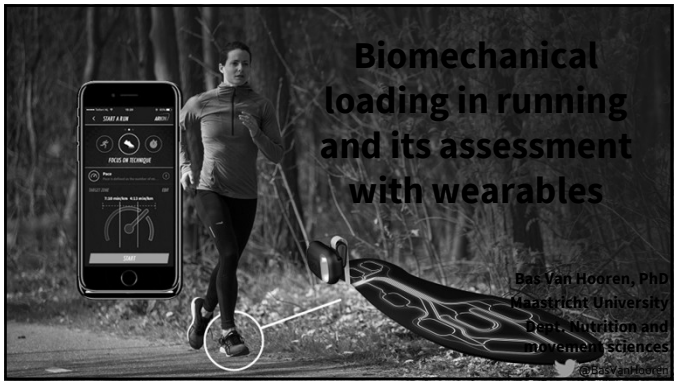


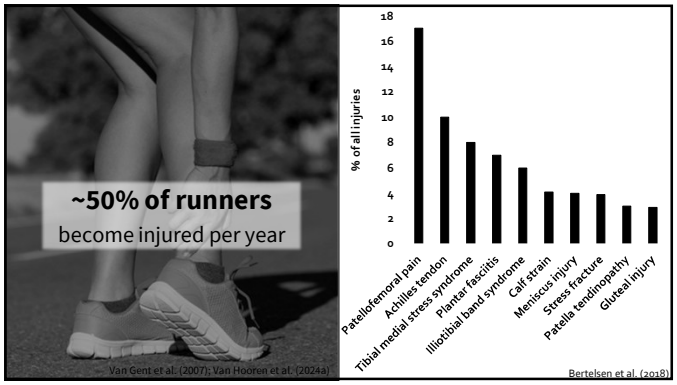
2

There are over **100 million runners** in Europe and the US alone

Strong evidence for **health benefits** of running

Brondvold et al. (2017); Oja et al. (2015)

5



Van Gent et al. (2007); Van Hooren et al. (2024a)

Bertelsen et al. (2018)

6

Repetitive loading leads to microdamage and running injuries

Schleicher et al. (2021)

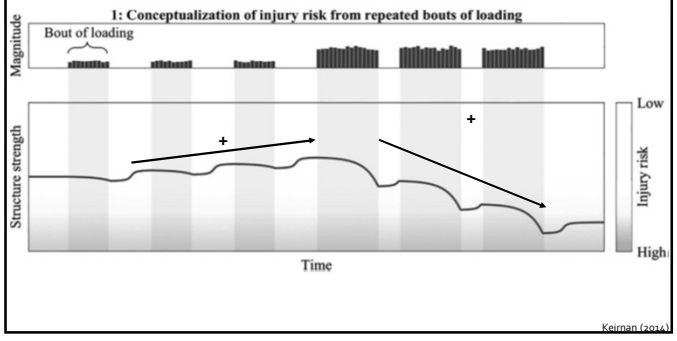
Load determined by

- Body mass
- Running speed
- Running technique
- Running shoes
- Etc.

Bertelsen et al. (2017); Edwards (2018)

7

Repetitive loading leads to microdamage and running injuries



Keiran (2014)

8

Quantification of loading in the lab

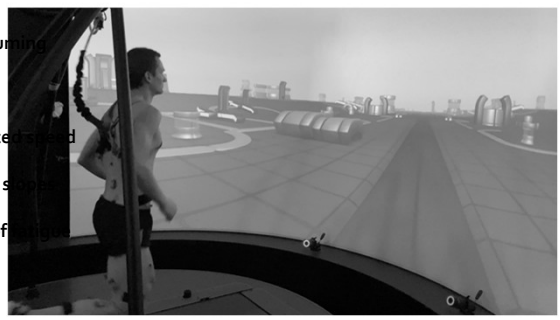
Time consuming

Expensive

Only selected speed

No/limited steps

No effect of fatigue



9

Wearables: measuring external loads

10

Wearable metrics may not reflect tissue loading

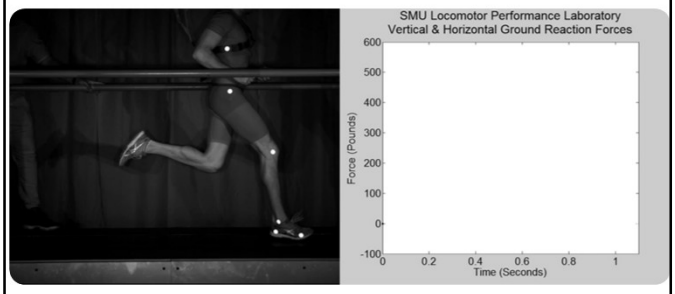
*"…a very **weak** (**r = 0.04**) and non-significant correlation between PTA and maximum tibial compression forces"*

PTA might reflect forces from outside the body, but likely not the compressive force from muscles on the tibial bone

Zandbergen et al. (2023)

11

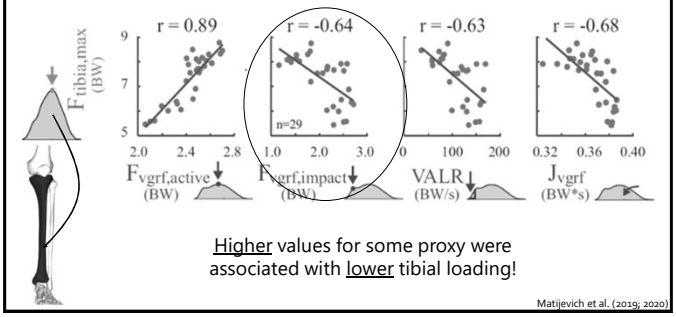
Impact peak, loading rate and running



Idea is that higher impact peaks and loading rates increase injury risk

12

External metrics do not always reflect internal loading

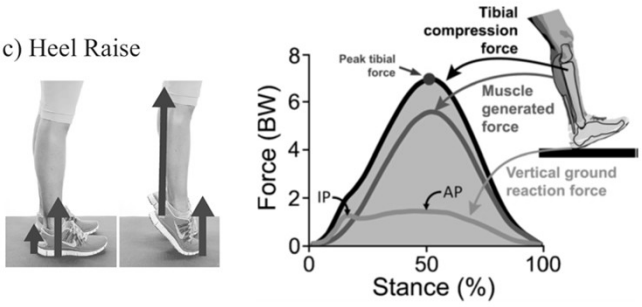


Higher values for some proxy were associated with lower tibial loading!

Matijevich et al. (2019, 2020)

13

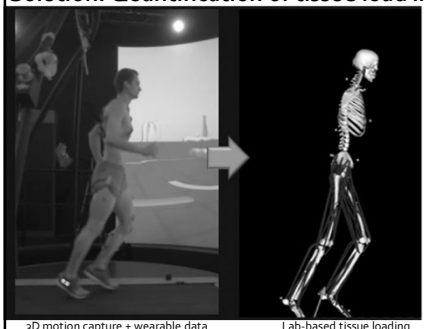
Muscle forces contribute more to tissue load then external force



Matijevich et al. (2019)

14

Solution: Quantification of tissue load in the lab



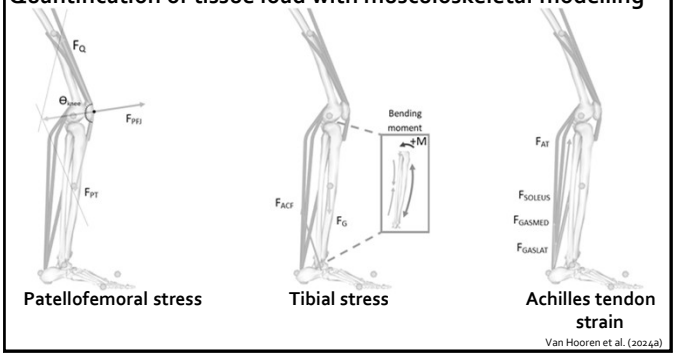
Wide variety of conditions

- Speeds from 2.78-5 m/s
- Uphill and downhill running (-6 to +6 deg)
- Reduced and increased cadence
- Forward trunk lean

Van Hooren et al. (2024a,b)

15

Quantification of tissue load with musculoskeletal modelling

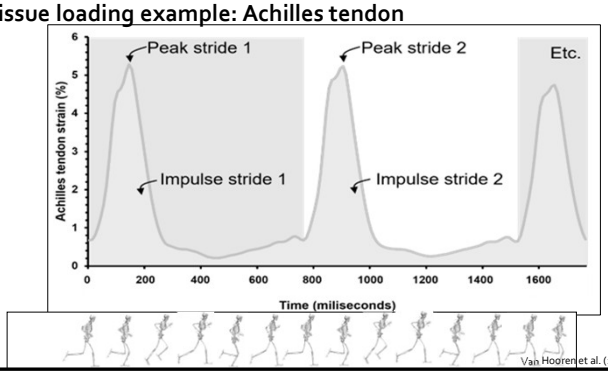


Patellofemoral stress | Tibial stress | Achilles tendon strain

Van Hooren et al. (2024a)

16

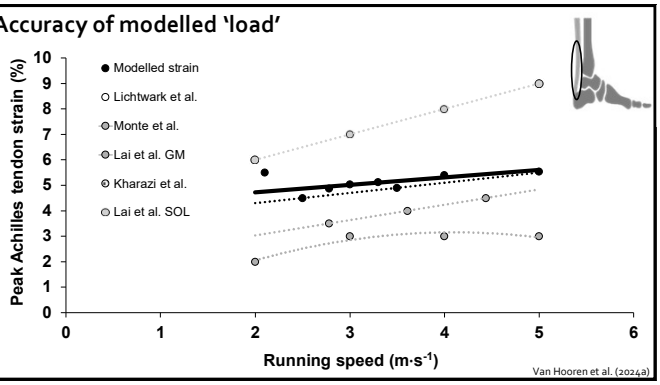
Tissue loading example: Achilles tendon



Van Hooren et al. (2024a)

17

Accuracy of modelled 'load'



Van Hooren et al. (2024a)

18

Load vs damage

Higher loads result in much more damage

1 x 1000 kg

1000 kg load
Accumulated
Huge damage

10.000 x 0.1 kg

1000 kg load
Accumulated
Minimal damage

Van Hooren et al. (2024a)

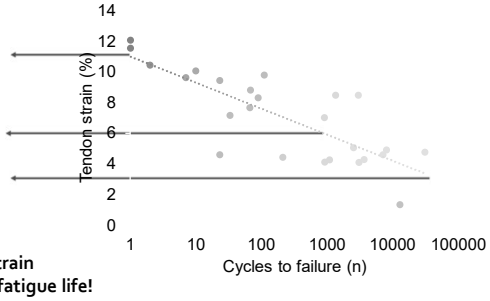
19

High strain is more damage than low strain applied often

13%: Immediate failure

6%: 1400 cycles before failure

3%: 93000 cycles before failure

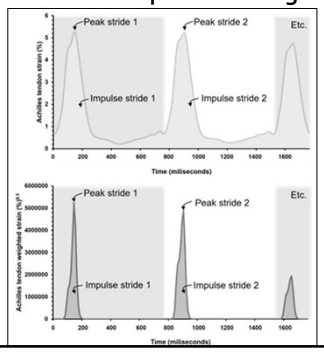


50% reduction in strain
6600% increase in fatigue life!

Wren et al. (2003)

20

Accounting for this relationship in modelling



Weighted impulse

Higher values have more importance

Van Hooren et al. (2024a)

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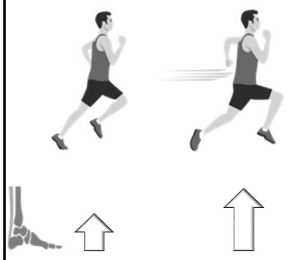
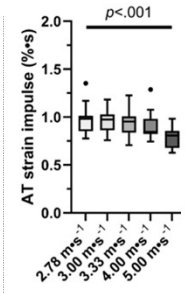
Example load vs damage





Impulse **decreases** with faster running speeds

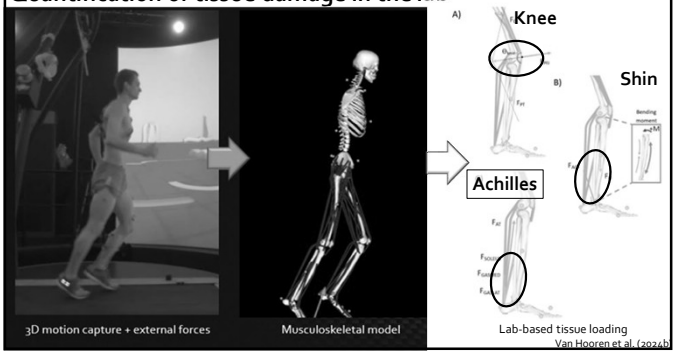
Misguides on injury risk!

McCrorryet al. (1999)

Van Hooren et al. (2024a)

22

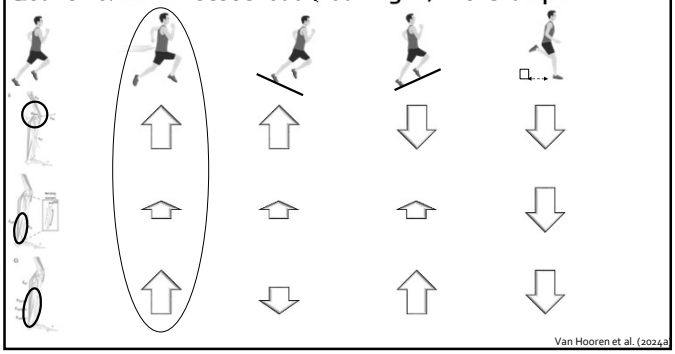
Quantification of tissue damage in the lab



Van Hooren et al. (2024b)

23

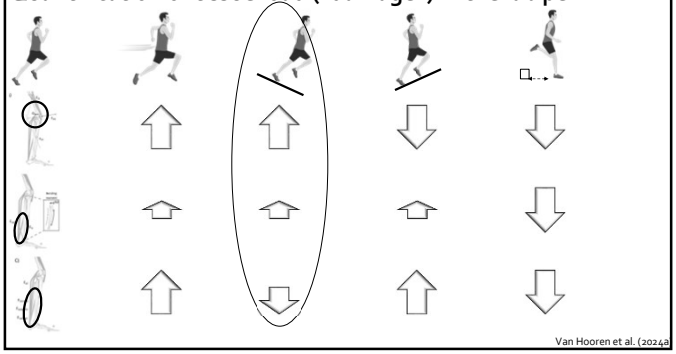
Quantification of tissue load ("damage") in the lab per km



Van Hooren et al. (2024a)

24

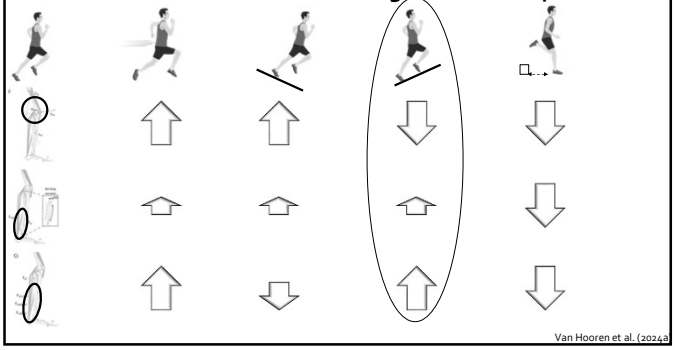
Quantification of tissue load ("damage") in the lab per km



Van Hooren et al. (2024a)

25

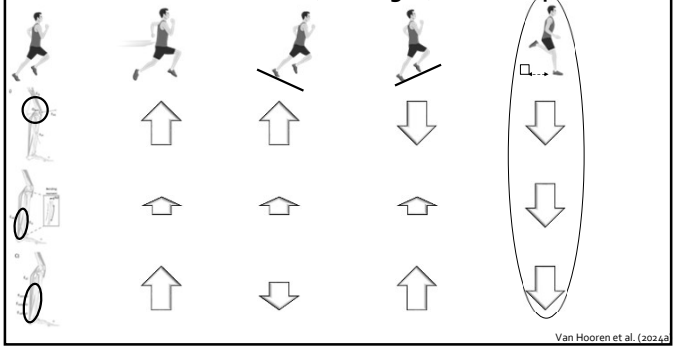
Quantification of tissue load ("damage") in the lab per km



Van Hooren et al. (2024a)

26

Quantification of tissue load ("damage") in the lab per km



Van Hooren et al. (2024a)

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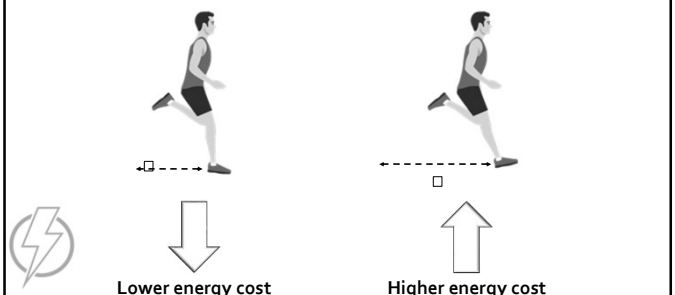
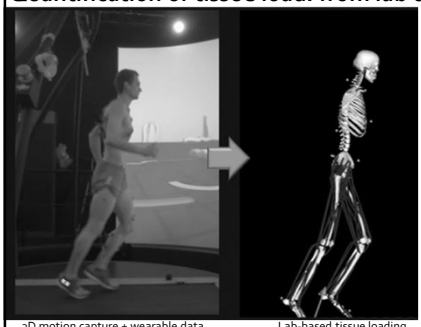
Reducing step length may improve running economy



Van Hooren et al. (2024d)

28

Quantification of tissue load: from lab to the field

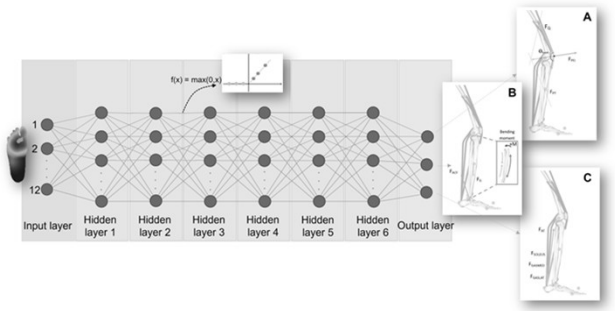


3D motion capture + wearable data | Lab-based tissue loading

Van Hooren et al. (2024b)

29

Quantification of in-field tissue load with machine learning



Van Hooren et al. (2024b)

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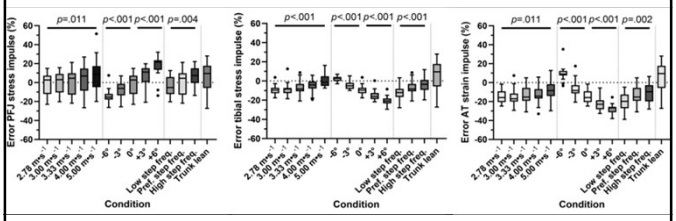
Accuracy of predicted 'load' impulses



-1.95% -7.37% -12.8%

Relative error of -13 to -2% across a wide variety of conditions and structures

Van Hooren et al. (2024b)

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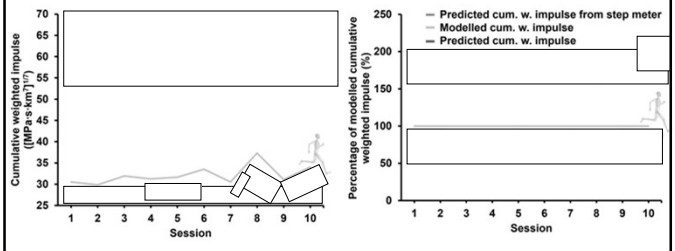
Accuracy cumulative damage



Wearable captures 'damage' much better than existing methods, but not perfectly

Van Hooren et al. (2024b)

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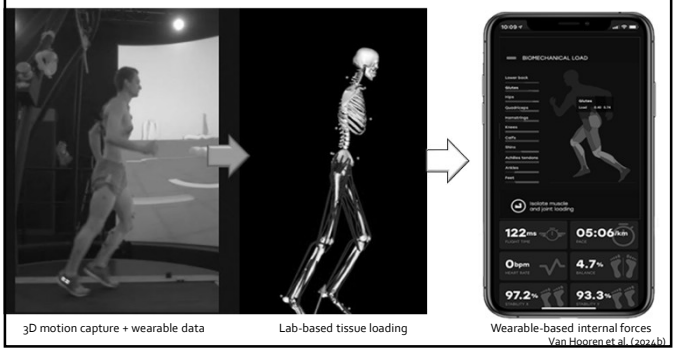
Quantification of tissue load: from lab to the field



3D motion capture + wearable data | Lab-based tissue loading | Wearable-based internal forces

Van Hooren et al. (2024b)

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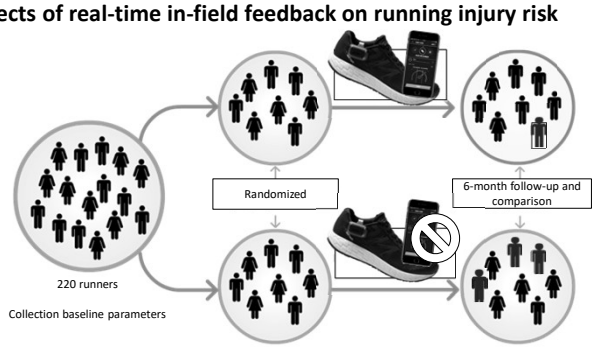
Effects of real-time in-field feedback on running injury risk



Van Hooren et al. (2024c)

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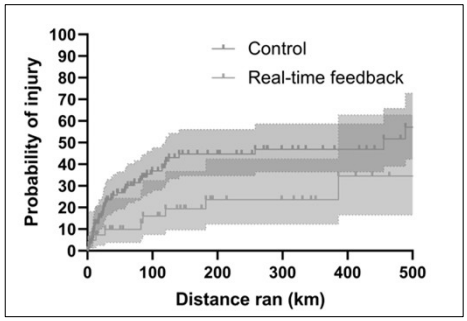
Lower injury risk when receiving feedback



Van Hooren et al. (2024c)

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Wearable-based feedback significantly reduced injury risk

Van Hooren et al. (2024c)

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Challenges

1. Assumptions about tissue properties
   - Similar tendon stiffness
   - Similar tibial cross-sectional area
   - Sex-specific PFJ contact area
2. Assumption about optimal muscle activation strategy
   - What if someone has an injury?
   - What is someone gets fatigued?
3. Very limited data on time required for tissue repair after given load
   - How long recovery is required?

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Potential solutions

1. Assumptions about tissue properties
   - Tendon stiffness → wearable US
   - Tibial cross-sectional area → SSM

2. Assumption about optimal muscle activation strategy
   - What if someone has an injury? → wearable EMG?
   - What is someone gets fatigued? → wearable EMG?

3. Very limited data on time required for tissue repair after given load
   - How long recovery is required? → Modelling?

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Key-points / conclusions

Mechanical loading is an important factor in the development of running injuries

External loading metrics do not always accurately reflect internal tissue loading (careful with wearables!)

Internal (tissue) loading can be quantified using wearables and machine learning

Future developments are required to further individualize the estimated tissue loads

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Wearable technology: current (biomechanical) applications

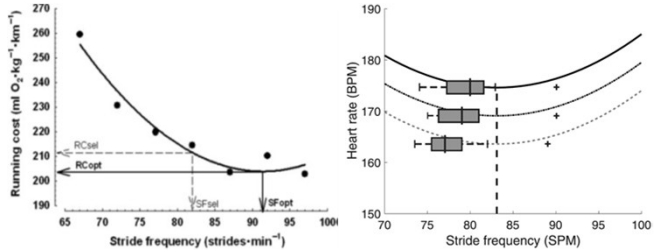
Often measure 'simple' outcomes such as contact time, stride frequency, vertical displacement

These outcomes *do* have *some* relevance for injury prevention and performance enhancement

Van Hooren et al. (2019)

40

Wearable technology: optimizing performance



Ruiter et al. (2014); Van Oeveren et al. (2017)

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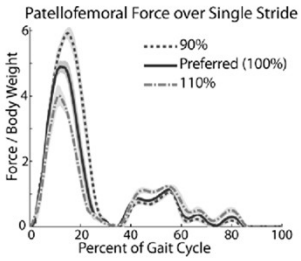
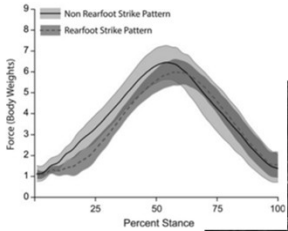
Wearable technology: reducing injury risk



Lenhart et al. (2014); Ten Braake et al. (submitted); Willy et al. (2016)

42

Wearable technology: reducing injury risk (2)



Higher AT force with non-rearfoot strike

Almonroeder et al. (2013); Barton et al. (2016)

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