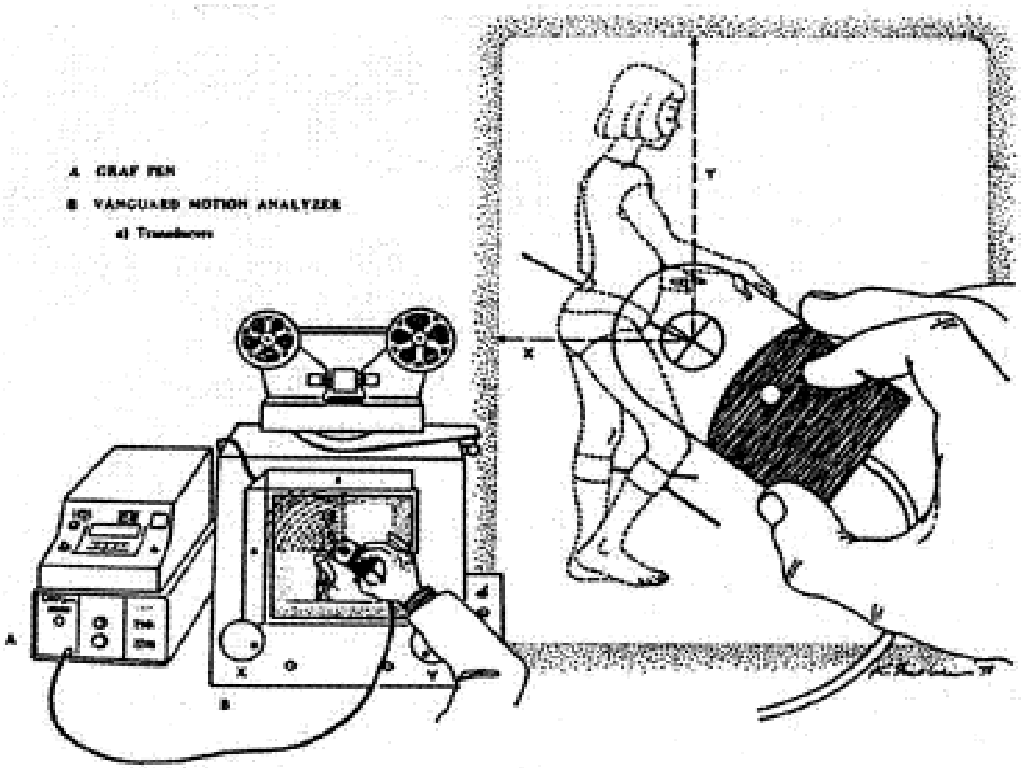
Analyzing biomechanics data ~~is~~ was hard!

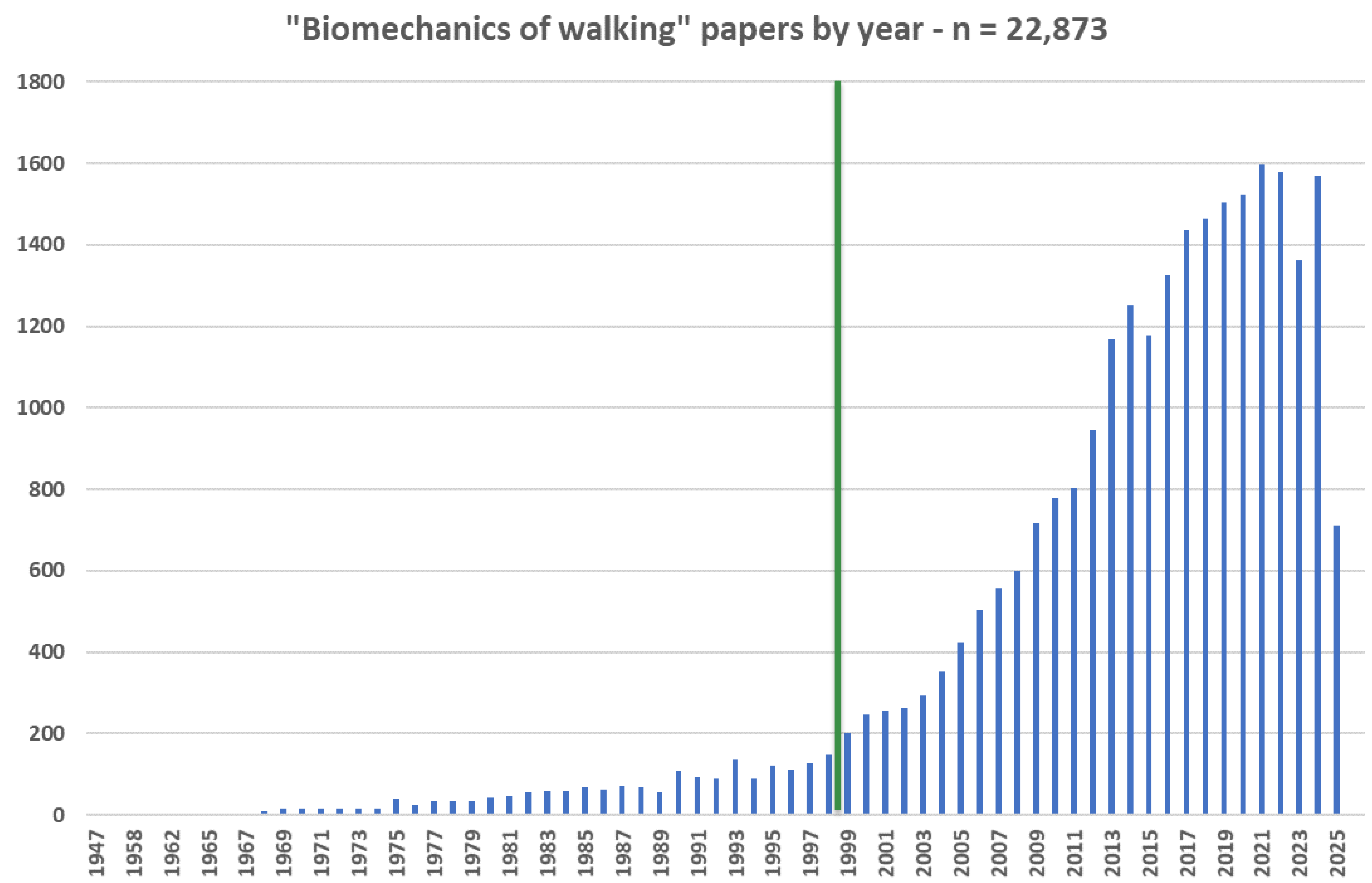
- Manual digitizing was a game changer!



Source: Sutherland et al. JBJS Am 1980

Analyzing biomechanics data ~~is~~ was hard!

- Manual digitizing was a game changer!
- Optoelectric collection and in-line processing (ie. automatic joint/segment identification) was another game changer!


"Biomechanics of walking" papers by year - n = 22,873
1800
1600
1400
1200
1000
800
600
400
200
0
1947
1958
1962
1965
1967
1969
1971
1973
1975
1977
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2019
2021
2023
2025

OpenCap

Musculoskeletal forces from smartphone video

theia

OpenSim

xsens
by Movella

plantiga

Biomechanics – historical context

- Biomechanics research (and thus applications) has long been limited by challenges in:
  - ~~Collection of data~~
  - ~~Analysis of data~~
  - Determining what is important to focus on
  - Interpretation of data
  - Uptake and acceptance of data

Barrier = technology

Barrier = thought

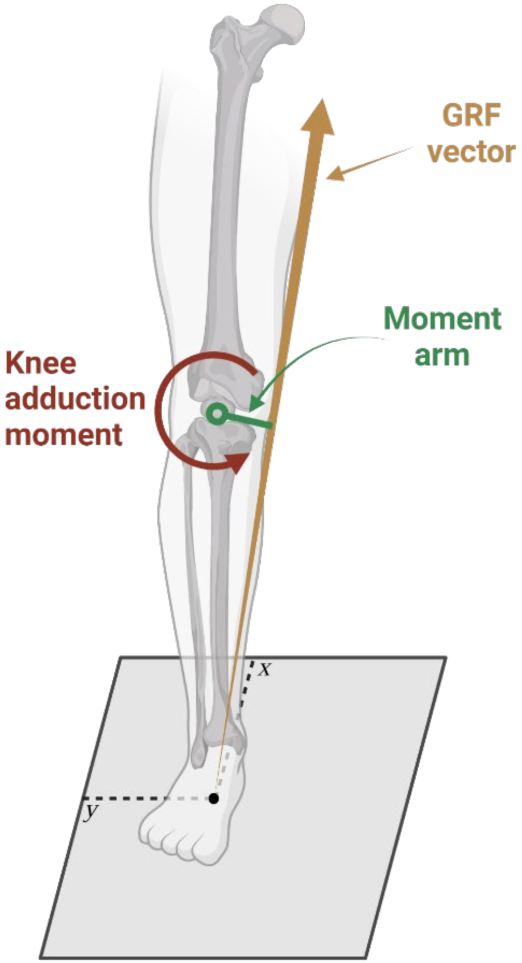
For your consideration please

- **How much** evidence is needed to guide clinical/industry decision making and/or research questions?

- What is/are the most **appropriate type(s)** of evidence for this?

The Knee Adduction Moment (KAM)

$$KAM \sim Moment\ Arm \times GRF\ vector$$



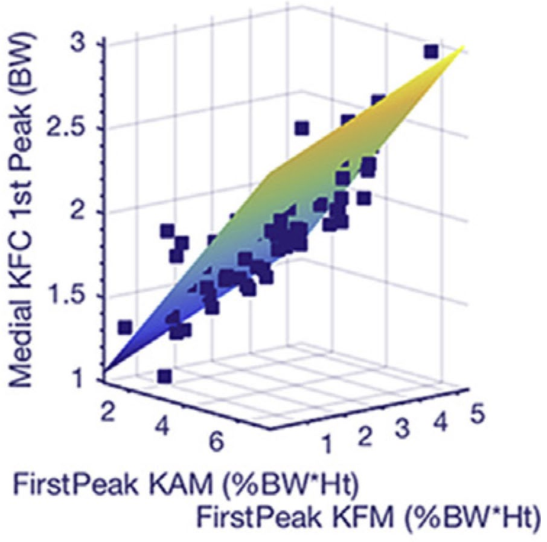
The Knee Adduction Moment (KAM)

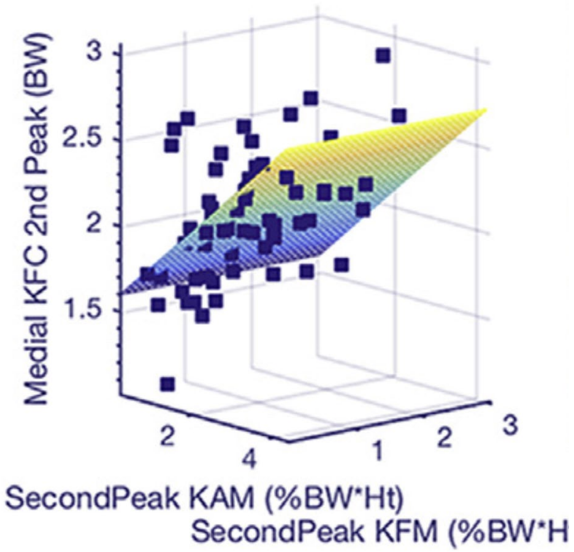
- Thought to be a proxy of the distribution of tibiofemoral joint load during walking (mainly medial compartment)

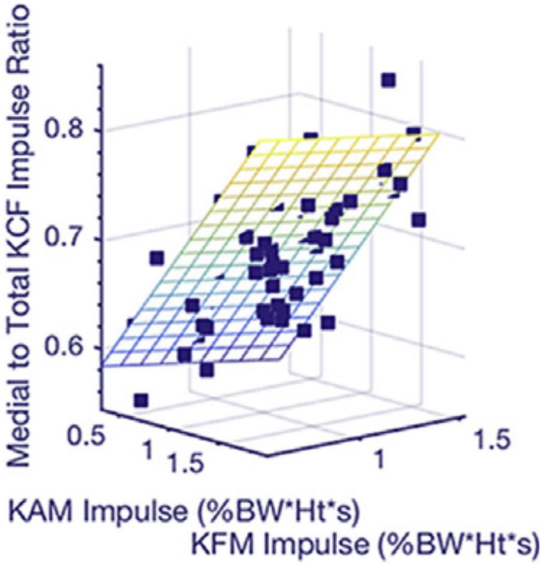
- Limitations:
  - It is an external measure
  - It is uniplanar
  - It is still almost exclusively measured in laboratory settings
  - It is not perfectly correlated with internal loading measurements

KAM and Knee Contact Force

- KAM1 <-> Medial Contact Force: $R^2 = 0.6$
- KAM2 <-> Medial Contact Force: $R^2 = 0.44$
- KAM Impulse <-> Med:Total Contact: $R^2 = 0.8$
- KAM peak <-> Medial Contact Force: $R^2 =0.6$
- KFM ~ half as strong a relationship







The Knee Adduction Moment (KAM)

Is not fully representative of the internal dynamic loading environment of the knee joint

Heart&Stroke™

Keep your blood pressure in check

High blood pressure is the number one risk factor for **stroke** and a major risk factor for **heart disease**. High blood pressure is when the blood pressure in your arteries rises and your heart has to work harder than normal to pump blood through the blood vessels. It is important that you have your blood pressure checked regularly by your healthcare provider.

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KAM & OA Progression

Structural

- Joint space narrowing

- Total knee arthroplasty

Symptom

- Increased odds of pain during

changes

Higher KAM magnitude linked t structural
progression and experiencin ed pain


Osteoarthritis and Cartilage

OARSI OSTEOARTHRITIS RESEARCH SOCIETY INTERNATIONAL

Review

Are biomechanics during gait associated with the structural disease onset and progression of lower limb osteoarthritis? A systematic review and meta-analysis

N. D'Souza, J. Charlton, J. Grayson, S. Kobayashi, L. Hutchison, M. Hunt, M. Simic

Research article | Open Access | Published: 14 March 2019

Knee. 2006 Dec;13(6):445-50. doi: 10.1016/j.knee.2006.08.005. Epub 2006 Sep 29.

Increased joint loads during walking--a consequence of pain relief in knee osteoarthritis

Marius Henriksen [1], Erik B Simonsen, Tine Alkjaer, Hans Lund, Thomas Graven-Nielsen, Bente Danneskiold-Samsøe, Henning Bliddal

Dave M. Walton, Kevin Willits, Robert B. Litchfield, Alan Getgood, Peter J. Fowler, J. Robert Giffin

Miyazaki et al. (2002) Ann Rhem Dis
Davis et al. (2018) Clin Biomech
Bennell et al. (2011) Ann Rheum Dis
Brisson et al. (2017) J Orthop Res
Chehab et al. (2014) Osteoarthritis Cartilage
Chang et al. [2015] Osteoarthritis Cartilage
Hatfield et al. (2015) Arthritis Care Res
D'Souza et al [2021] Osteoarthritis Cartilage
Birmingham et al. (2018) Arthritis Care Res
Boyer & Hafer. (2019) BMC Musc Dis
Henriksen et al. (2010) Arthritis Care Res
Henriksen et al (2006) Knee

KAM & OA Progression

- Findings are relatively consistent across:
  - Study lengths (12 months to 6 years)
  - Progression metric
    - Imaging (x-ray JSN, x-ray KL grade, MRI cartilage thickness, MRI cartilage volume, MRI bone marrow lesions)
    - Clinical (pain, progression to joint arthroplasty)
  - KAM metric
    - Overall peak, midstance, impulse

The KAM is modifiable!

- Immediate changes
  - Single-session experimental studies

A lack of evidence of effect is NOT the same as evidence of lack of effect

- **MINIMAL EVIDENCE RE: LONG TERM CHANGES, ASSOCIATIONS WITH OTHER RELEVANT CHANGES, PLACEBO-CONTROLLED RCTs**

How much is enough?

- Criteria for establishment of "relevance":
  - Established validity and reliability of measurement
  - Consistency of evidence across a broad range of study designs
  - Consistency of evidence across a broad range of collection/reporting parameters
  - Establishment of a plausible and acceptable physiological rationale

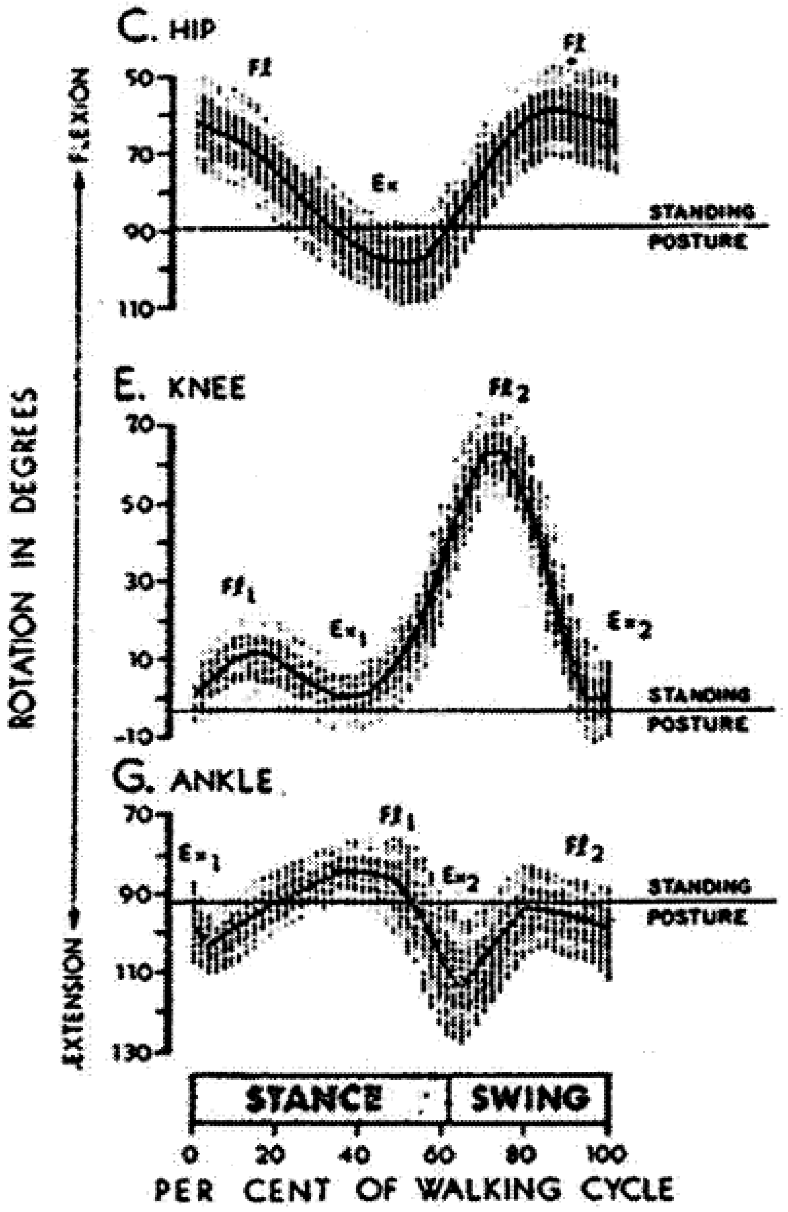
- Perfec

"An 80% solution is better than no solution at all, 100% of the time"

For your consideration please

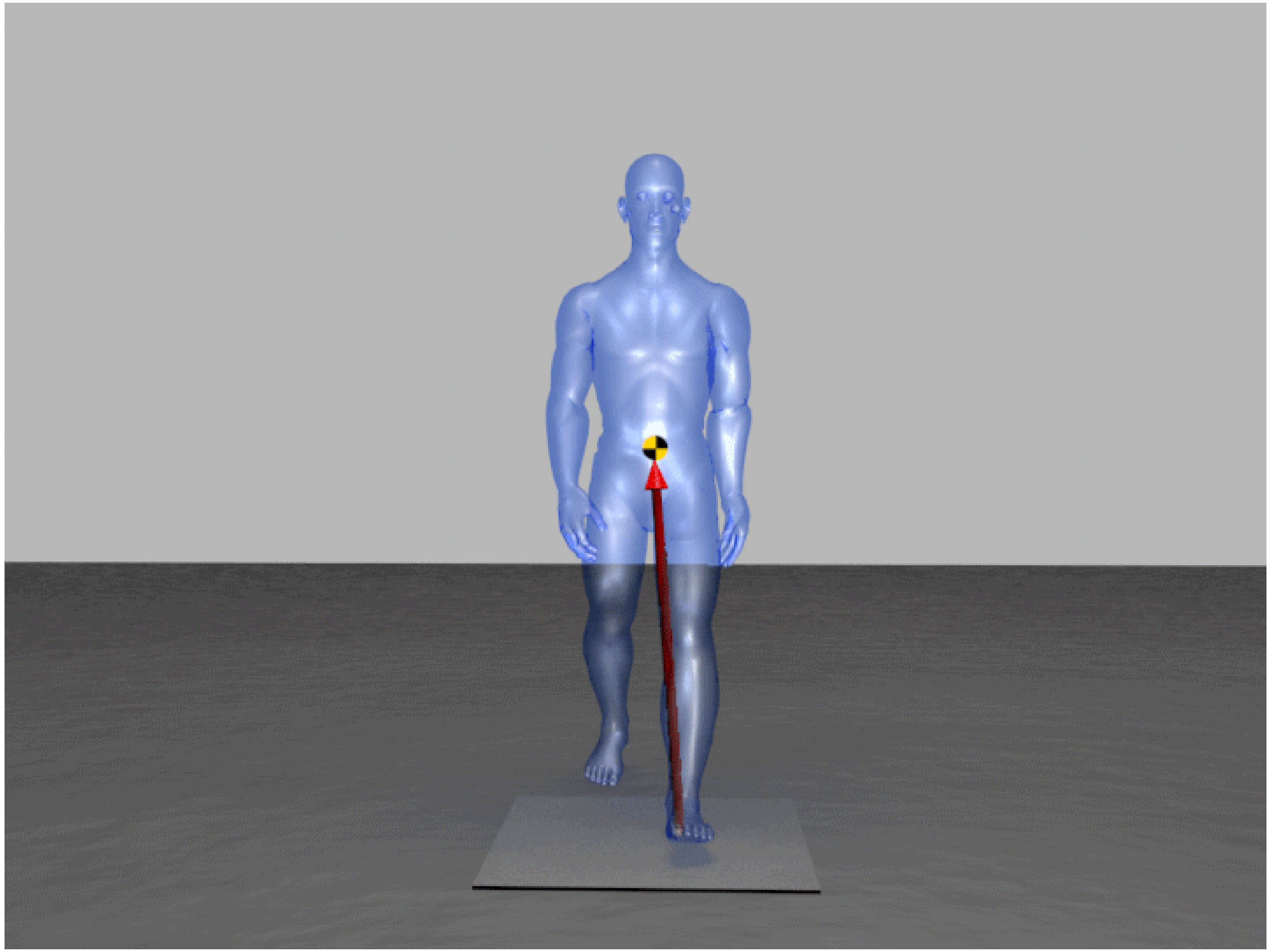
- Are state of the art approaches always best to acquire this evidence?

- IT DEPENDS!
  - What other options are available?
  - What are you trying to achieve/measure?
  - Who are you measuring it for?



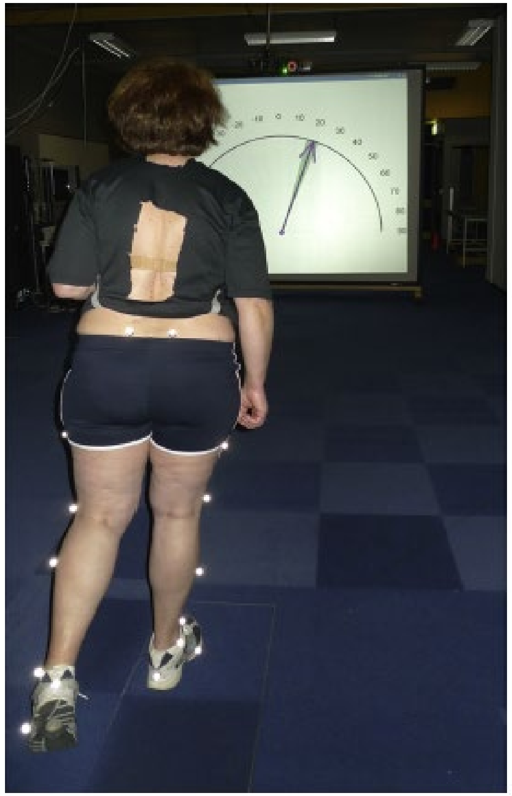
Murray et al (1970) Arch Phys Med Rehabil

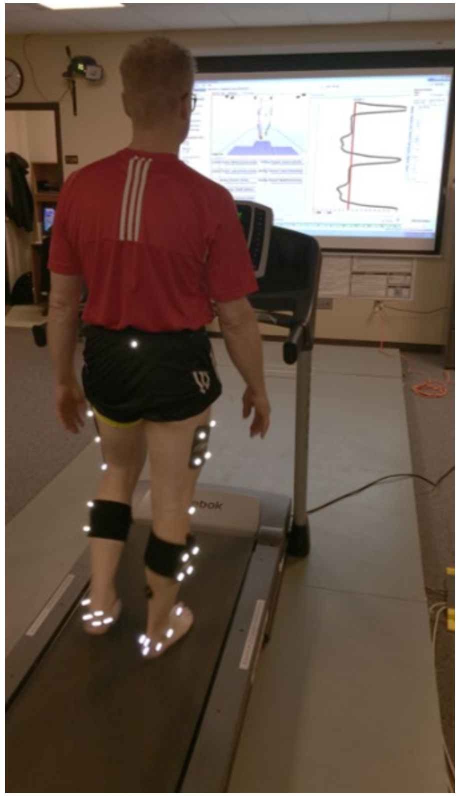
Reduced KAM via FPA modification

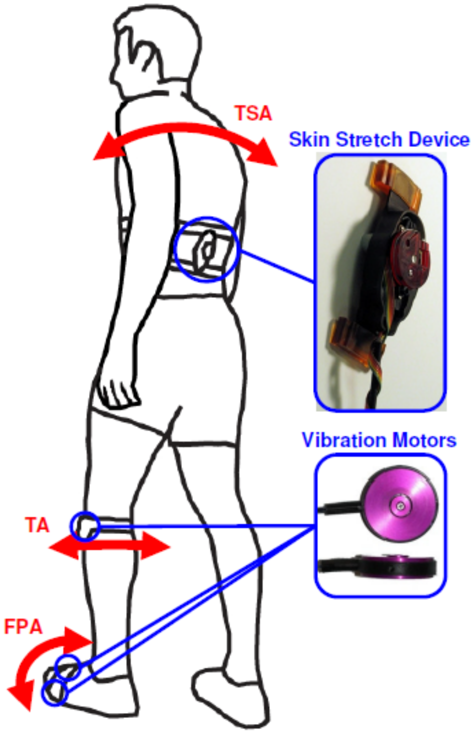


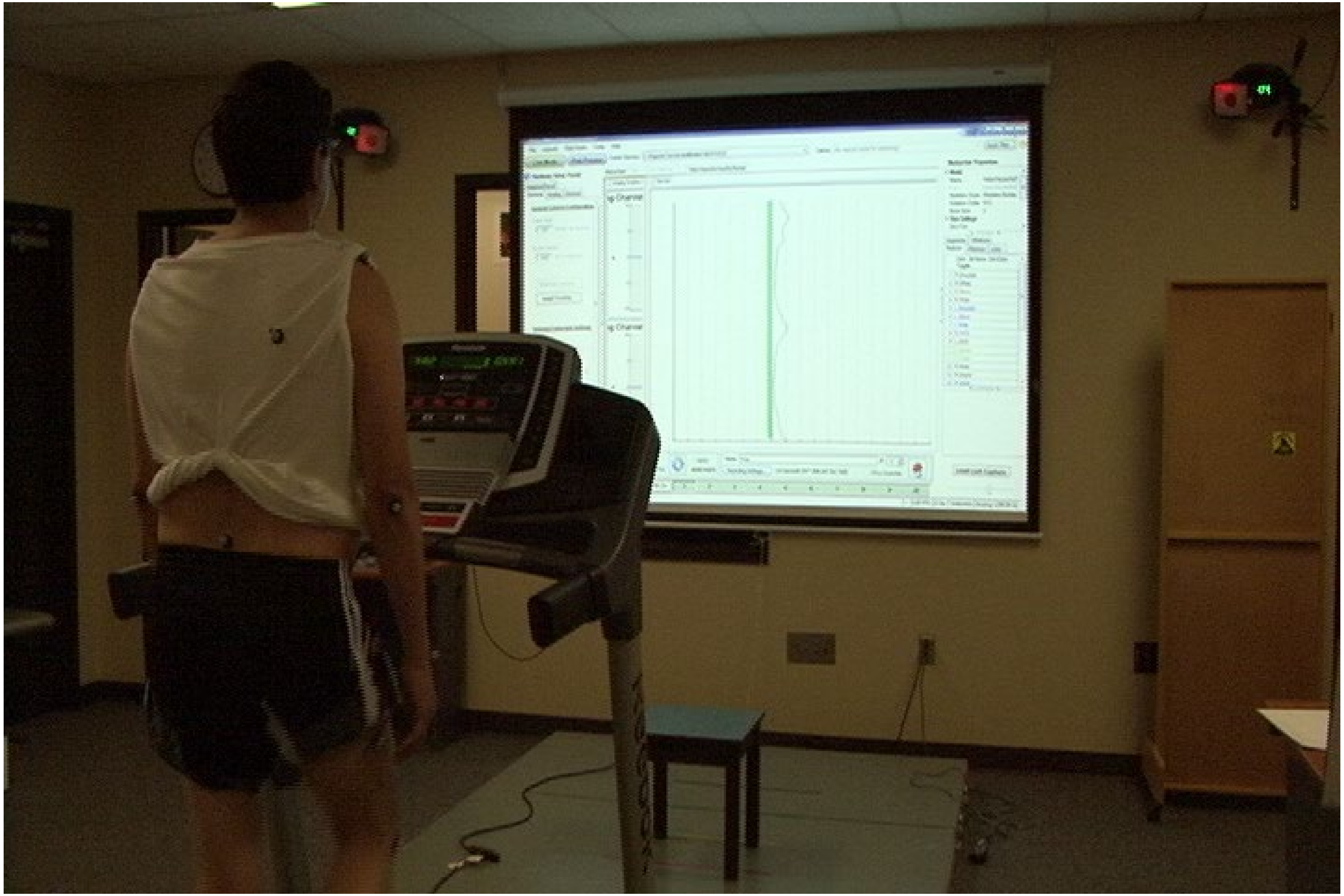
Commonalities of early FPA modification research

- Guided by state-of-the-art real-time biofeedback









ACRM
AMERICAN CONGRESS OF REHABILITATION MEDICINE

Archives of Physical Medicine and Rehabilitation
journal homepage: www.archives-pmr.org
Archives of Physical Medicine and Rehabilitation 2014;95:1912-7

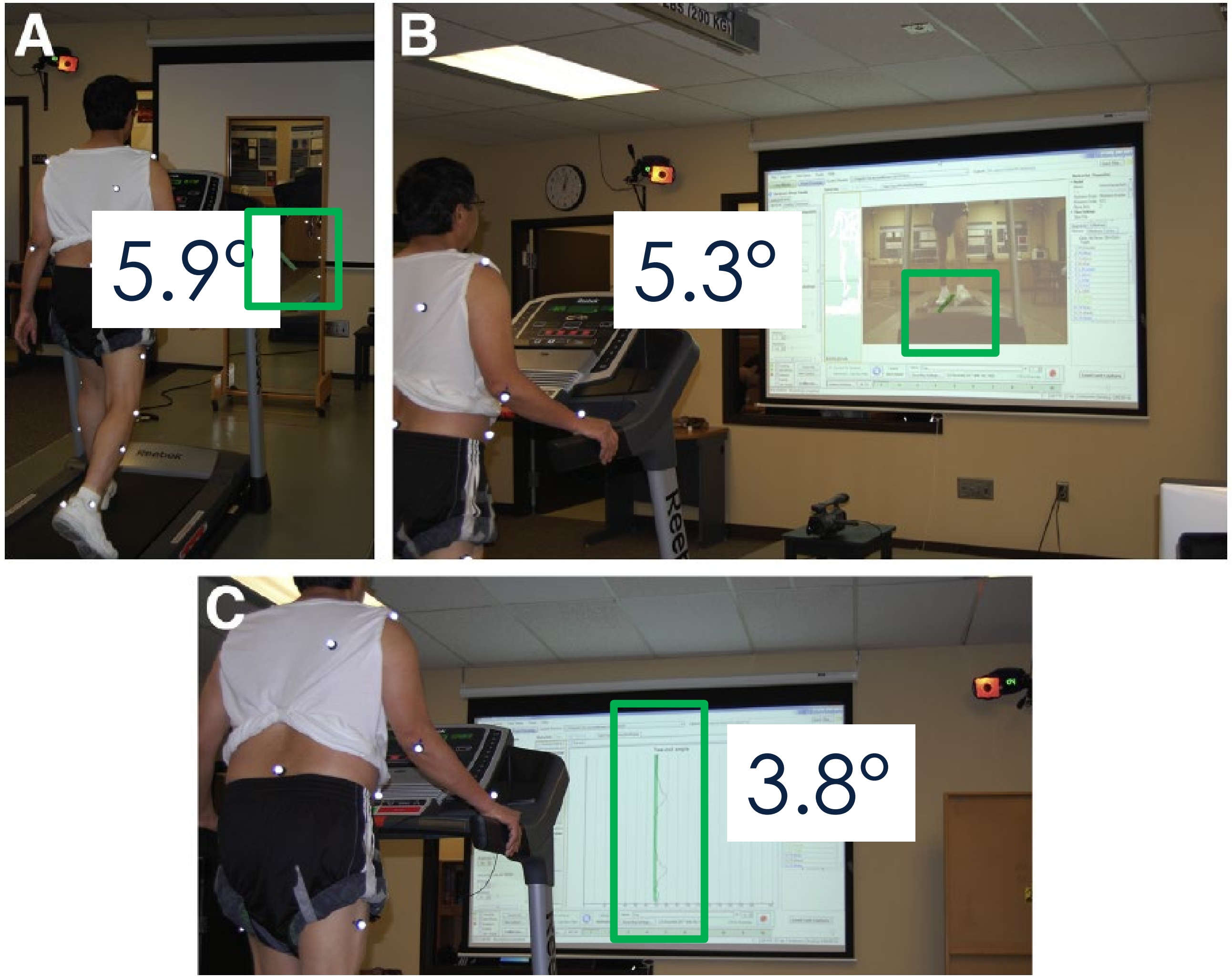
ORIGINAL ARTICLE

Comparison of Mirror, Raw Video, and Real-Time Visual Biofeedback for Training Toe-Out Gait in Individuals With Knee Osteoarthritis

CrossMark

Michael A. Hunt, PhD, Judit Takacs, MSc, Katie Hart, MPT, Erika Massong, MPT, Keri Fuchko, MPT, Jennifer Biegler, MPT

From the Department of Physical Therapy, University of British Columbia, Vancouver, BC, Canada.



Osteoarthritis and Cartilage 26 (2018) 903–911

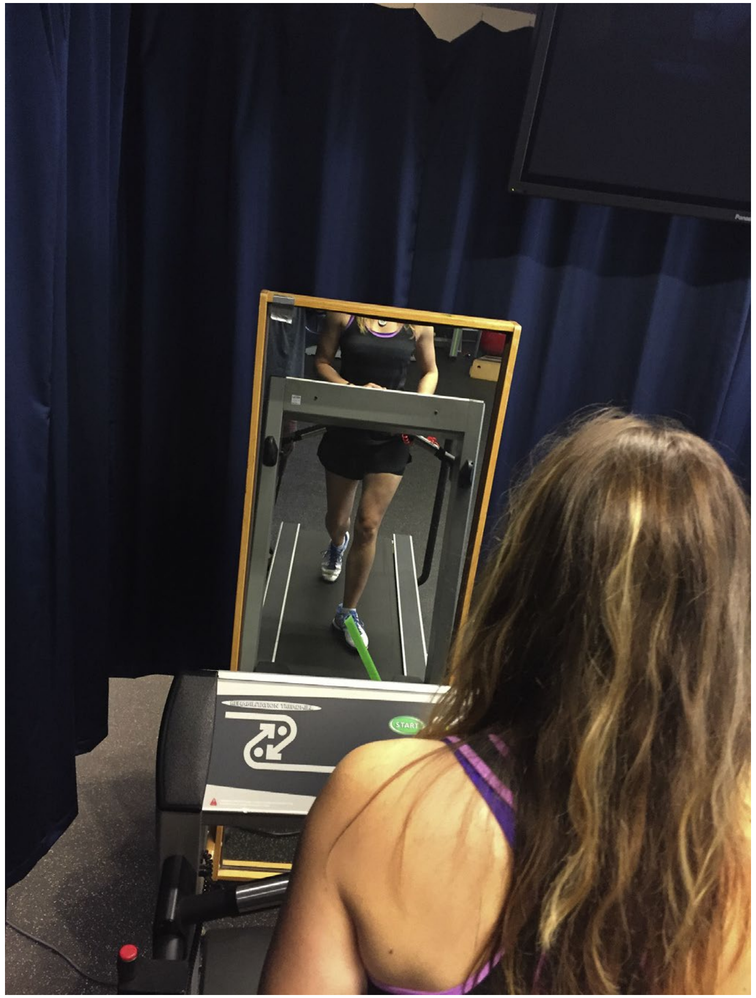
Osteoarthritis and Cartilage

OARSI OSTEOARTHRITIS RESEARCH SOCIETY INTERNATIONAL

Clinical and biomechanical changes following a 4-month toe-out gait modification program for people with medial knee osteoarthritis: a randomized controlled trial

Check for updates

M.A. Hunt † *, J.M. Charlton †, N.M. Krowchuk †, C.T.F. Tse †, G.L. Hatfield † ‡



Quantifying real world gait assessment

Journal of Biomechanics 61 (2017) 193–198

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Contents lists available at ScienceDirect

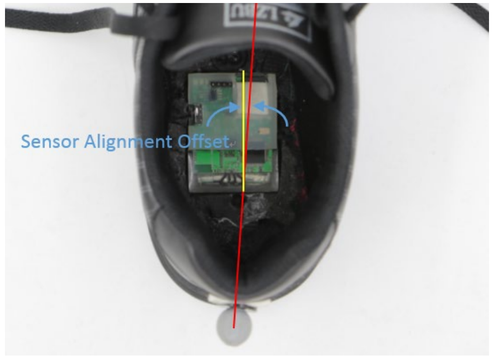
Journal of Biomechanics

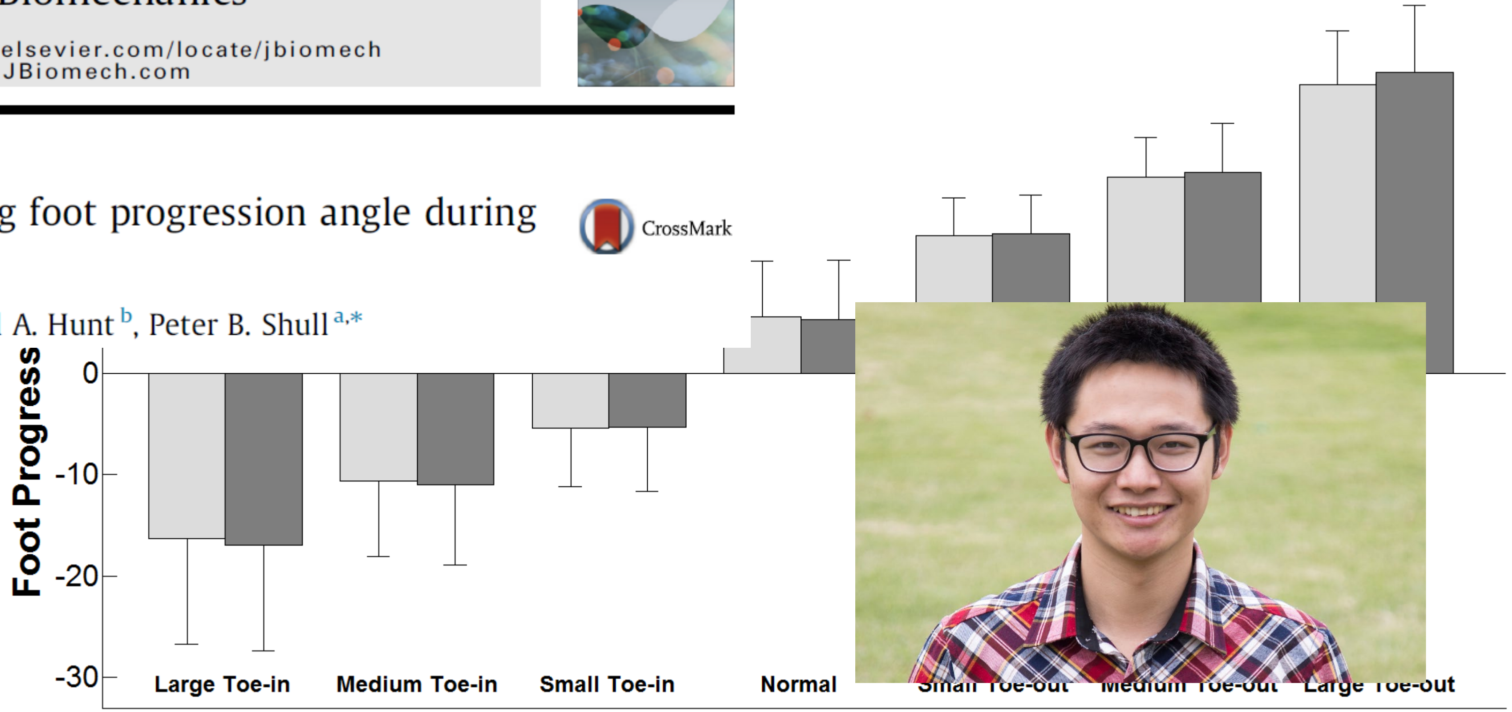
journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Validation of a smart shoe for estimating foot progression angle during walking gait

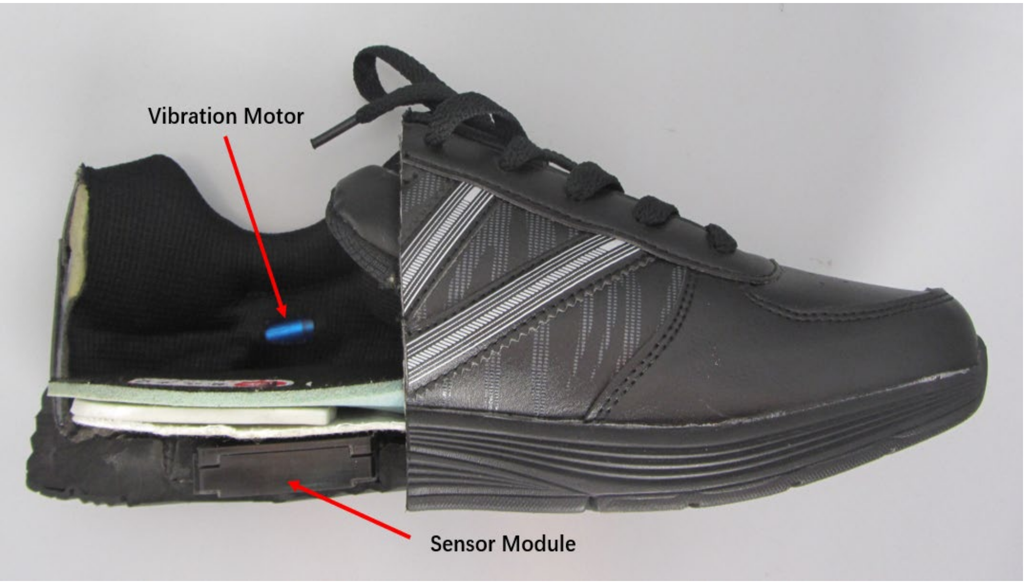
CrossMark

Haisheng Xia [a], Junkai Xu [a], Jianren Wang [a], Michael A. Hunt [b], Peter B. Shull [a,*]





Haptic-induced gait modification



Journal of Biomechanics 107 (2020) 109789

Contents lists available at ScienceDirect

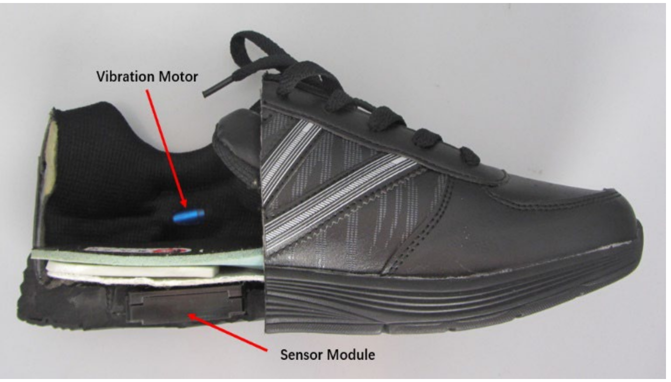
Journal of Biomechanics

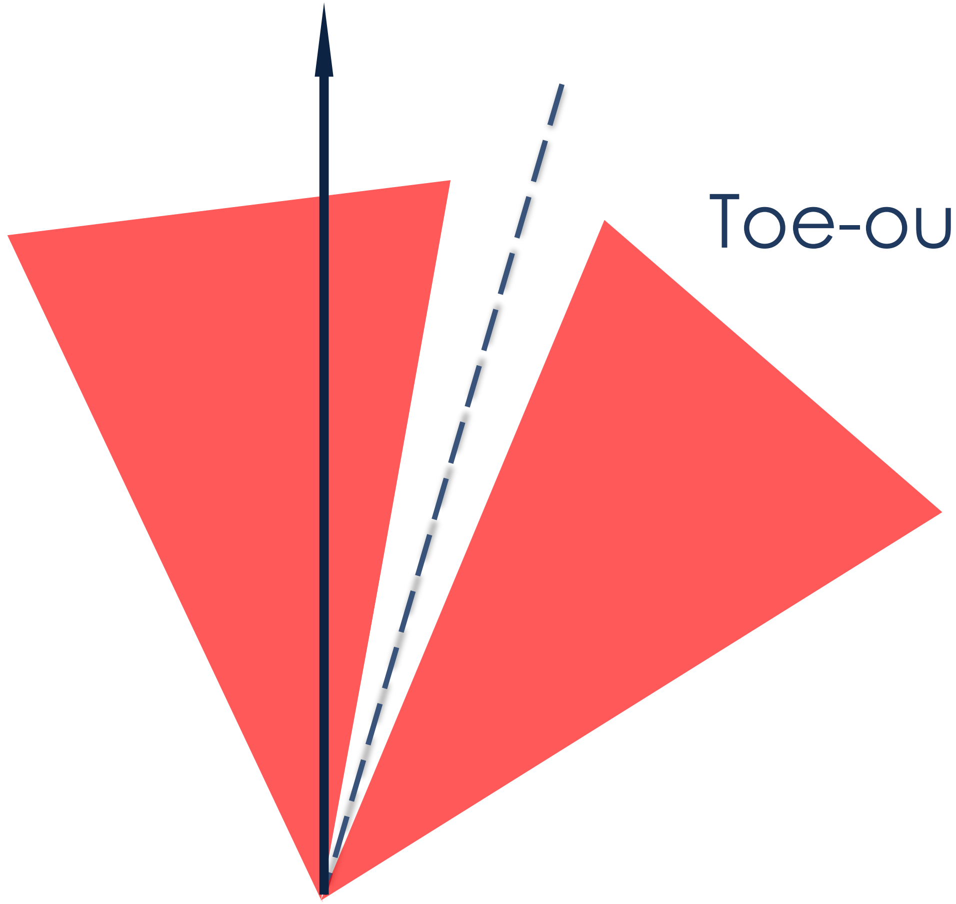
journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

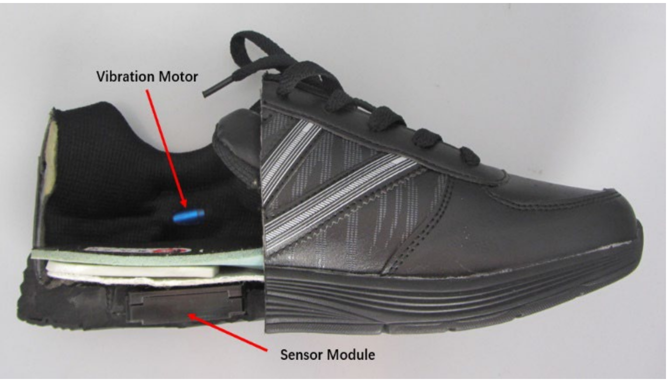
ELSEVIER

Portable, automated foot progression angle gait modification via a proof-of-concept haptic feedback-sensorized shoe

Haisheng Xia [a], Jesse M. Charlton [b,c], Peter B. Shull [a], Michael A. Hunt [b,c,*]


Vibration Motor
Sensor Module


Walking direction
Toe-out training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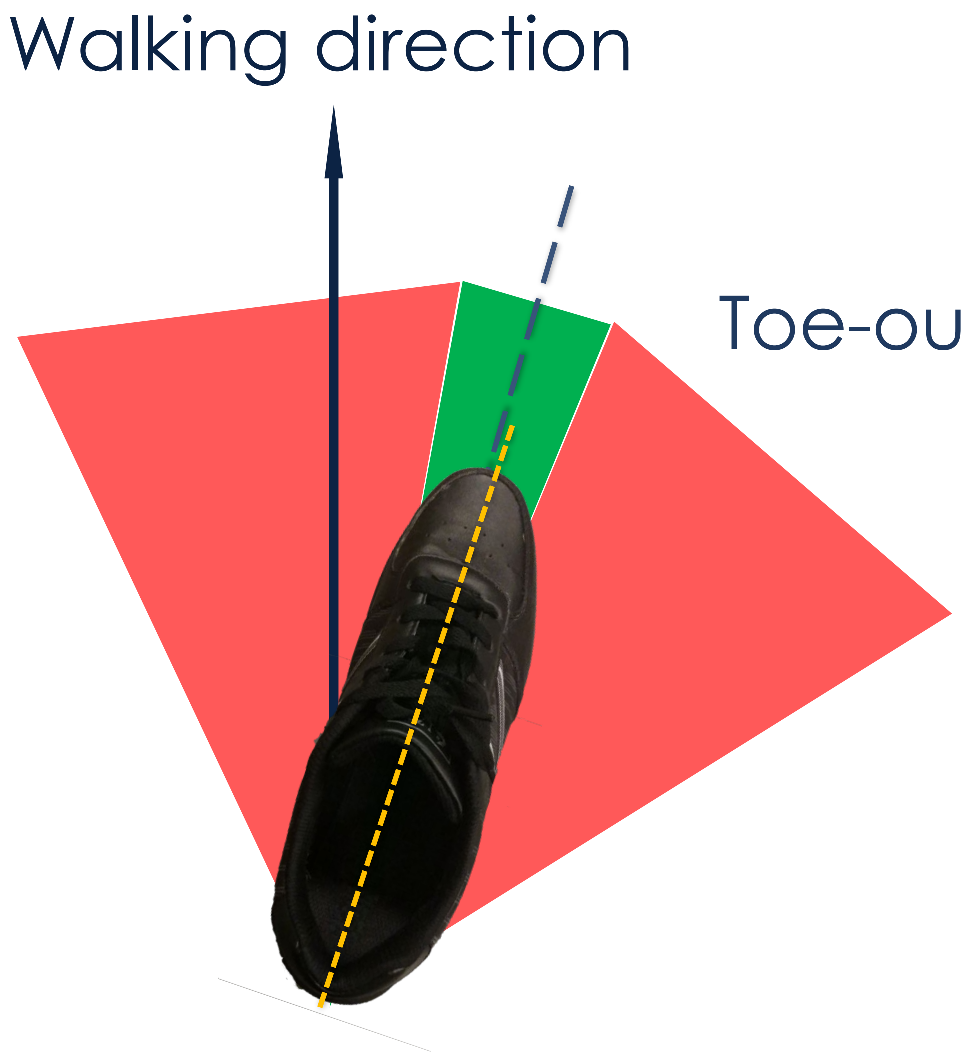
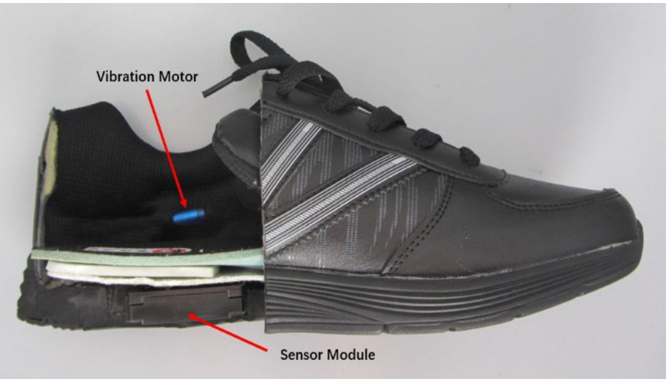
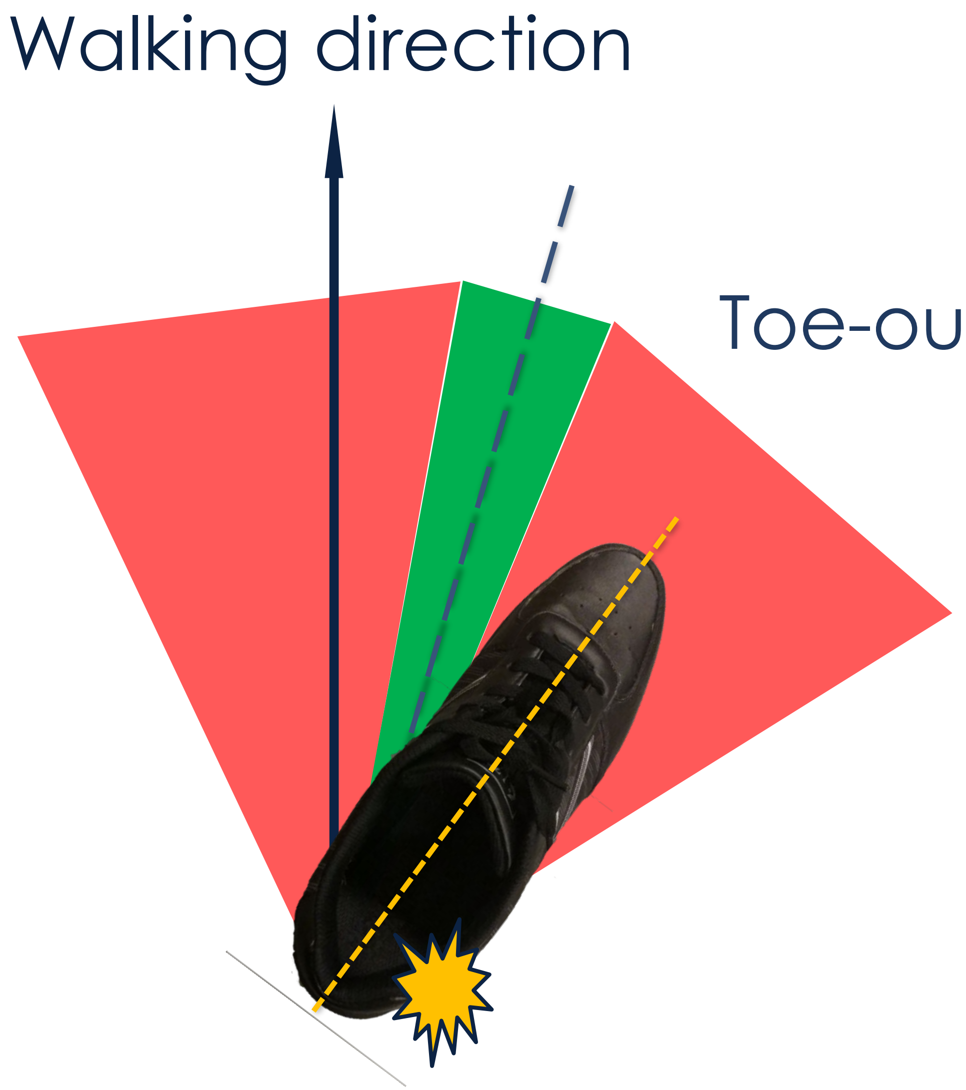
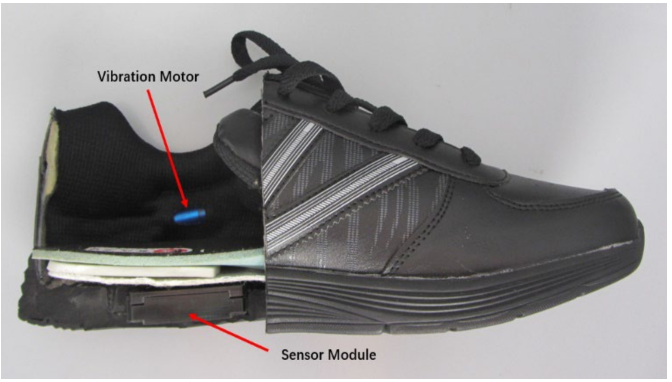
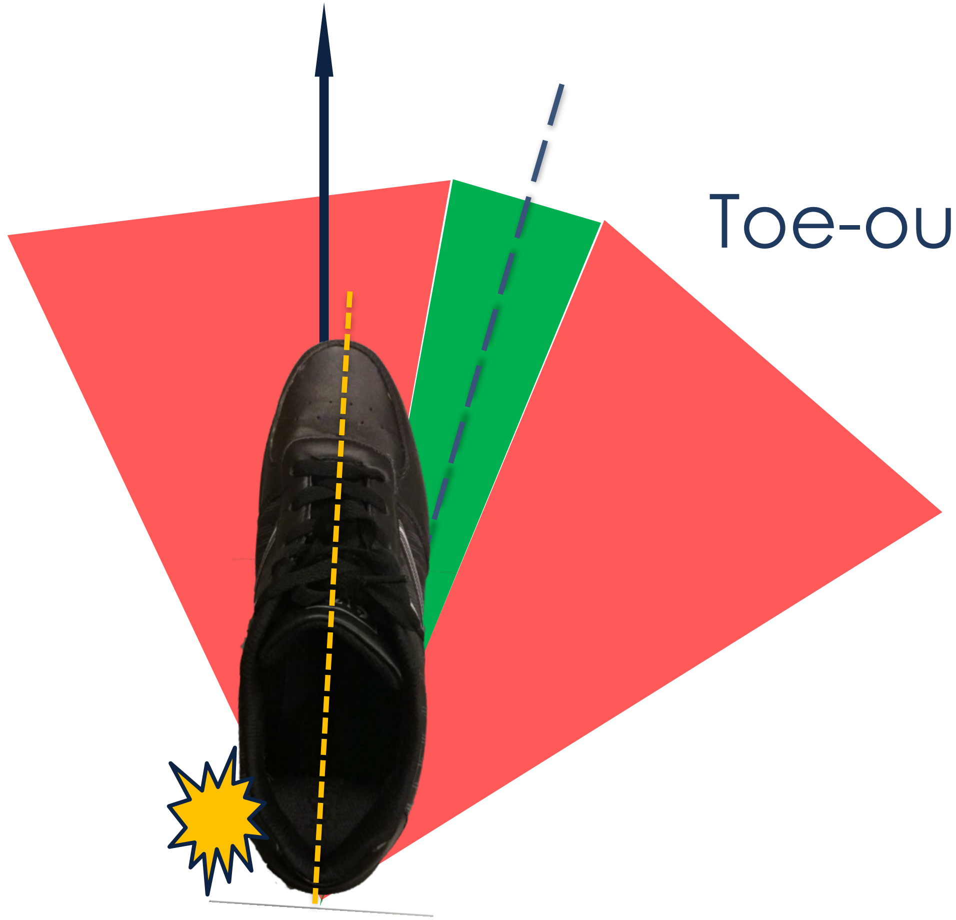
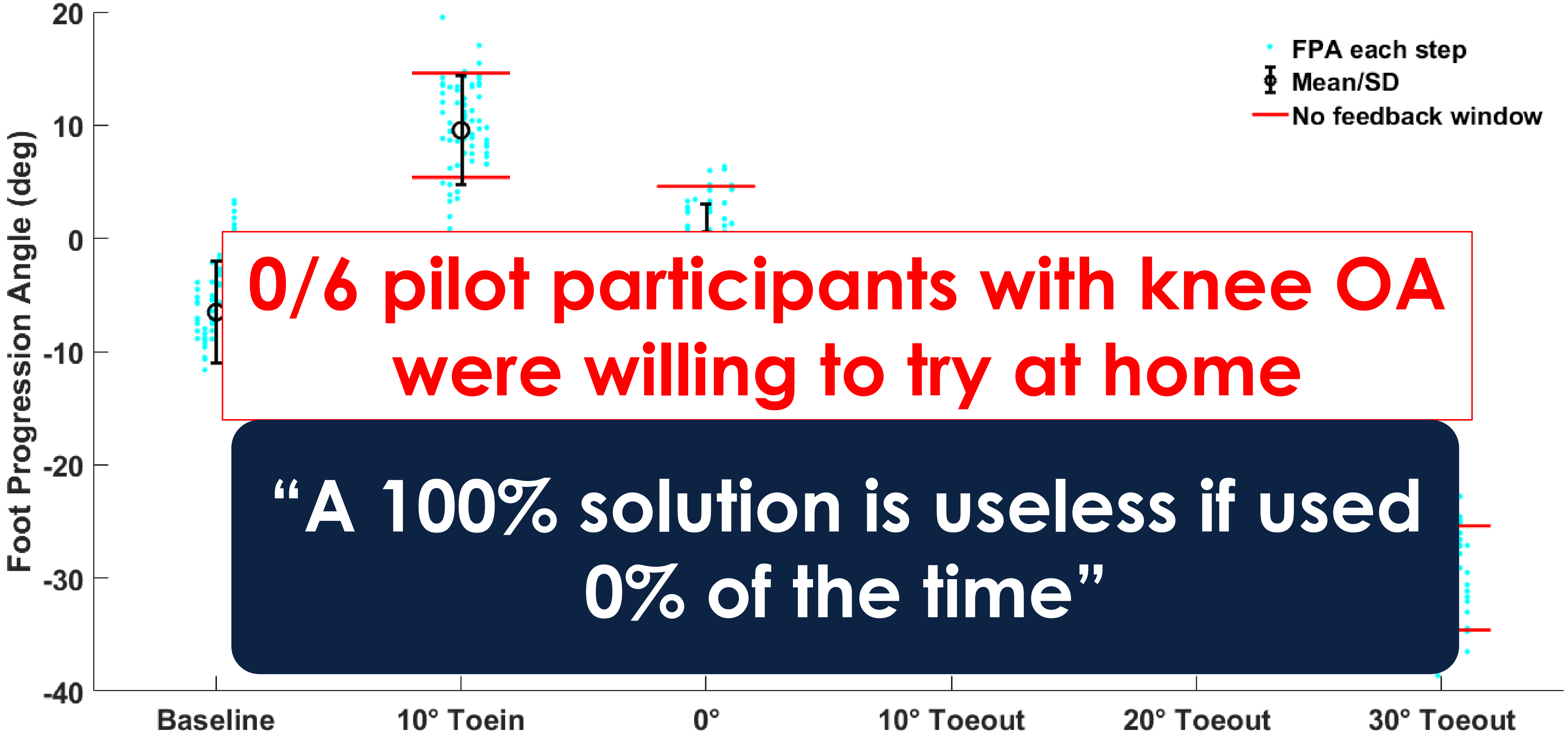

Walking direction
Toe-out training


Vibration Motor
Sensor Module


Walking direction
Toe-out training


Vibration Motor
Sensor Module


Walking direction
Toe-out training



0/6 pilot participants with knee OA were willing to try at home

"A 100% solution is useless if used 0% of the time"

- Individualized based on screening
- Remotely delivered
- Self-directed
- Monitored out of lab

Clinical Biomechanics 106 (2023) 105981

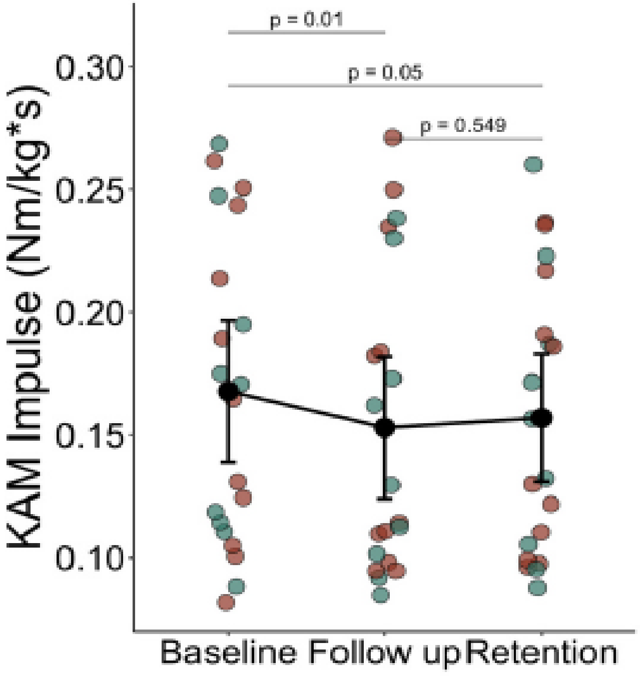
Contents lists available at ScienceDirect

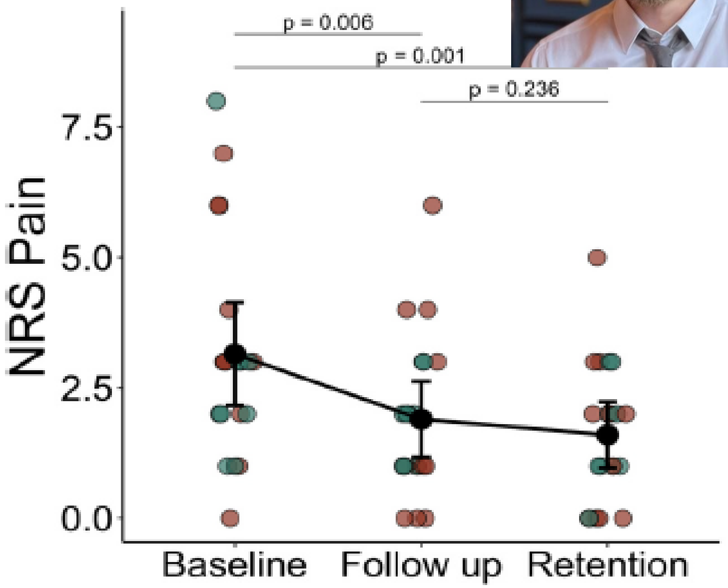
Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

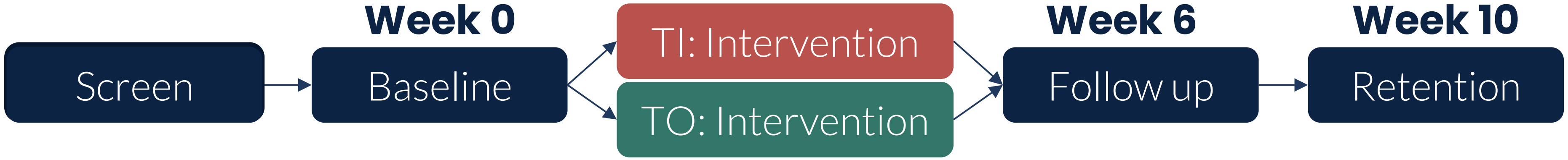
Remotely delivered, individualized, and self-directed gait modification for knee osteoarthritis: A pilot trial

Jesse M. Charlton [a,b,c,d,*], Natasha M. Krowchuk [a,c], Janice J. Eng [a,d], Linda C. Li [a,e], Michael A. Hunt [a,c,d]



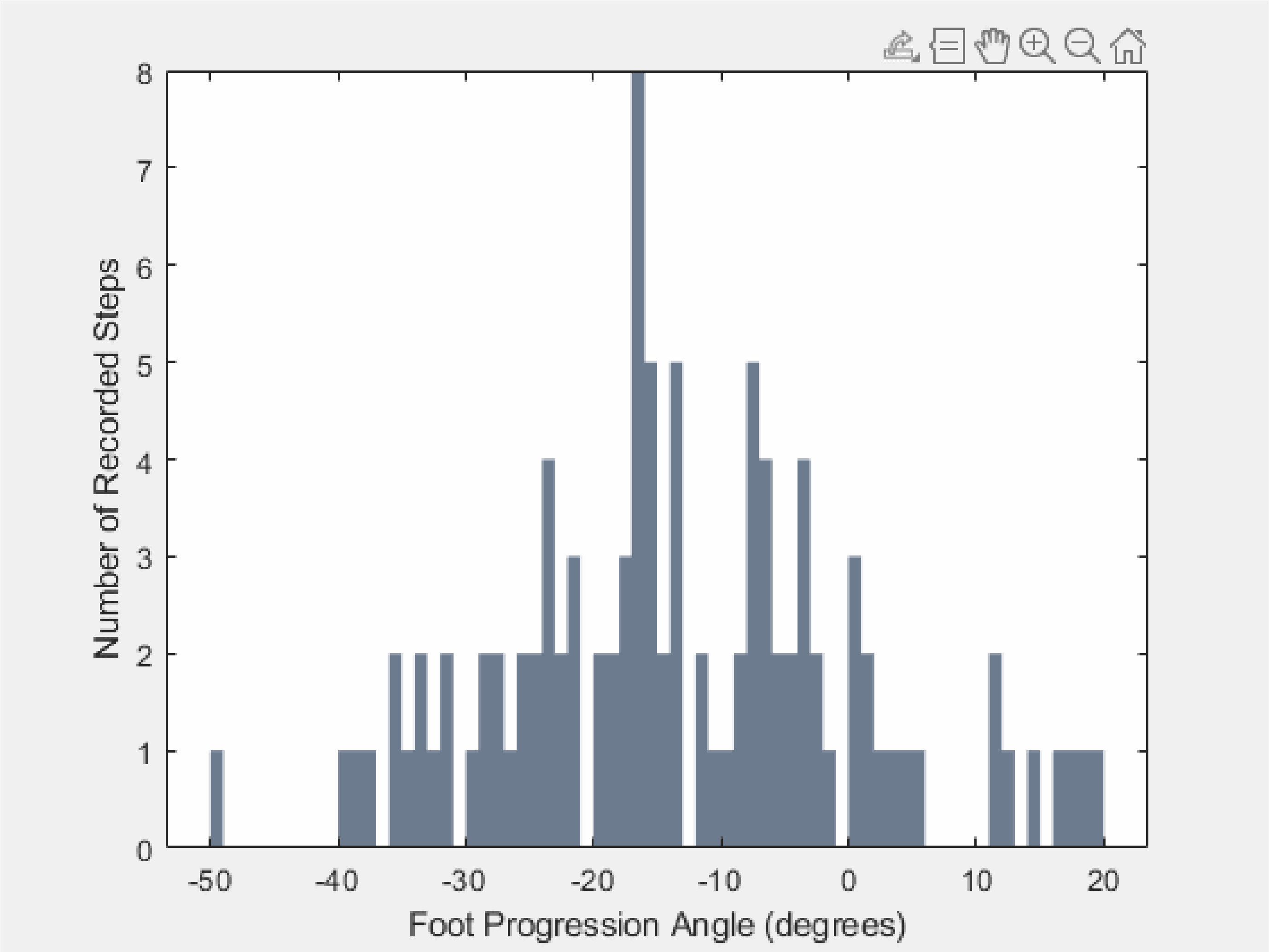


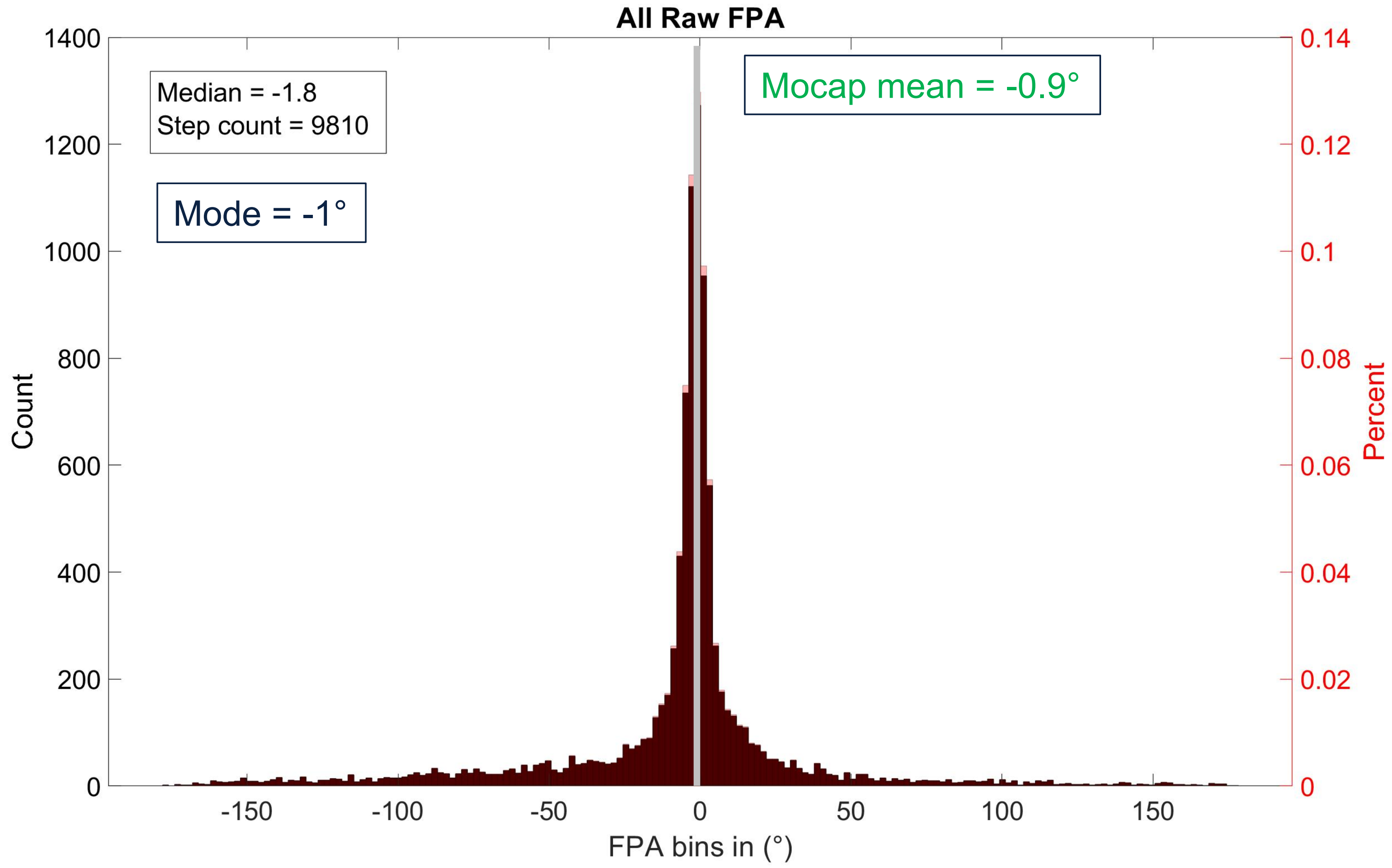
Charlton et al. [2023] Clin Biomech

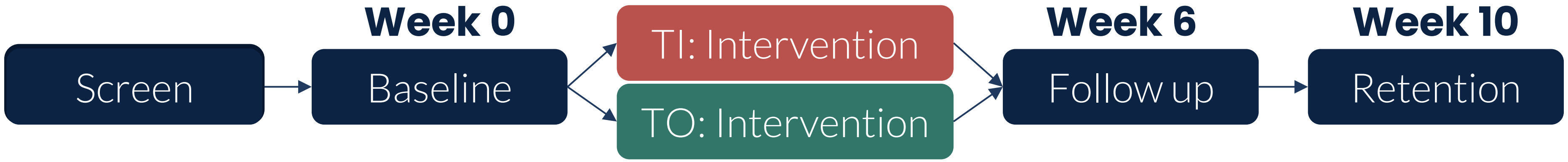

Week 0
Week 6
Week 10
Screen
Baseline
TI: Intervention
TO: Intervention
Follow up
Retention

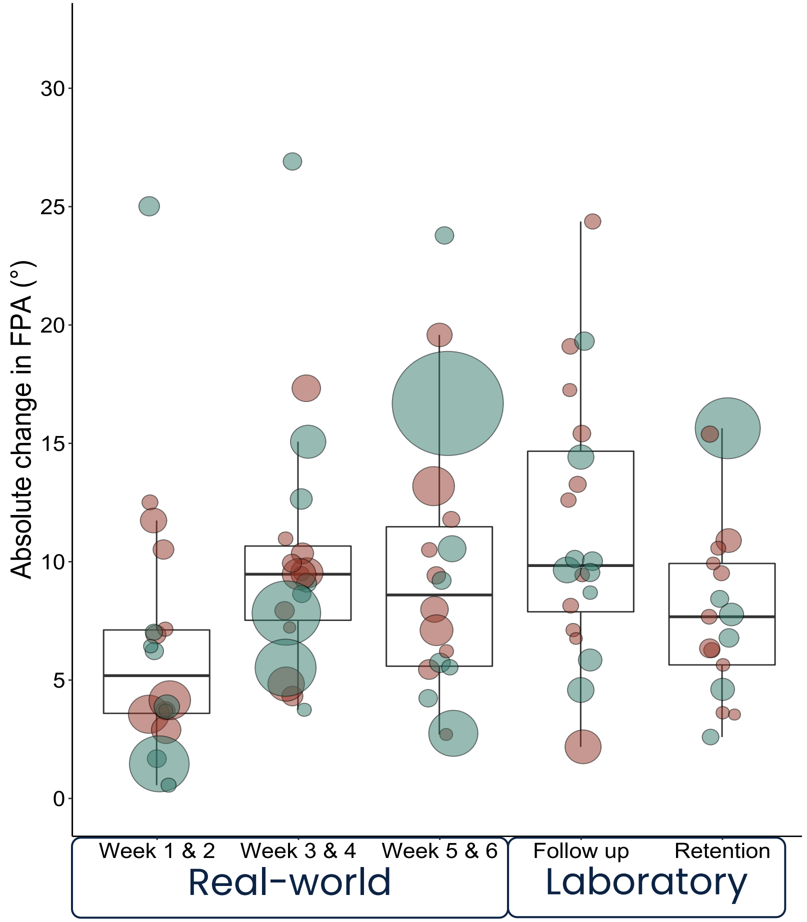

Absolute change in FPA (°)
0
5
10
15
20
25
30
Week 1 & 2
Week 3 & 4
Week 5 & 6
Follow up
Retention
Real-world
Laboratory
Toe-in
Toe-out
Low
Variability
High
Variability

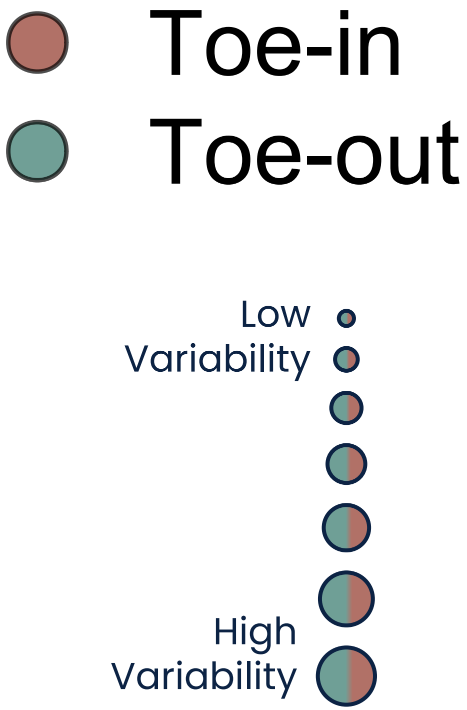
Real world gait assessment




All Raw FPA
Median = -1.8
Step count = 9810
Mode = -1°
Mocap mean = -0.9°
Count
Percent
FPA bins in (°)
0
200
400
600
800
1000
1200
1400
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
-150
-100
-50
0
50
100
150



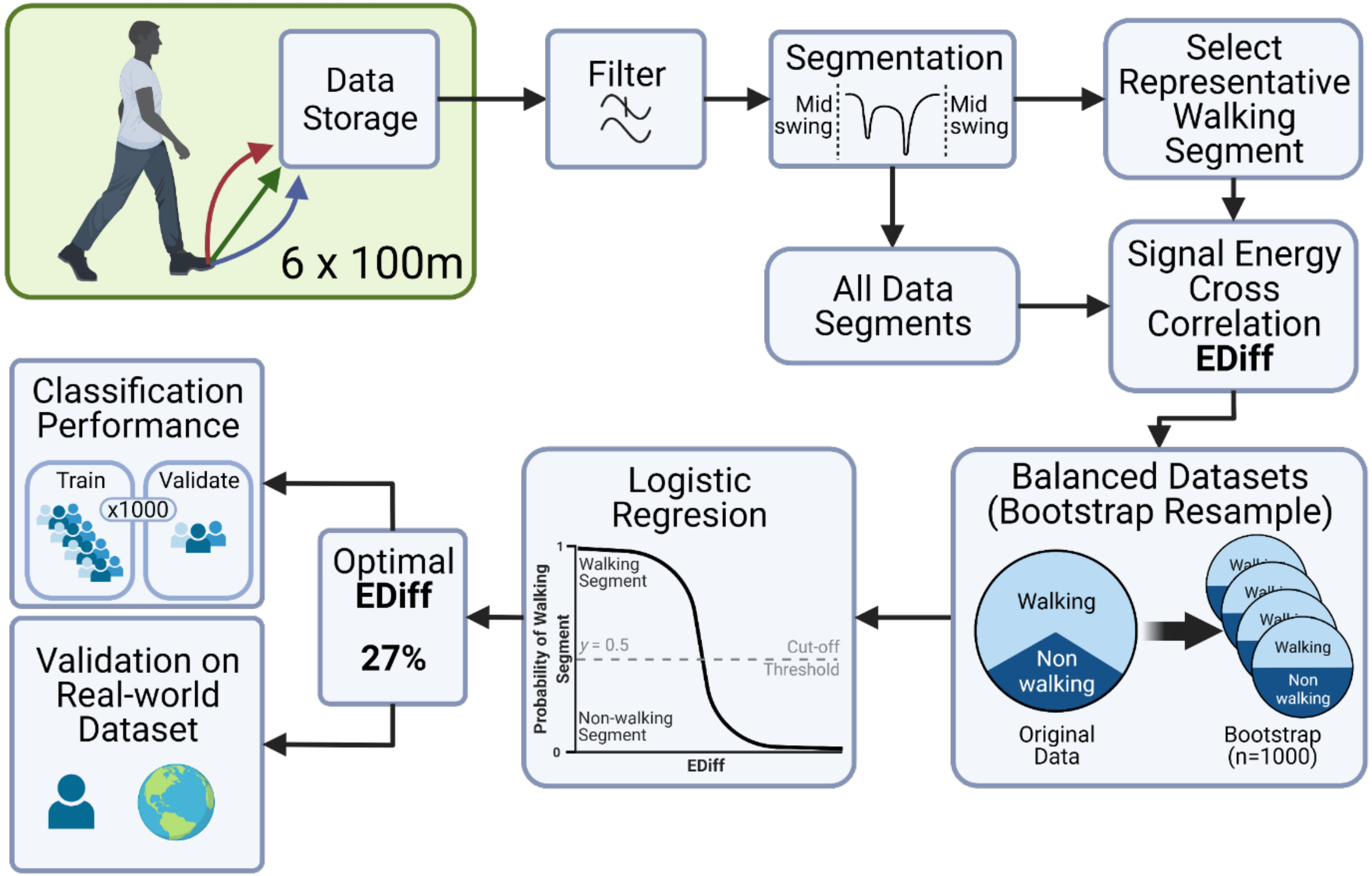




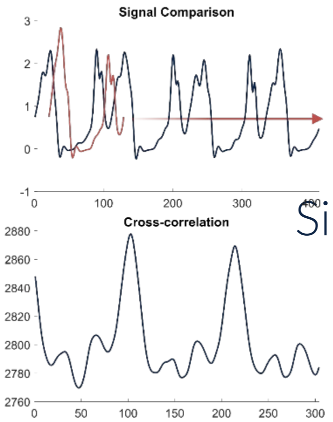
Charlton et al. [2023] Clin Biomech

Classification

Data Collection



Classification Variable (EDiff)



Cross-Correlation

$$(f * g)[n] = \sum_{m=-\infty}^{\infty} \overline{f[m]}\, g[m+n]$$

Signal Energy = 100% Signal Correlation

$$E = \sum_{m=-\infty}^{\infty} |f[m]|^2$$

Maximum Cross Correlation

$$\mathrm{abs}(\max(\mathrm{Cvec})) = \mathrm{mC}$$

Percent Difference (Energy vs xCorr)

$$\mathrm{EDiff} = \mathrm{abs}\left(\frac{E - \mathrm{mC}}{(E + \mathrm{mC})/2}\right)$$

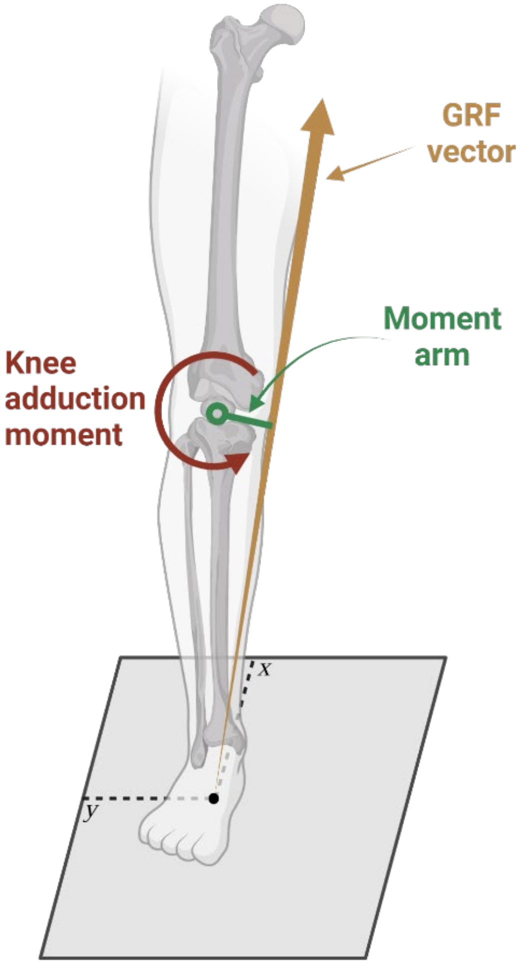
How to best summarize your data?

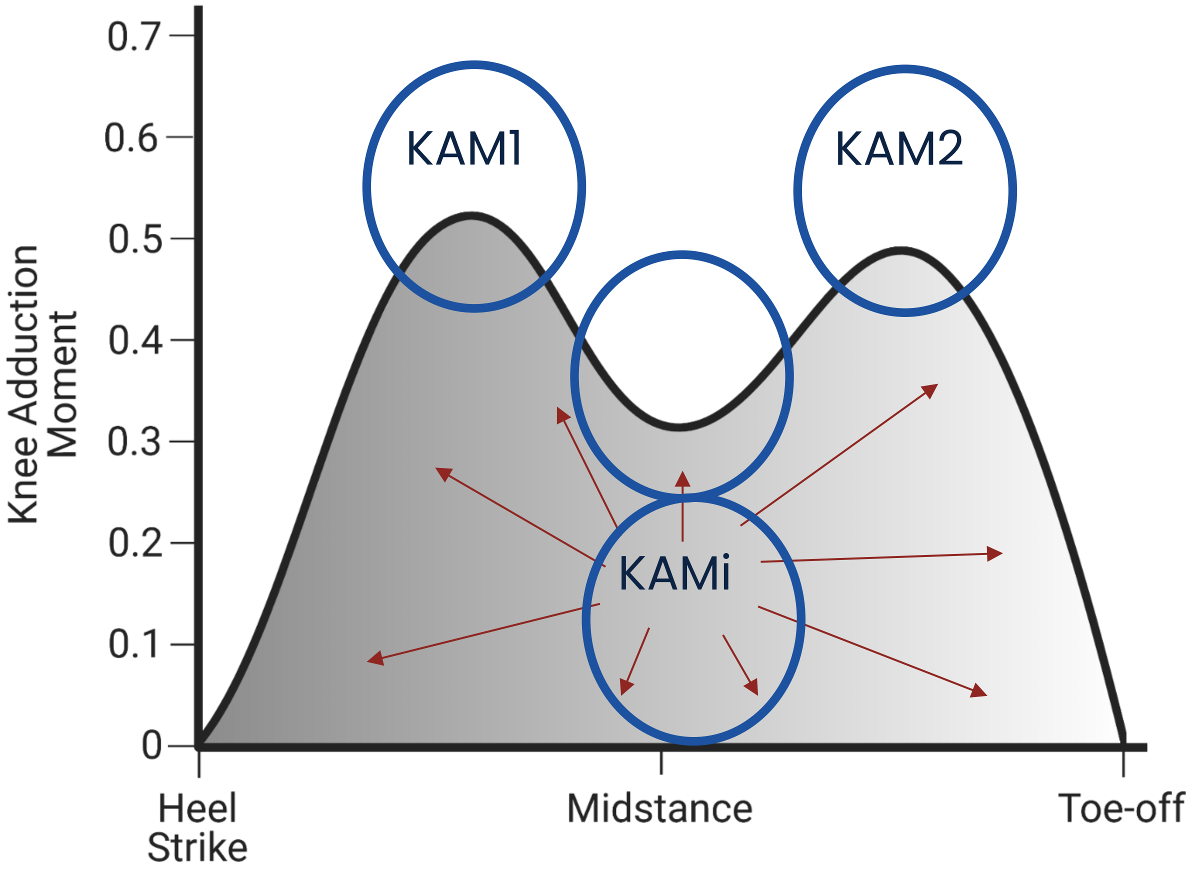
- What is the question trying to be answered?

- Who is trying to answer the question?
  - What is their level of: expertise, time, resources to act

The Knee Adduction Moment (KAM)

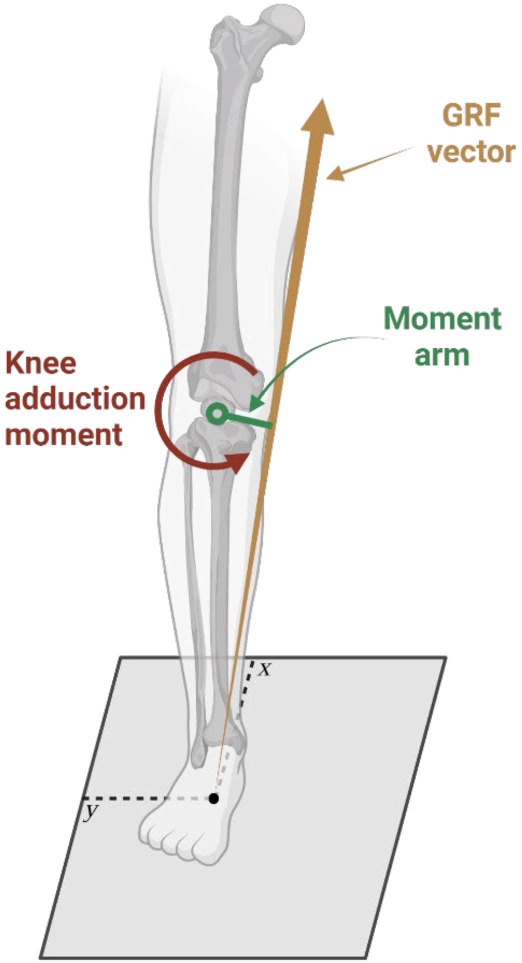
$$KAM \sim Moment\ Arm \times GRF\ vector$$

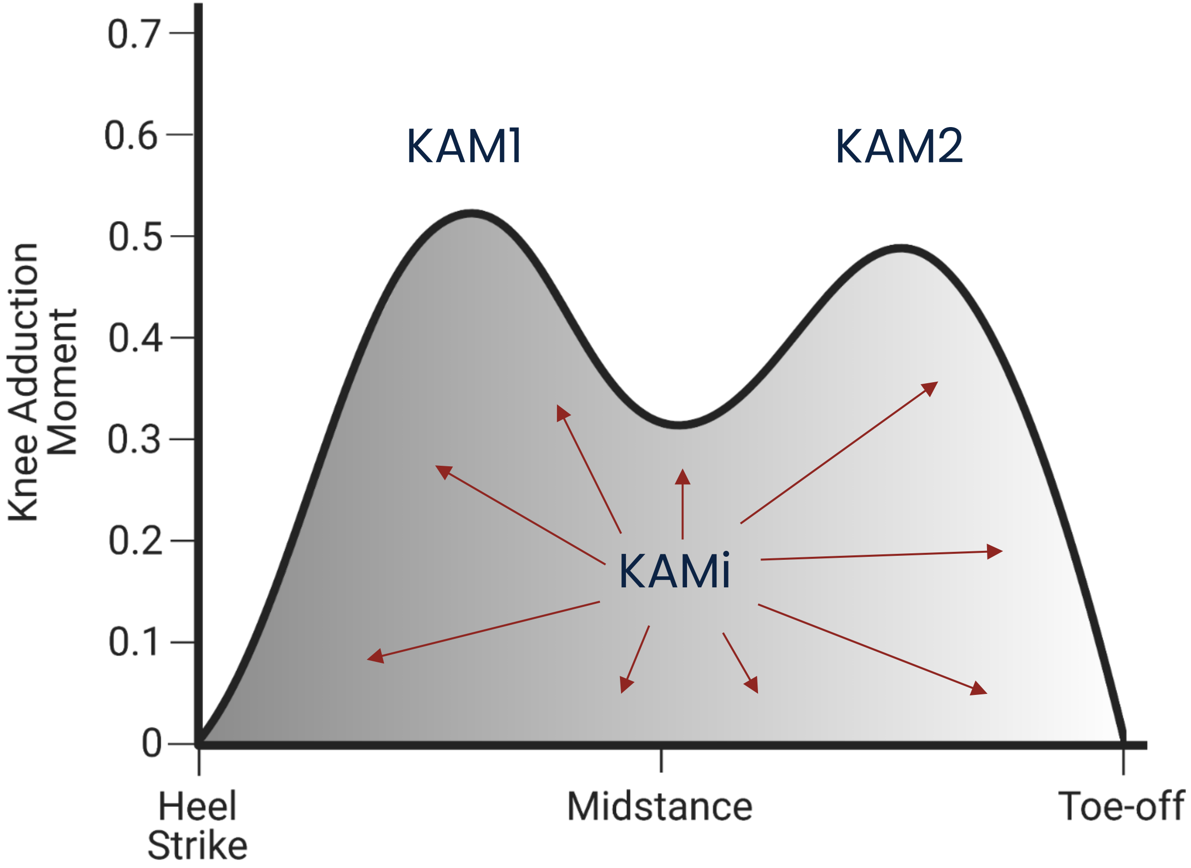




The Knee Adduction Moment (KAM)

$KAM \sim Moment\ Arm \times GRF\ vector$





How to best summarize your data?

- What is the question trying to be answered?

- Who is trying to answer the question?
  - What is their level of: expertise, time, resources to act

- Who are they trying to answer the question for?
  - What is their level of: expertise, time, resources to act

General Scheme to Reduce the Knee Adduction Moment by Modifying a Combination of Gait Variables

Julien Favre,[1,2] Jennifer C. Erhart-Hledik,[2,3,4] Eric F. Chehab,[2,4,5] Thomas P. Andriacchi[2,3,4]

Fifty-four gait trials were collected for each participant. They consisted of all combinations of modifications ($54 = 3 \times 3 \times 3 \times 2$) in progression angle (decreased, normal, and increased), step width (decreased, normal, and increased), walking speed (decreased, normal, and increased), and trunk sway (normal and increased ipsilateral sway).

Participant Experience

- Continued modification post-intervention

Positive (+)	Negative (−)
"Because it works!! I have very little pain when I modify my walk"	"Hoping to impact on a longer-term basis."
"Foot rotation has become a habit which is easy to maintain doing."	"On short walks only, not comfortable for long distances ."
"Sometimes I'm unaware I'm already doing it. Often times when I am aware I try to keep up the modification."	"Feels too awkward and very little if any noticeable difference. As well, irritates upper leg to walk with outward foot rotation for any length of time."

Where do we need to go from here?

- Understanding human movement must continue to move beyond the lab

- Biomechanical data in isolation is ineffective
  - Questionnaires, imaging and medical history, training logs, performance outcomes

- Advances in efficiencies must occur in conjunction with understanding the user experience of data

Determining the importance of your data

- What is important?

- Who gets to decide what is important?
  – Who is it important to?

- How do we find out what is important?

- How do we best visualize/convey what is important?

UX considerations

Sample → Population → Individual

- What is working well? What is not working well?
- What is the necessary level of individualization?
- How do we convey the importance and relevance of the data?
- What are the barriers and facilitators to effective and continual use?

Take home messages

- Be comfortable and deliberate with the amount and type of information necessary to guide/inform your research/clinical care/product development
  - Should differ based on question, area, presentation
- Select the tools and approaches necessary for the job
  - Consider: cost, burden, training, access, equity
  - Nothing wrong with simpler if it is effective and more accessible!
- Quantitative + qualitative is key!