50 years of ISB – a lifelong connection with sports

Sports injury biomechanics

Helen Bayne

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Sports injury biomechanics: presentation outline

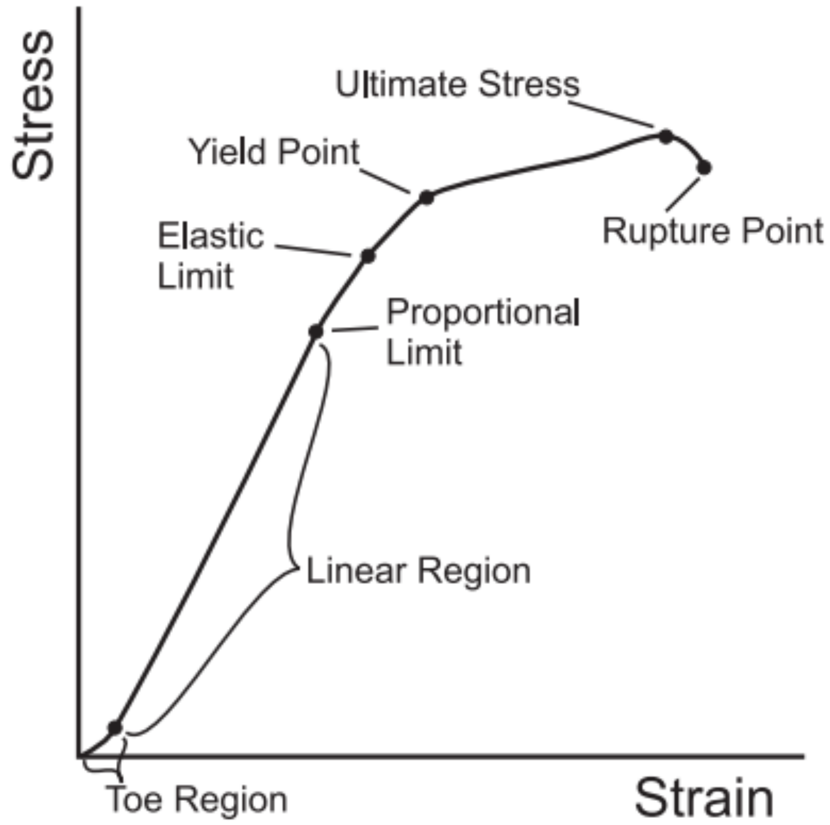
Model of injury causation

Success stories

Challenges

Opportunities

Model of injury causation



A generalized stress-strain curve for biological tissues

Whiting, W.C. and Zernicke, R.F. Biomechanics of Musculoskeletal Injury. Human Kinetics

<u>Load (L) </u>: external force applied to the structure

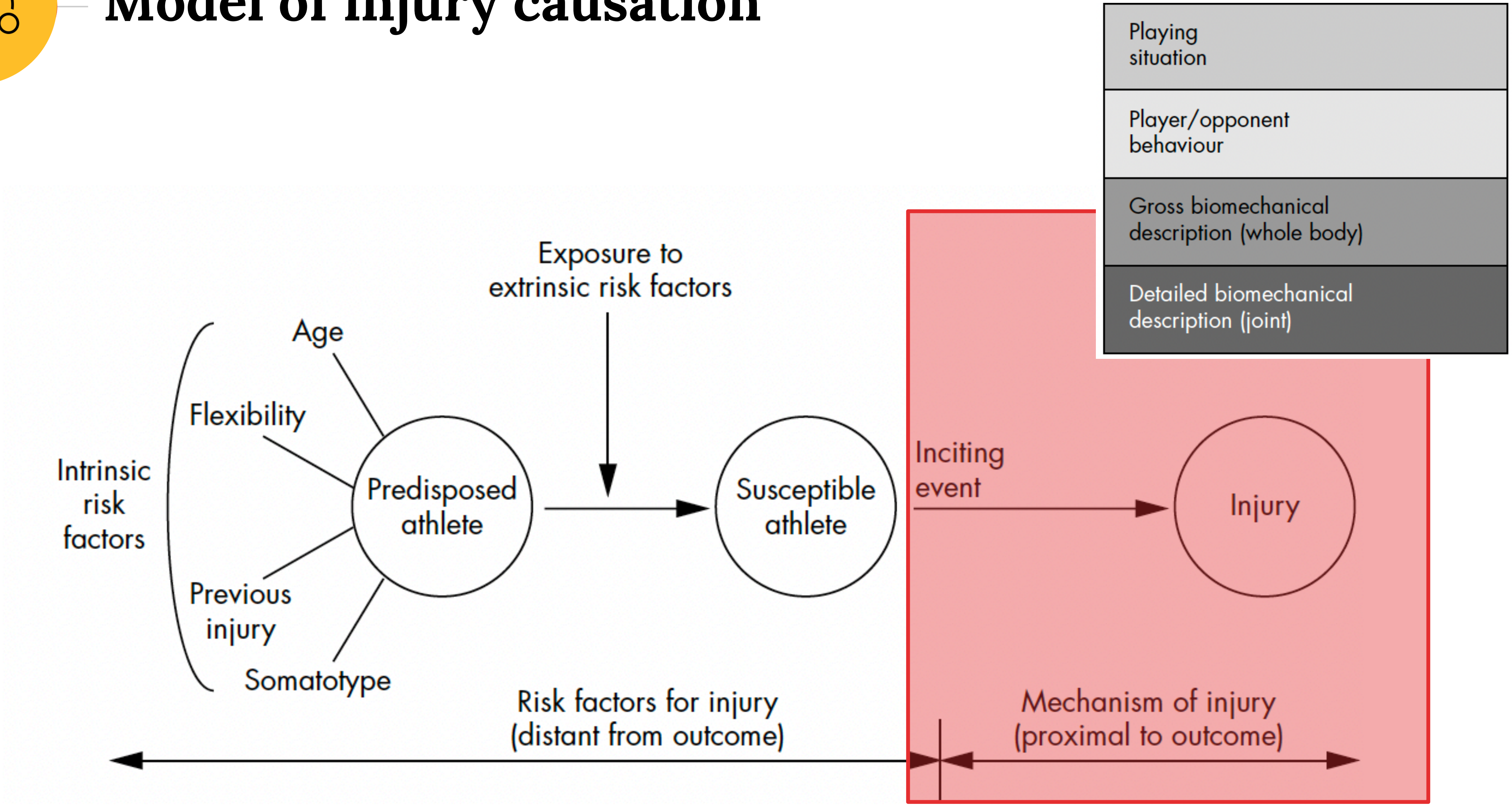
<u>Stress</u>: internal resistance to an applied load, expressed relative to cross-sectional area

<u>Strain</u>: change in length relative to the normal length

Strain (%) = (dimension change/unloaded dimension) x 100

Injury = Load > Tissue capacity

Model of injury causation



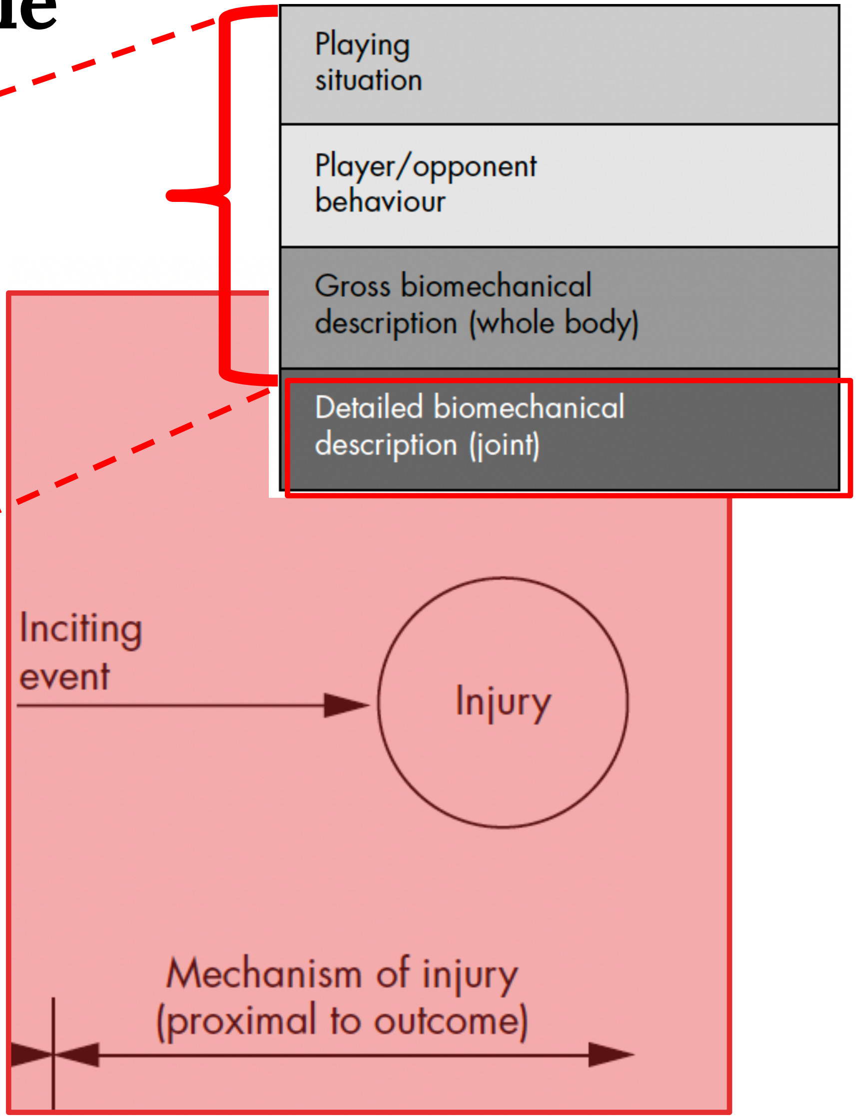
Bahr, R. and Krosshaug, T. (2005) Br J Sports Med.

Success stories: An ACL example

Side step cut

Changing direction to avoid an opponent

Plant leg during direction change

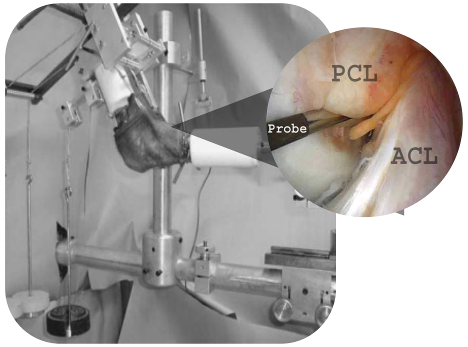


Bahr, R. and Krosshaug, T. (2005) Br J Sports Med.

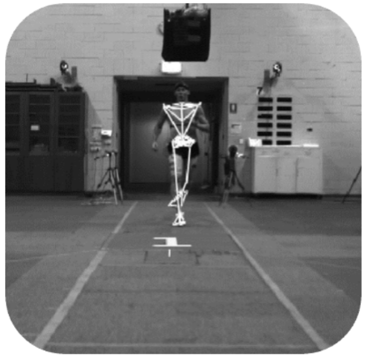
Success stories: An ACL example

- Playing situation
- Player/opponent behaviour
- Gross biomechanical description (whole body)
- Detailed biomechanical description (joint)

Cadaveric

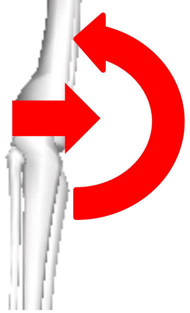


Laboratory

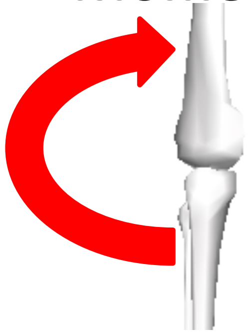


Simulation

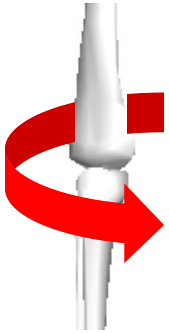
Flexion Moment

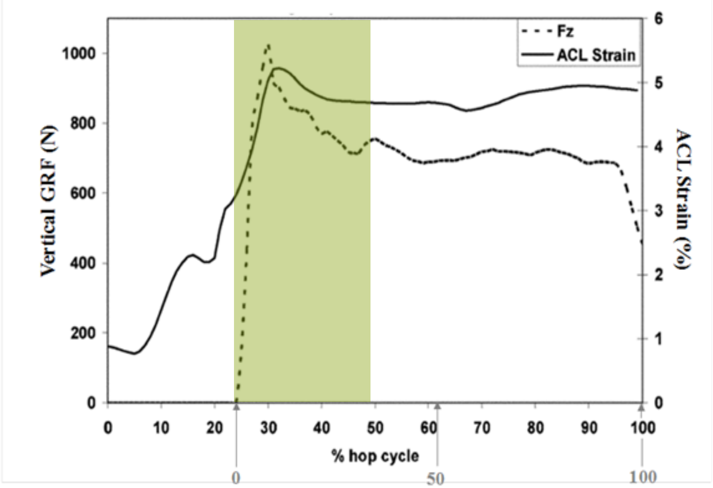


Valgus Moment



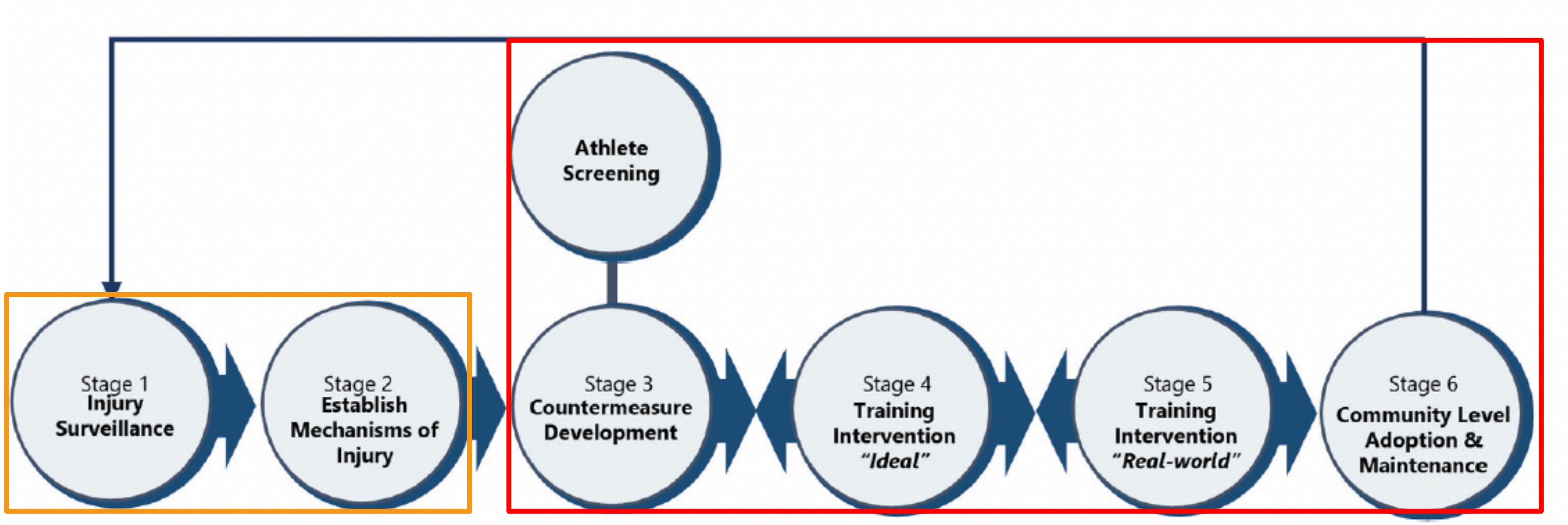
Int. Rot. Moment



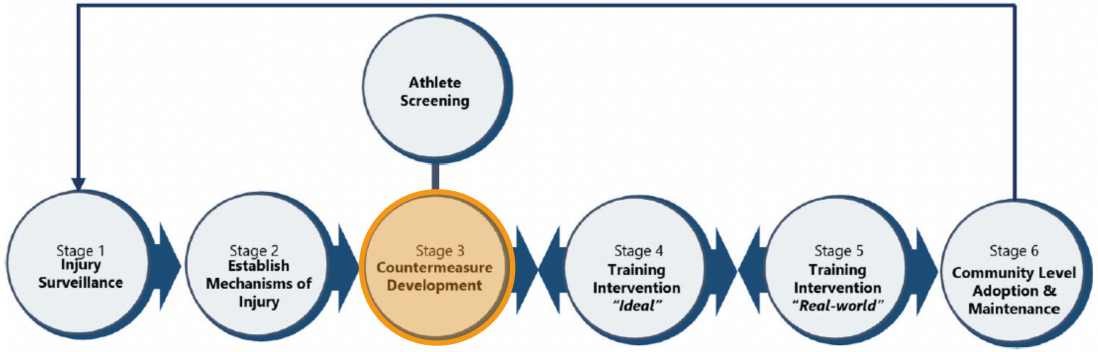


Besier et al., (2001); Cerulli et al., (2003); Donnelly et al. (2012; 2014); Markolf, et al., (1995); Mclean et al., (2004; 2006; 2008); Woo et al., (1987).
Graphic courtesy of Gillian Weir

Success stories: An ACL example



Finch, C., et al. (2006) J Sci Med Sport; Donnelly, C. J., et al. (2012) Res Sports Med; Weir, G. (2022) Sports Biomech



SPORTS BIOMECHANICS
https://doi.org/10.1080/14763141.2021.2016925
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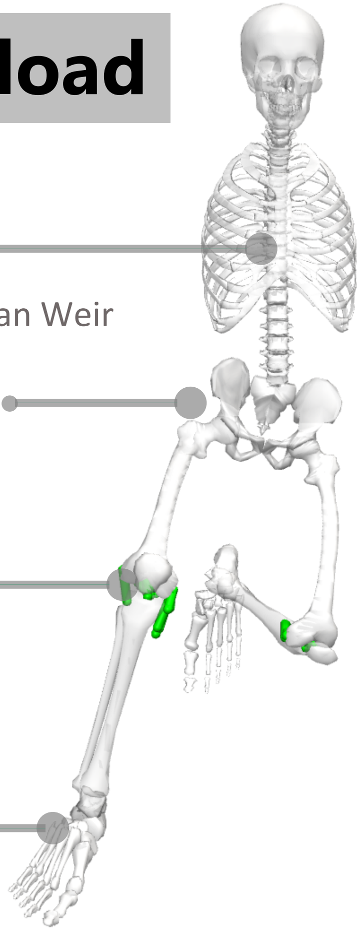
Anterior cruciate ligament injury prevention in sport: biomechanically informed approaches

Gillian Weir

Biomechanics Laboratory, University of Massachusetts, Amherst, MA, USA; School of Human Sciences, University of Western Australia, Perth, Australia

↓ external load



Upper body kinematics (trunk lateral flexion and rotation) (McLean et al., 2005; Dempsey et al., 2007; Chaudhari et al., 2005; Donnelly et al., 2012; Zazulak et al., 2012)

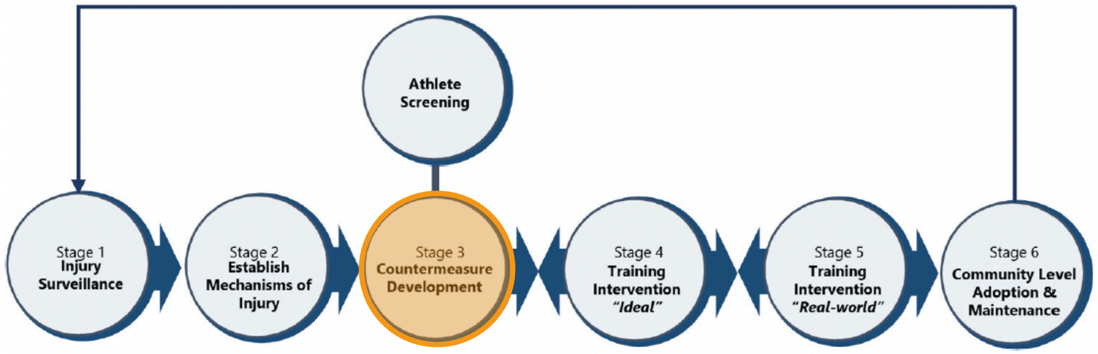
Graphic courtesy of Gillian Weir

Dynamic knee valgus posture
(Krosshaug et al., 2007; Hashemi et al., 2011)

↓ Knee flexion angle (Krosshaug et al., 2007; Hashemi et al., 2011)

Rear foot foot strike postures
(David et al., 2018; Donnelly et al., 2017)

Graphic courtesy of Gillian Weir



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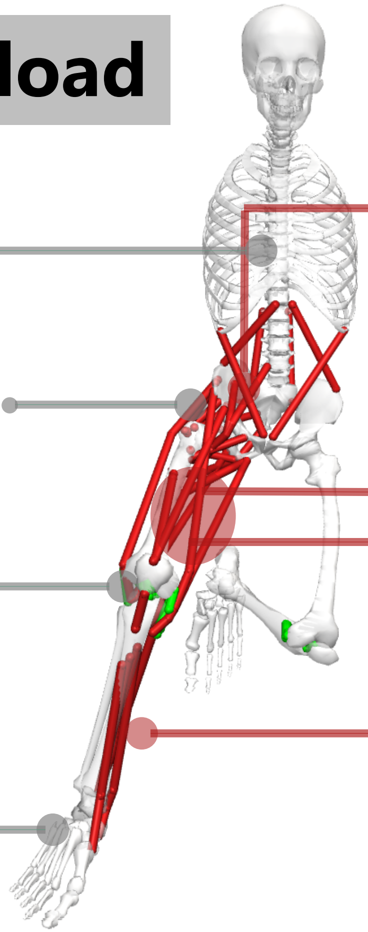
↓ external load

↑ muscle support



Upper body kinematics (trunk lateral flexion and rotation) (McLean et al., 2005; Dempsey et al., 2007; Chaudhari et al., 2005; Donnelly et al., 2012; Zazulak et al., 2012)

Dynamic knee valgus posture (Krosshaug et al., 2007; Hashemi et al., 2011)

↓ Knee flexion angle (Krosshaug et al., 2007; Hashemi et al., 2011)

Rear foot foot strike postures (David et al., 2018; Donnelly et al., 2017)

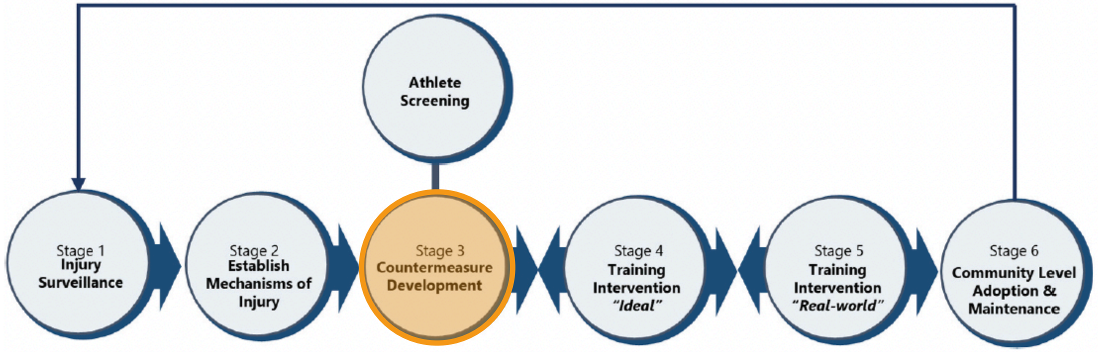
Hip external rotator muscle forces (Maniar et al., 2018)

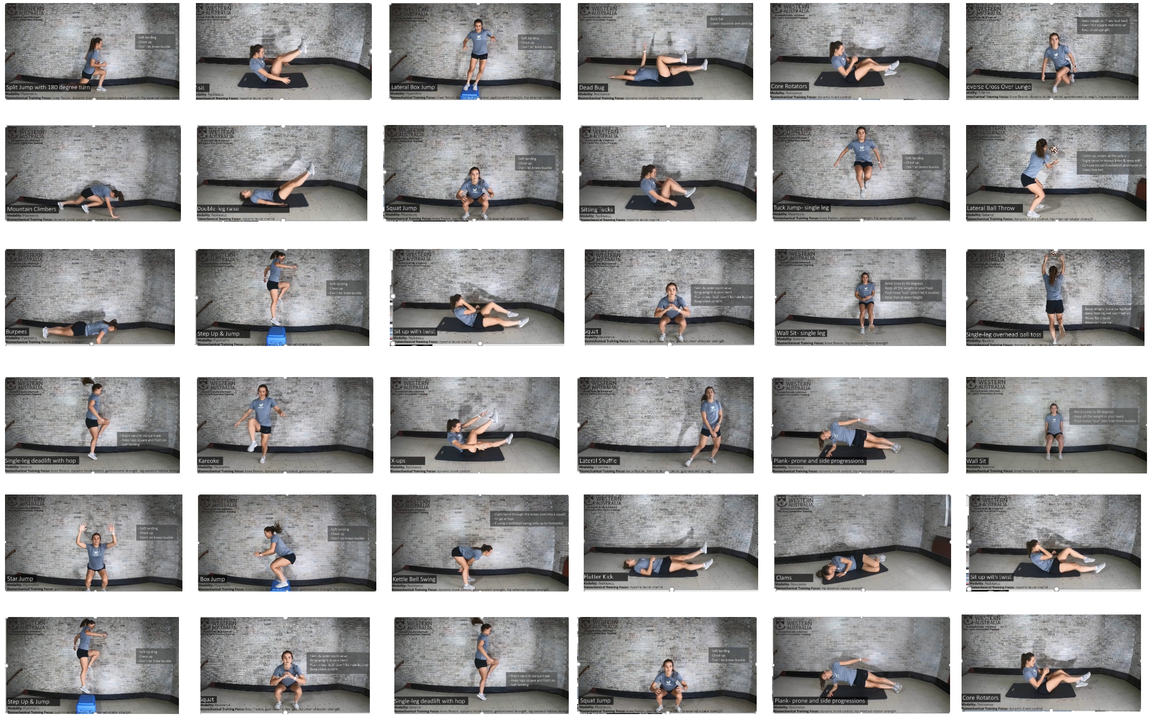
Hamstring muscle forces and strength (Maniar et al., 2018; Li, et al., 1999)

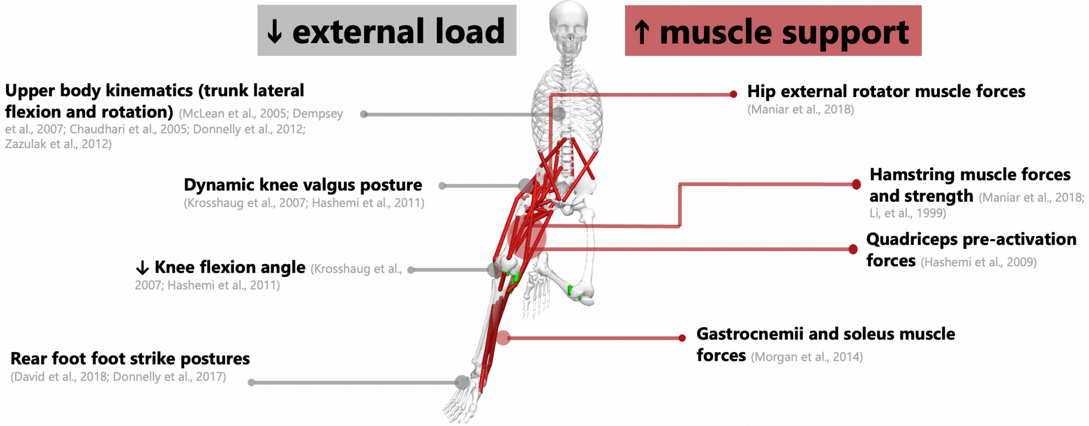
Quadriceps pre-activation forces (Hashemi et al., 2009)

Gastrocnemii and soleus muscle forces (Morgan et al., 2014)

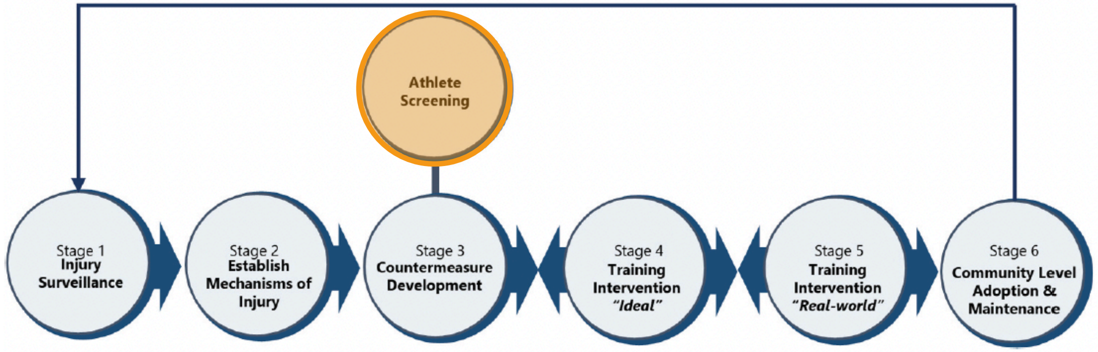
Graphic courtesy of Gillian Weir







Weir, G. (2022) Sports Biomech
Weir, G., et al. (2019) Transl J Am Coll Sports Med

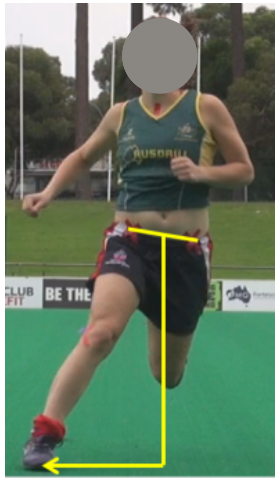


- Athlete screening
  - Based on strong relationship between the measured modifiable biomechanical factor within the screening test and ACL injury risk

Knee Flexion Angle (^{0})

Knee Flexion RoM (^{0})

Trunk Flexion RoM (^{0})



Foot Placement (cm)

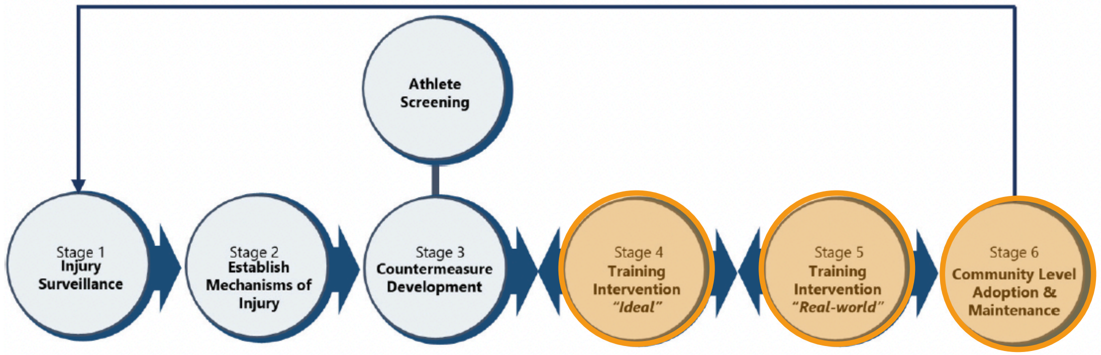
Thigh Abduction Angle (^{0})

Trunk Lateral Flexion Angle (^{0})

Knee Valgus Angle (^{0})

Frontal plane knee distance (cm)

Weir, G., et al (2018) Int J Sports Med.



Intervention stages:

- Understanding of the sporting and individual athlete behaviours context in which the interventions are to be implemented
- Potential modification of interventions to take this intervention context into account

Hockeyroos

⇩ knee valgus moments
⇧ desirable muscle activation strategies
63% ⇩ in lower limb injuries overall
Zero ACL ruptures

Finch, C., et al. (2006) J Sci Med Sport
Weir, G. (2022) Sports Biomech
Weir, G., et al. (2019) Transl J Am Coll Sports Med

Challenges

Measurement of load

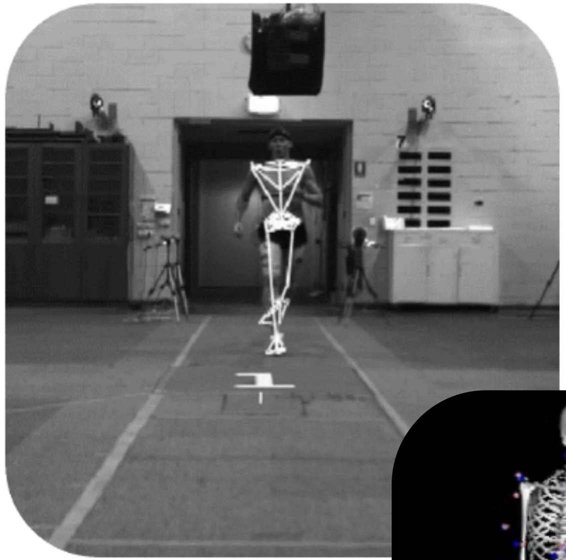
- Inverse dynamics
- Musculoskeletal modelling

<u>Limitations:</u>

Ecological validity of laboratory scenarios

Cost, time, complexity prohibits use in the field

Individualised, real-time feedback



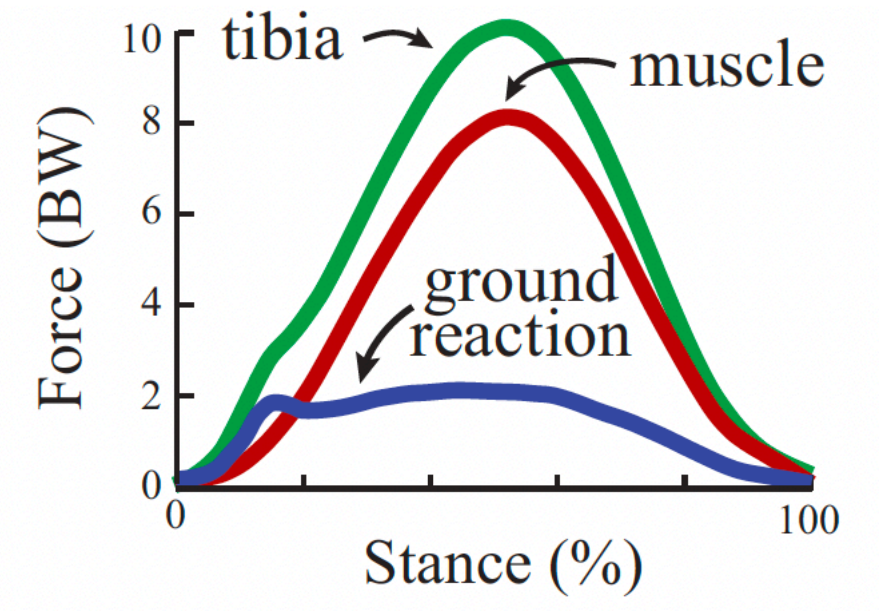
Xu, H., et al (2014) Comput Methods Biomech Biomed Engin
Besier, T., et al (2003) J Biomech

Challenges

Measurement of load

Example: Proxy measures of tibial force

- **GRF** assumed to represent tibial bone load during running, however:



RESEARCH ARTICLE

Ground reaction force metrics are not strongly correlated with tibial bone load when running across speeds and slopes: Implications for science, sport and wearable tech

Emily S. Matijevich[1]*, Lauren M. Branscombe[1], Leon R. Scott[2], Karl E. Zelik[1,3,4]

1 Department of Mechanical Engineering, Vanderbilt University, Nashville, TN, United States of America, **2** Department of Orthopaedics, Vanderbilt University, Nashville, TN, United States of America, **3** Department of Biomedical Engineering, Vanderbilt University, Nashville, TN, United States of America, **4** Department of Physical Medicine & Rehabilitation, Vanderbilt University, Nashville, TN, United States of America

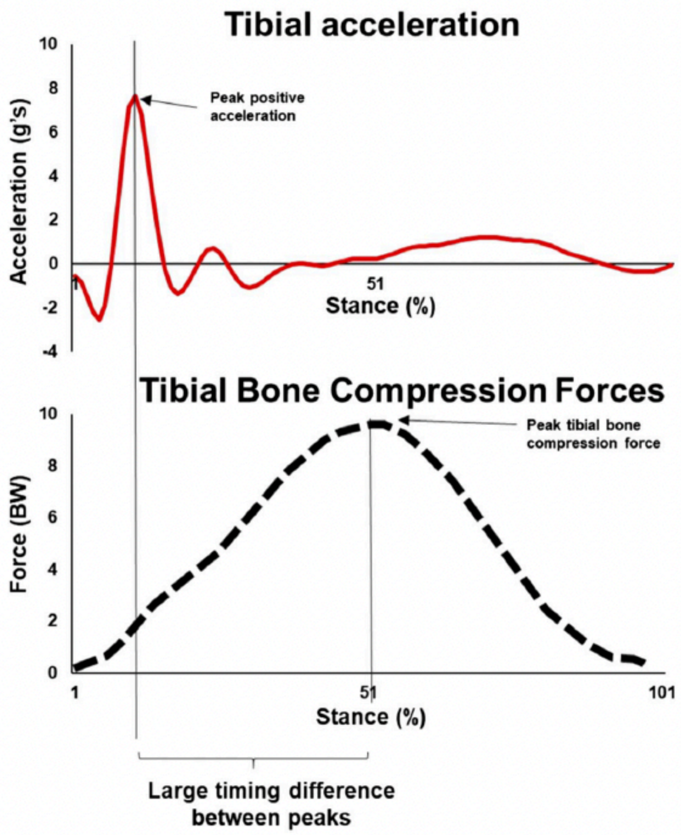
Matijevich, E., et al (2019) Plos ONE
Matijevich, E., et al (2020) Hum Mov Sco

Challenges

Measurement of load

Example: Proxy measures of tibial force

- **Wearable sensors** are appealing as accessible tools to measure correlates of load
- Tibial acceleration measured using an inertial measurement unit (IMU) worn on the lower tibia



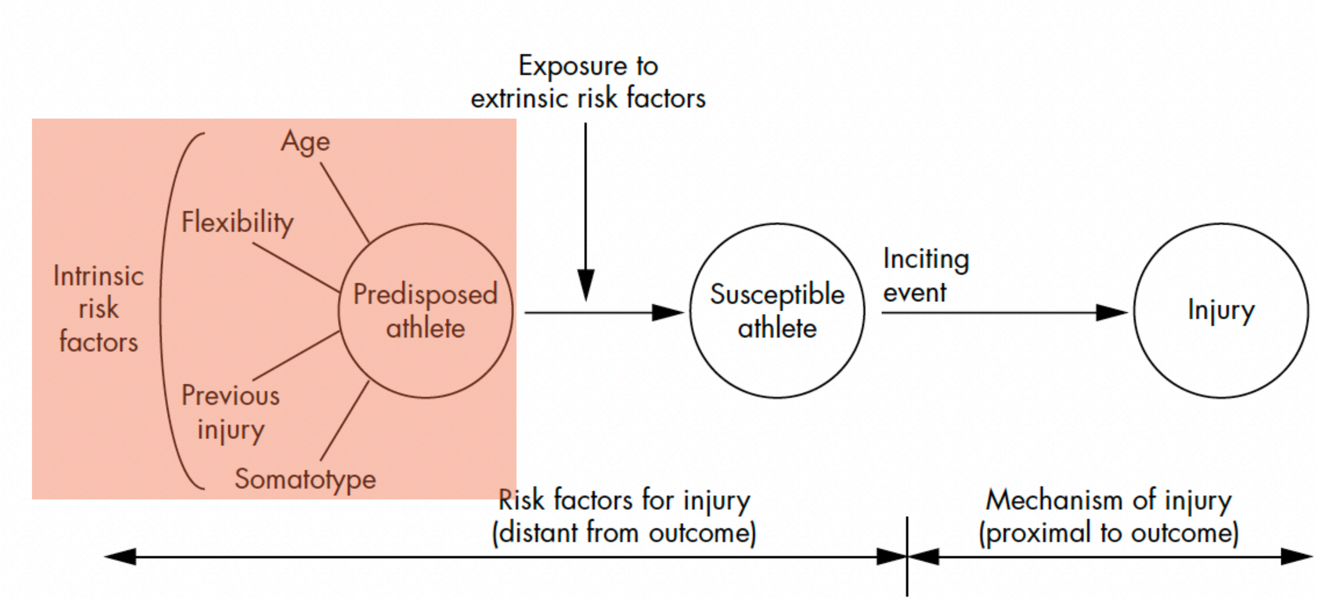
Moore, I., Will, R. (2019) Curr Sports Med Reports

Challenges

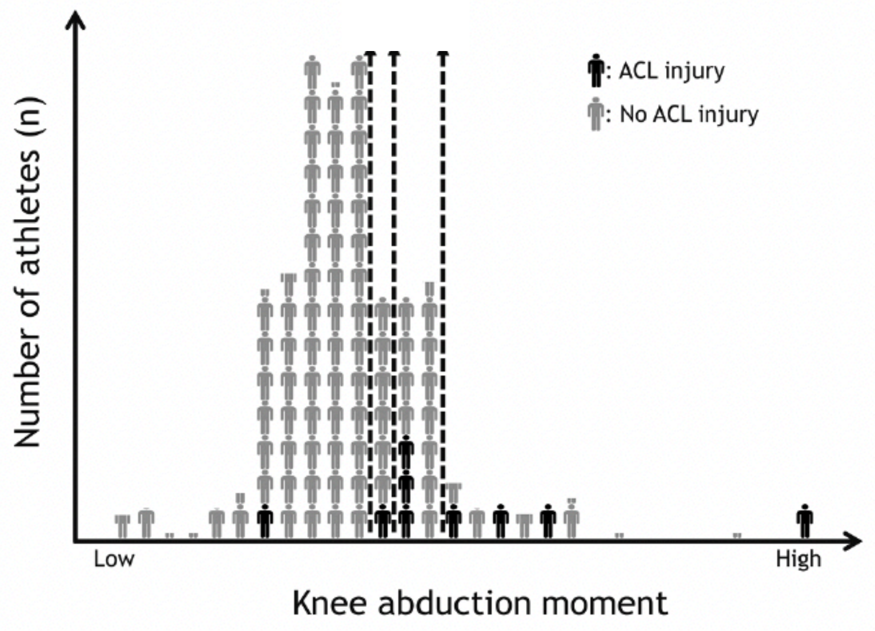
Injury = Load > Tissue capacity

Understanding tissue capacity

Intrinsic risk factors



Prospective cohort studies:
Injured vs uninjured



Bahr, R. and Krosshaug, T. (2005) Br J Sports Med
Bahr, R. (2016) Br J Sports Med

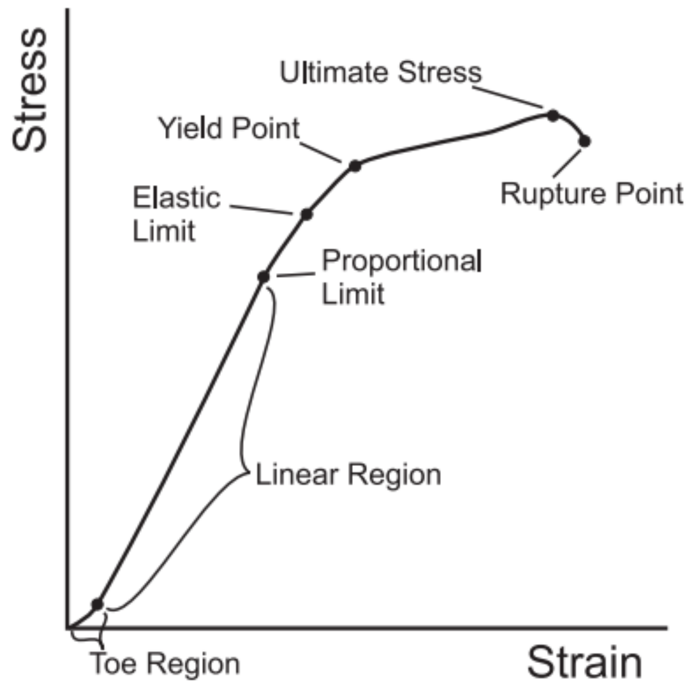
Challenges

Injury = Load > Tissue capacity

Understanding tissue capacity

Individualised responses to load

- Stress and strain affected by tissue geometry and material properties
- For example, in bone:
  - Microarchitecture affects the stress concentrations when load is applied
  - Lower bone mineral density increases bone stress injury risk



Loundagin, L. et al (2020) Bone Reports
Loundagin, L. et al (2021) Bone
Alway, P., et al (2022) J Sci Med Sport

Opportunities

JOURNAL OF SPORTS SCIENCES
https://doi.org/10.1080/02640414.2022.2107816

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SPORTS MEDICINE AND BIOMECHANICS

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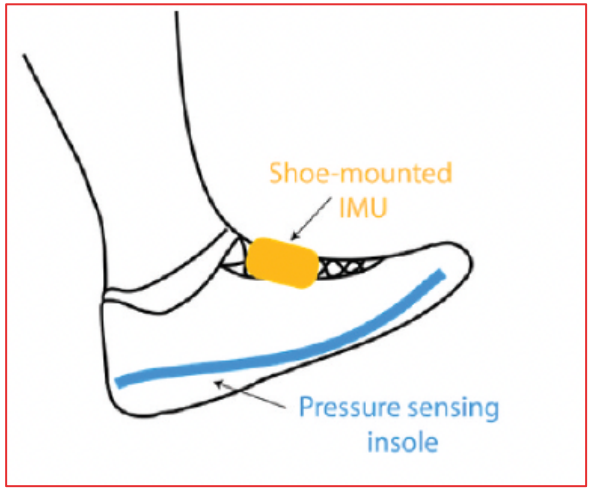
Tibial bone forces can be monitored using shoe-worn wearable sensors during running

L.J Elstub[a*], C.A Nurse[a*], L.M Grohowski[a], P. Volgyesi[b], D.N Wolf[a] and K.E. Zelik[a,c,d]

[a]Department of Mechanical Engineering, Vanderbilt University, Nashville, Tennessee, United States; [b]Institute for Software Integrated Systems, Vanderbilt University, Nashville, Tennessee, United States; [c]Department of Biomedical Engineering, Vanderbilt University, Nashville, Tennessee, United States; [d]Department of Physical Medicine & Rehabilitation, Vanderbilt University, Nashville, Tennessee, United States

Wearable sensors

- Machine learning algorithms to determine critical signals needed to predict tibial bone force
- GRF estimates from pressure sensing insole + foot orientation angle from shoe-mounted IMU
- Tibial bone force prediction with <6% error compared to lab-based inverse dynamics and musculoskeletal modelling procedures



Elstub, L., et al (2022) J Sports Sci

Opportunities

JOURNAL OF SPORTS SCIENCES
https://doi.org/10.1080/02640414.2022.2107816

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SPORTS MEDICINE AND BIOMECHANICS

Tibial bone forces can be monitored using shoe-worn wearable sensors during running

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iversity, Nashville, Tennessee, United States; [b]Institute for Software Integrated Systems,
es; [c]Department of Biomedical Engineering, Vanderbilt University, Nashville, Tennessee,
abilitation, Vanderbilt University, Nashville, Tennessee, United States

Wearable sensor

- Machine learnin
needed to pred
- GRF estimates f
orientation angl
- Tibial bone forc
based inverse d
procedures

Karl Zelik
@KarlZelik

5 years ago I was confused & concerned about how forces/impacts were being (mis)used in running #biomechanics & wearable tech to assess risks.

Now we've validated a new wearable capability that overcomes these issues.

8 things I learned along the way...

Journal of Sports Sciences @JSportsSci · Aug 22

🚨 First empirical evidence that shoe-worn wearable sensors combined with a trained ML algorithm can monitor tibial bone forces during running.

Applications may include sports #biomechanics, athlete management, or prevention of bone stress injuries.

tandfonline.com/doi/abs/10.108...

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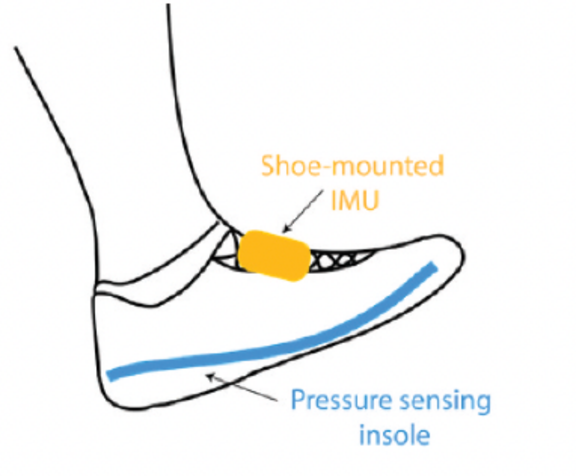


Elstub, L., et al (2022) J Sports Sci

Opportunities

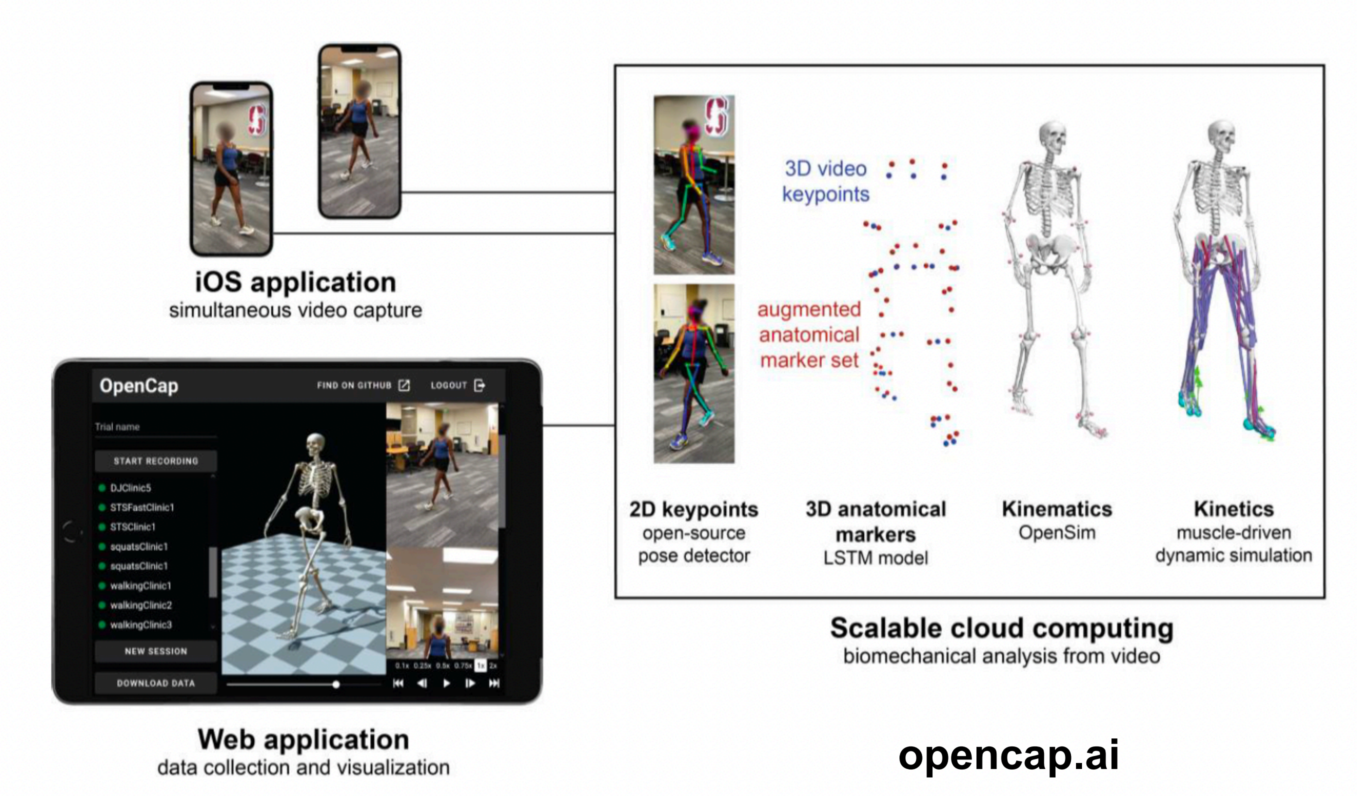
Video-based analyses

bioRχiv

OpenCap: 3D human movement dynamics from smartphone videos

Scott D. Uhlrich, Antoine Falisse, Łukasz Kidziński, Julie Muccini, Michael Ko, Akshay S. Chaudhari, Jennifer L. Hicks, Scott L. Delp

doi: https://doi.org/10.1101/2022.07.07.499061



Boswell, M., et al (2021); Song, S., et al (2021); Kidzinski, L., et al (2020); Ulrich, S., et al (2020); Kidzinski, L., et al (2019); Halilaj, E., et al (2018)

Conclusion

Injury occurs when applied load exceeds the tissue capacity to withstand the load

Biomechanical knowledge is fundamental in understanding injury mechanisms, which underpins the development of countermeasures

Framework for injury risk reduction should also consider targeting most at-risk athletes and steps to improve programme adoption and compliance

Current challenges:

- Accessible measures of joint/tissue load
- Incorporating individual intrinsic factors in injury causation models

Opportunities:

- Technology and advances in data science enabling translation from the lab to the field and handling of multiple data sources

Thank you

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