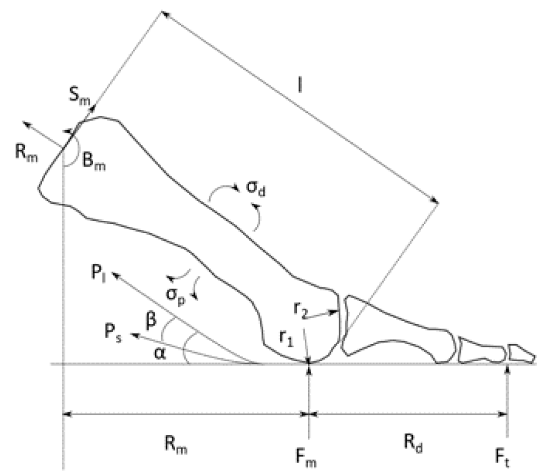
Estimating bone loading during physical activity: where do we go next?

Hannah Rice



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Estimating bone loading during physical activity: where do we go next?

- Bone stress injuries
- Identification of risk factors
- Internal loading
- Participant-specificity
- Real-time and real-world
- Validation

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Running Overuse Injuries

- Overall incidence 19% – 79% [1]
- 2.5 – 33.0 injuries per 1000 hours of running [2]
- Bone stress injuries can be particularly problematic:
  - several months of time loss[3]
  - recurrence [4,5]

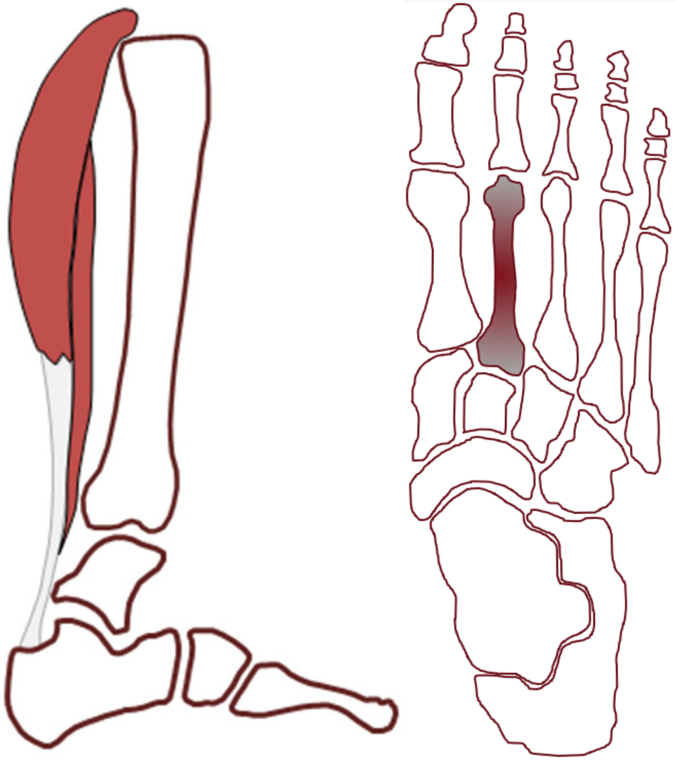
1. Van Gent et al.,2007; 2. Videbæk et a., 2015; 3. Wood et al., 2014; 4. Milgrom et al., 1985, Giladi et al., 1986
1,2, Retrieved from Willwacher et al., 2022

Bone Stress Injuries

- Bone stress injuries are a continuum of injuries [1]
  from bony microfracture to visible cortex fracture
- Stress fractures are the most serious
- up to 30% of running-related injuries [2]

1. Diehl et al., 2006; 2. Robertson & Wood, 2017;

Bone Stress Injuries



- tibia is the most common site of stress injury [1]
- followed by second and third metatarsals [2,3,4,5]

1. Wood et al., 2014; 2. Bennell et al., 1996; 3. Fetzer & Wright, 2006; 4. Gross & Bunch, 1989; 5. Iwamoto & Takeda, 2003.

Bone Stress Injuries

- Repetitive loading can lead to microdamage accumulation [1,2]
- This is a normal response to bone loading and can be beneficial [3]
- But excessive accumulation can impair bone properties [4], and increase SF risk [5].

1. Burr et al., 1997; 2. Warden et al., 2014; 3. Frost, 1994; 4. Burr et al., 1998; 5. Burr et al., 2011

Identifying risk factors for bone stress injury

What can we do?

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Prospective study of injury in Royal Marines recruits

Nunns et al., 2016; Rice at al., 2017; Dixon et al., 2019

Injuries by site in RM recruits (% of all injuries):

MSF = 11.4%
TSF = 8.3%

Median recovery time:

MSF = 32.5 weeks
TSF = 23 weeks

(Munnoch, 2008)

Prospective study of injury in Royal Marines recruits

- 1065 male recruits
- 32 week training programme

Aim: to identify biomechanical gait characteristics during barefoot running that may be associated with increased risk of a lower limb injury during Royal Marines training.

Nunns et al., 2016; Rice at al., 2017; Dixon et al., 2019

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Prospective study of injury in Royal Marines recruits

- anthropometrics
- kinematics
- plantar pressure
- passive range of motion

- barefoot running at 3.6 $m.s^{-1}$

Nunns et al., 2016; Rice at al., 2017; Dixon et al., 2019

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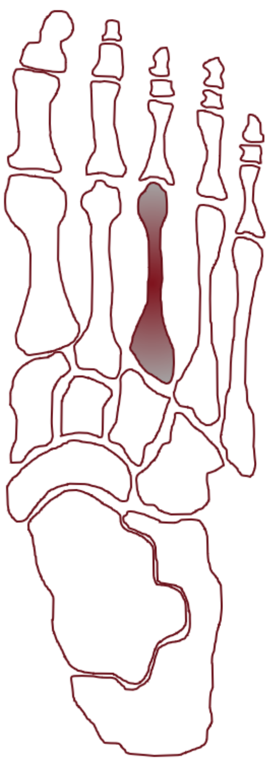
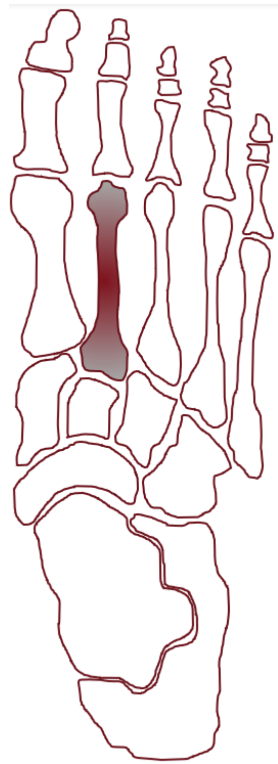
Injury Outcomes

419 (39.3%) completed training at the first attempt injury-free

14 (1.3%)
MT3 SF



7 (0.7%)
MT2 SF



10 (0.9%)
tibial SF

Nunns et al., 2016; Rice at al., 2017; Dixon et al., 2019

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Tibial stress fracture

Four variables associated with increased risk of TSF

- ↓ BMI
- ↓ Bimalleolar breadth
- ↓ Tibial rotation
- ↑ Peak heel pressure

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Tibial stress fracture

Lower BMI associated with increased risk

one unit ↓ associated with 79% ↑ risk

Lower bimalleolar breadth associated with increased risk

one mm ↓ associated with 37% ↑ risk

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Tibial stress fracture

Lower tibial internal rotation ROM associated with increased risk

1°↓ associated with 28% ↑ risk

Greater peak heel pressure associated with increased risk

1 N.cm^{-2} ↑ associated with 25% ↑ risk

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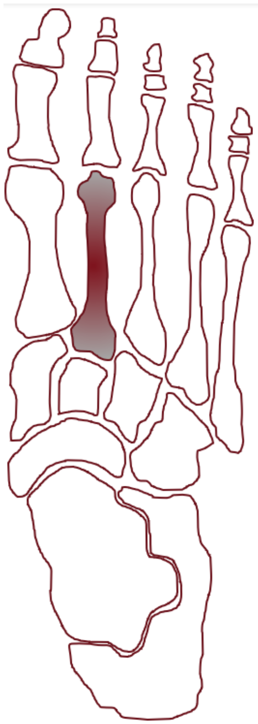
Challenges with approach of identifying risk factors



Sample size requirements

Injury mechanisms for different sites

Retrospective study design

Focus on single variables

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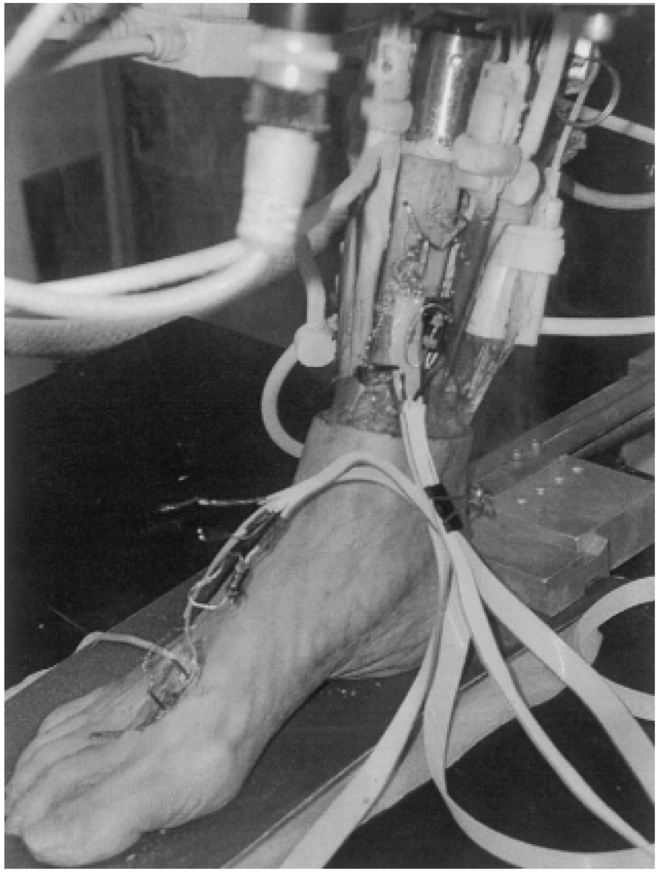
What is happening internally?

External vs internal loading



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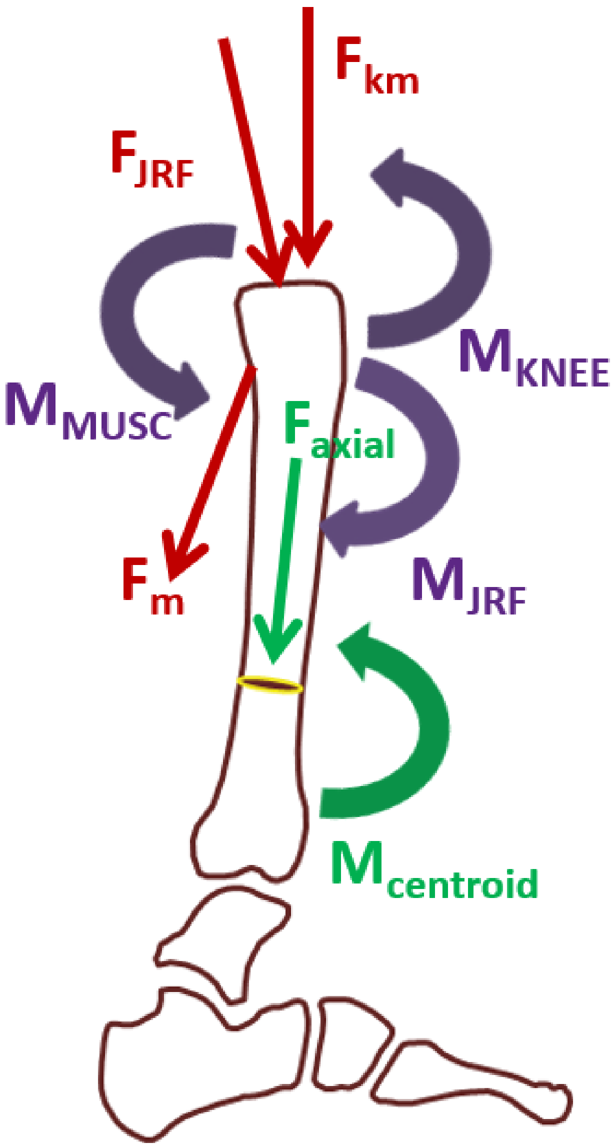
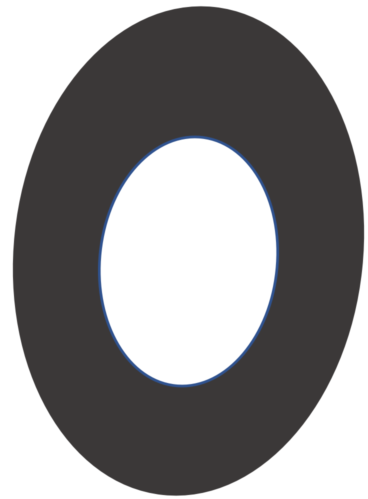
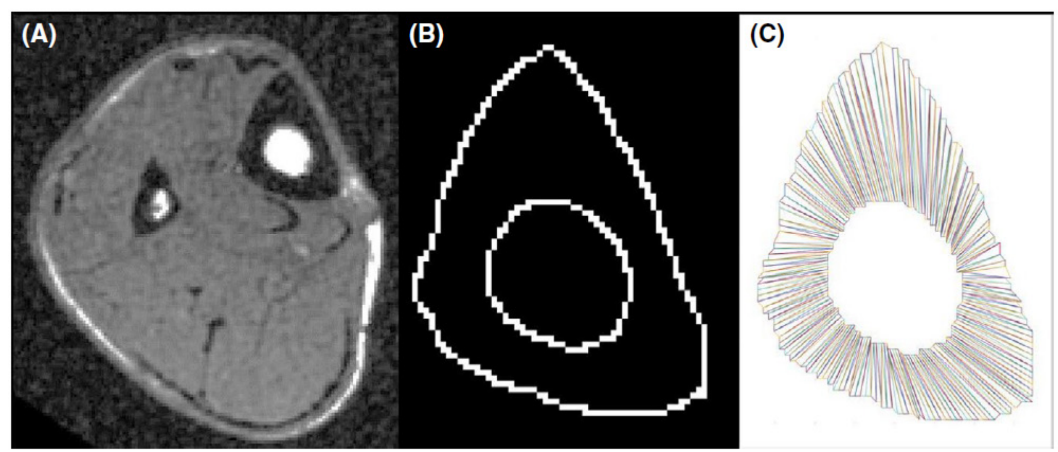
Modelling approaches







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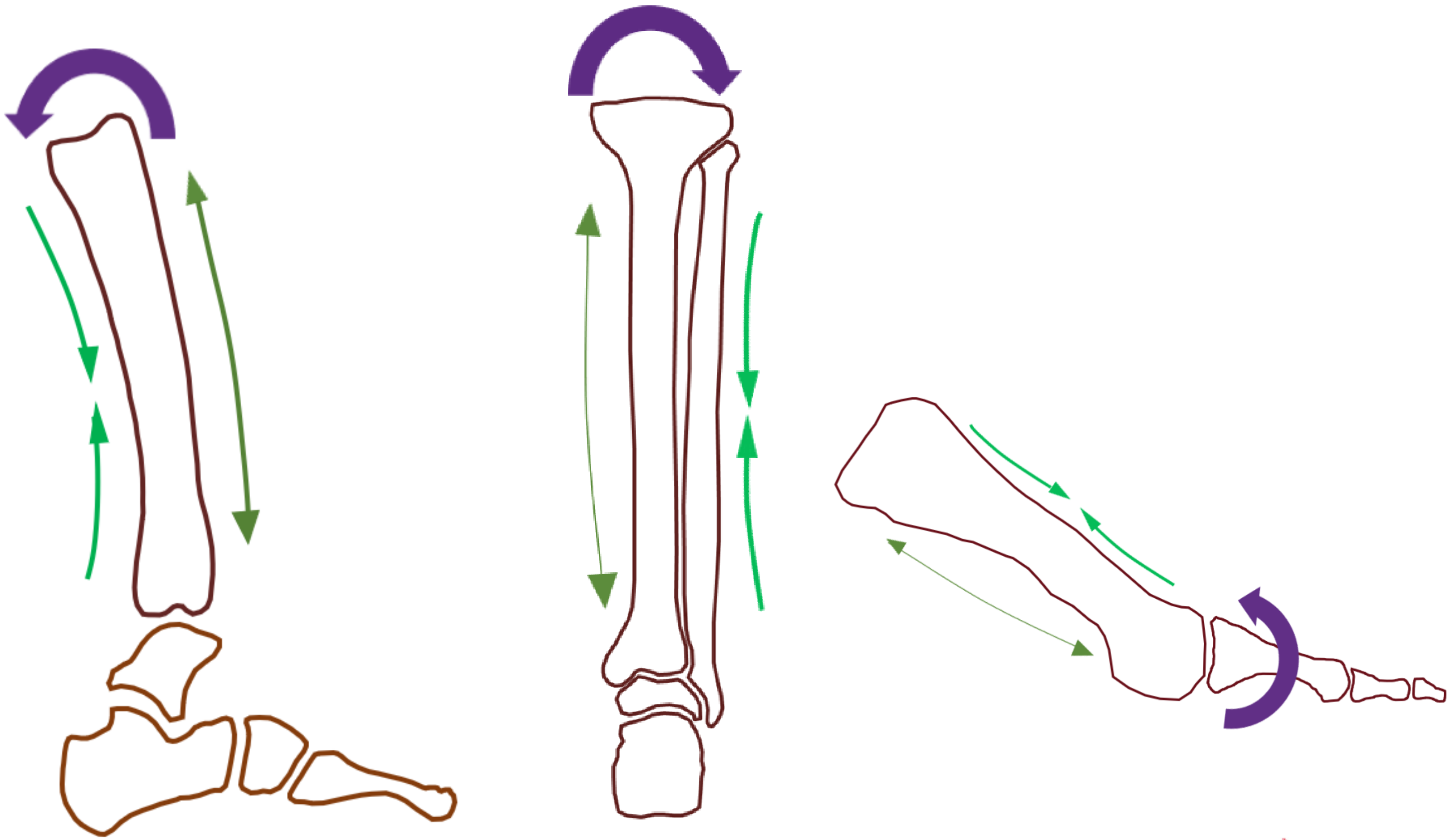
What happens when we load the long bones?



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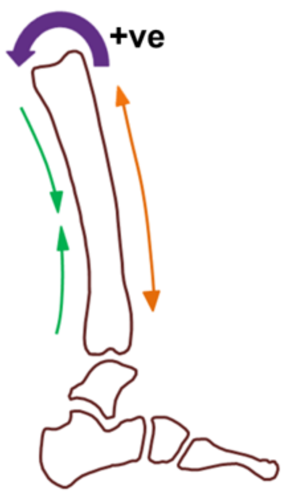
Tibial stress estimates during running

SCANDINAVIAN JOURNAL OF
MEDICINE & SCIENCE IN SPORTS

ORIGINAL ARTICLE | Open Access

Tibial stress during running following a repeated calf-raise protocol

Hannah M. Rice, Megan Kenny, Matthew A. Ellison, Jon Fulford, Stacey A. Meardon, Timothy R. Derrick, Joseph Hamill



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Outline

Images

APPLIED SCIENCES

Estimating Tibial Stress throughout the Duration of a Treadmill Run

RICE, HANNAH[1,2]; WEIR, GILLIAN[2]; TRUDEAU, MATTHIEU B.[3]; MEARDON, STACEY[4]; DERRICK, TIMOTHY[5]; HAMILL, JOSEPH[2]

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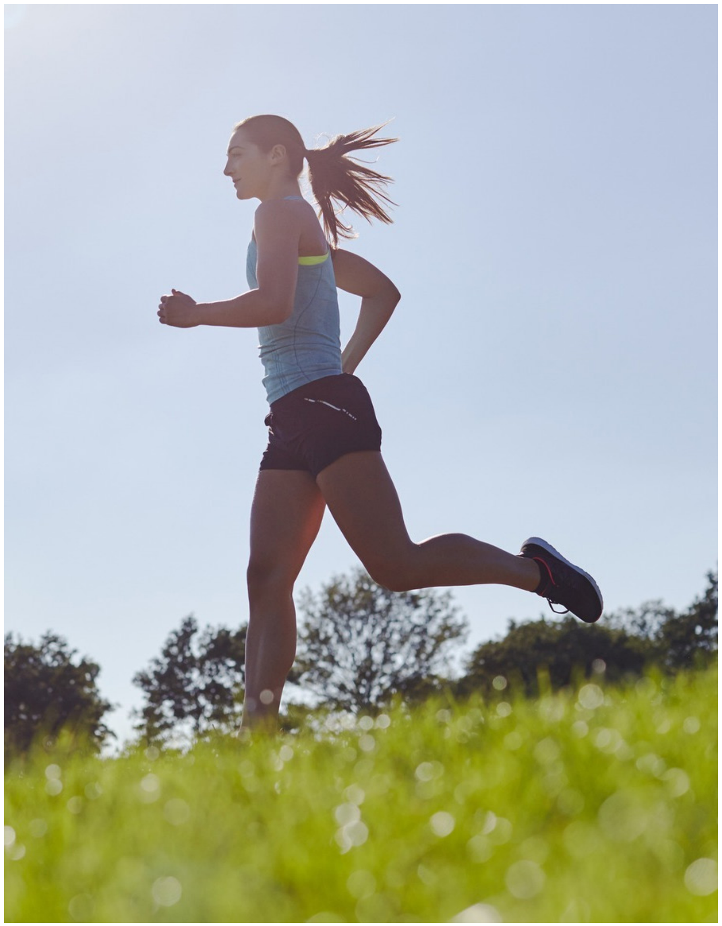
Surface steepness and running speed affect tibial loading during running

Rice, Mai,...Willwacher (*under review*)



Aim: to quantify tibial bending moments and stress when running at different speeds on surfaces of different gradients

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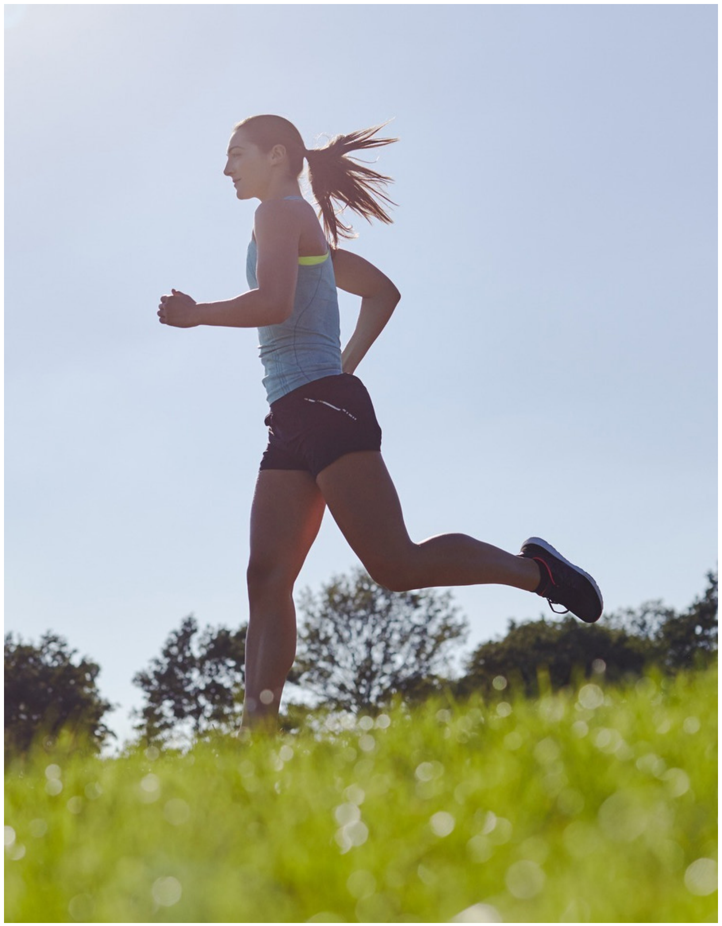
Surface steepness and running speed affect tibial loading during running



Rice, Mai,...Willwacher (*under review*)

- 20 recreational runners (male and female)

- Ran at 3 speeds (2.5 $m.s^{-1}$, 3.0 $m.s^{-1}$, 3.5 $m.s^{-1}$)
- On different gradients (level: 0%;
- ±5%, ± 10%, ± 15%)

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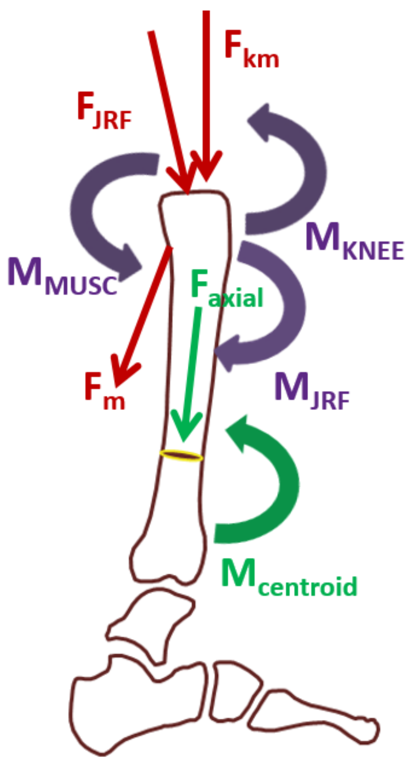
Surface steepness and running speed affect tibial loading during running

Rice, Mai,…Willwacher (*under review*)



- Synchronised kinematic and kinetic data collected
- Bending moments at distal 1/3 tibia
- 2-way repeated measures ANOVA
- ROI SPM analysis from 10% – 90% of stance

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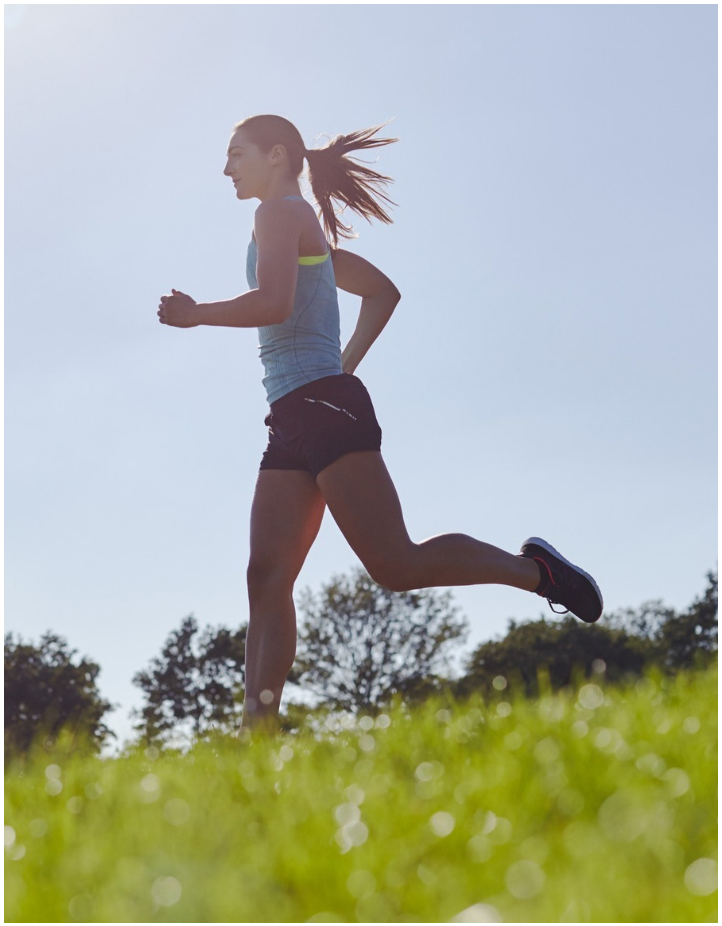

Rice, Mai,...Willwacher (*under review*)

Results

Peak M_{BE}:

- No interaction effect
- Main effect for running speed
- Main effect for gradient

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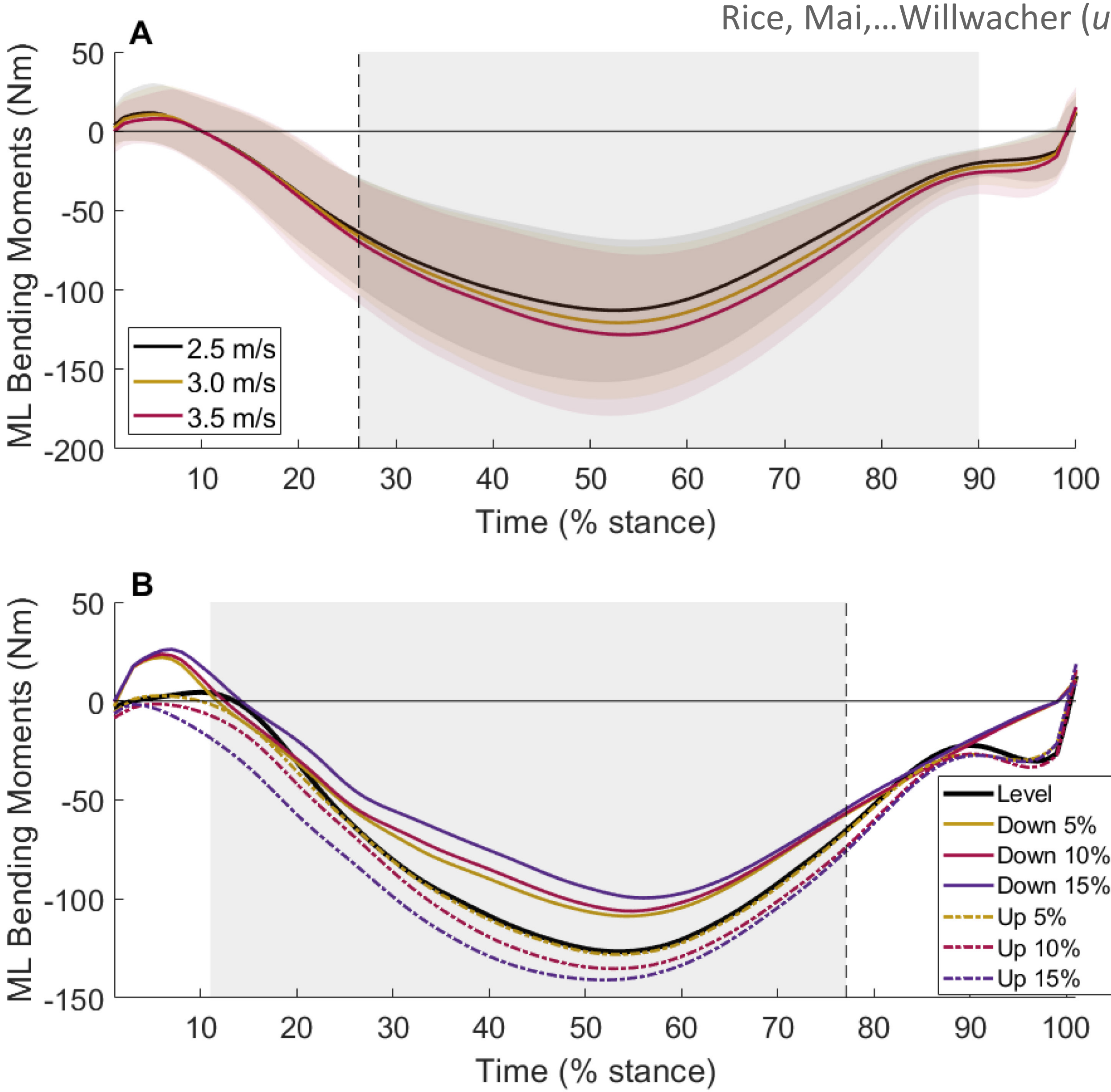
Rice, Mai,…Willwacher (*under review*)



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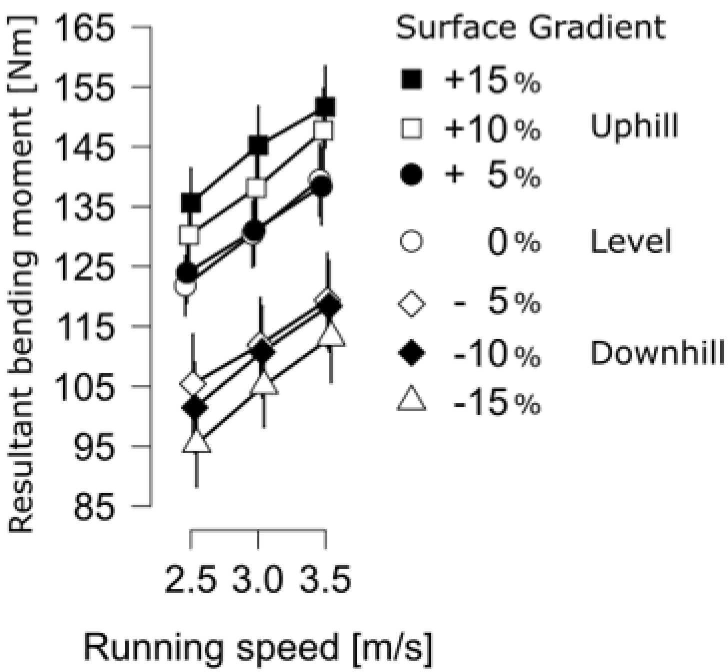
Surface steepness and running speed affect tibial loading during running



Rice, Mai,…Willwacher (*under review*)

- Running at faster speeds and uphill on gradients ≥+10% increased internal tibial loading
- Slower running and downhill running reduced internal loading

Adapting running speed according to the gradient could be a protective mechanism

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Influence of speed and weight carriage on tibial internal loading

Aim: to quantify the effects of running at a faster speed and with increased weight on tibial loading

Population: 14 male distance runners, running at least 40 km/week

Rice, Seynnes,…, Werkhausen (*in preparation*)

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Influence of speed and weight carriage on tibial internal loading

Protocol:
Barefoot running

Preferred speed, + 20% preferred speed
3.1 ± 0.3 $m.s^{-1}$, 3.7 ± 0.3 $m.s^{-1}$

with and without +20% of body weight

Synchronised kinematic and kinetic data collected

Rice, Seynnes,…, Werkhausen (*in preparation*)

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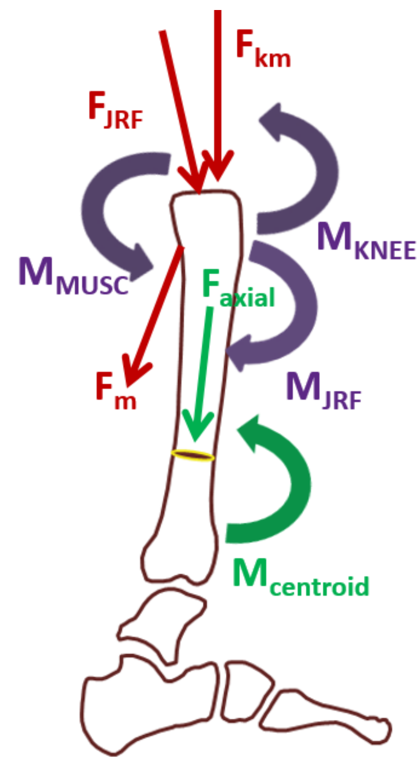
Influence of speed and weight carriage on tibial internal loading

- 2-way repeated measures ANOVA
- ROI SPM analysis from 10% – 90% of stance



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Influence of speed and weight carriage on tibial internal loading

SPM Results

No interaction effect ($p > 0.05$)

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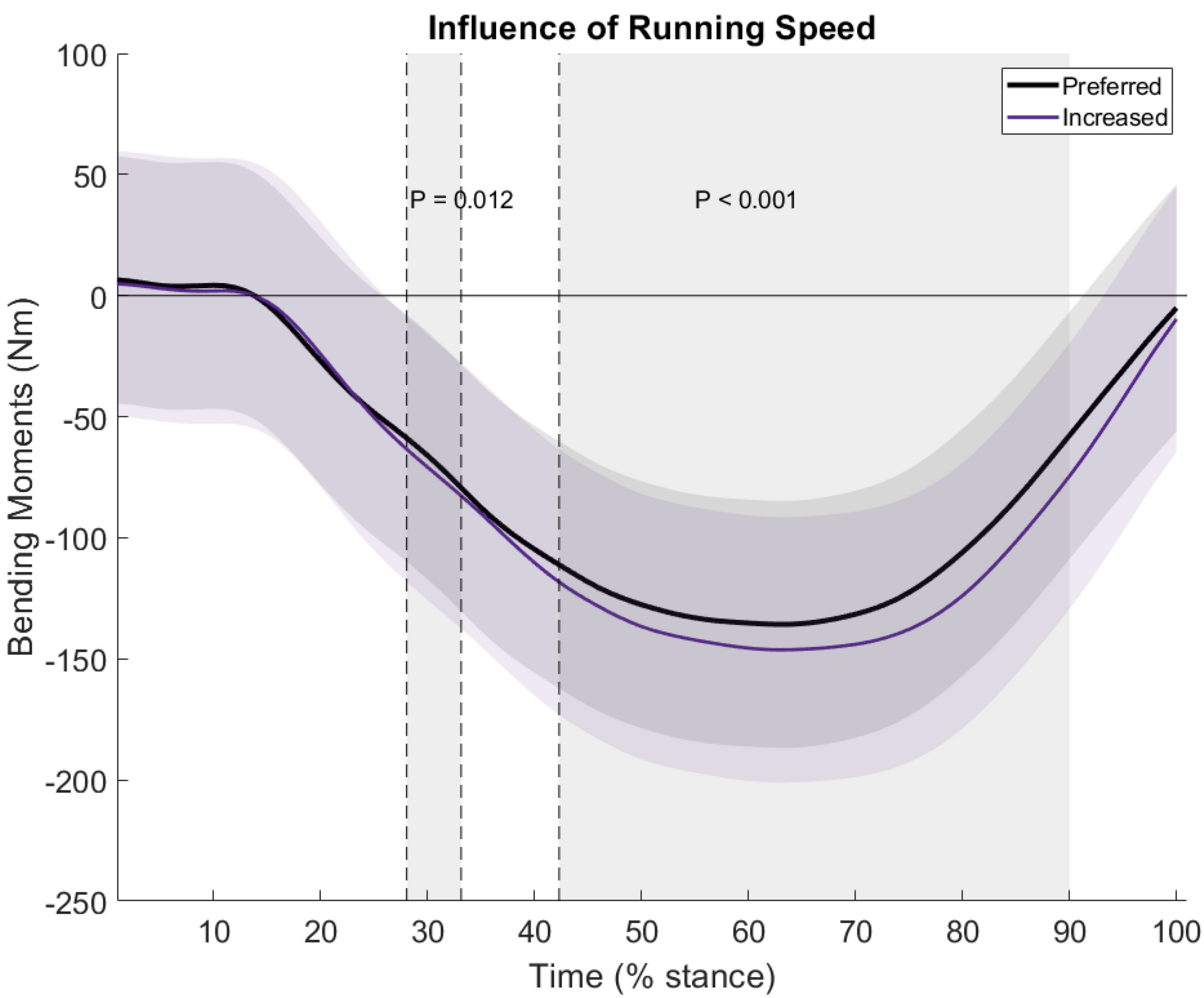
Main effect for running speed



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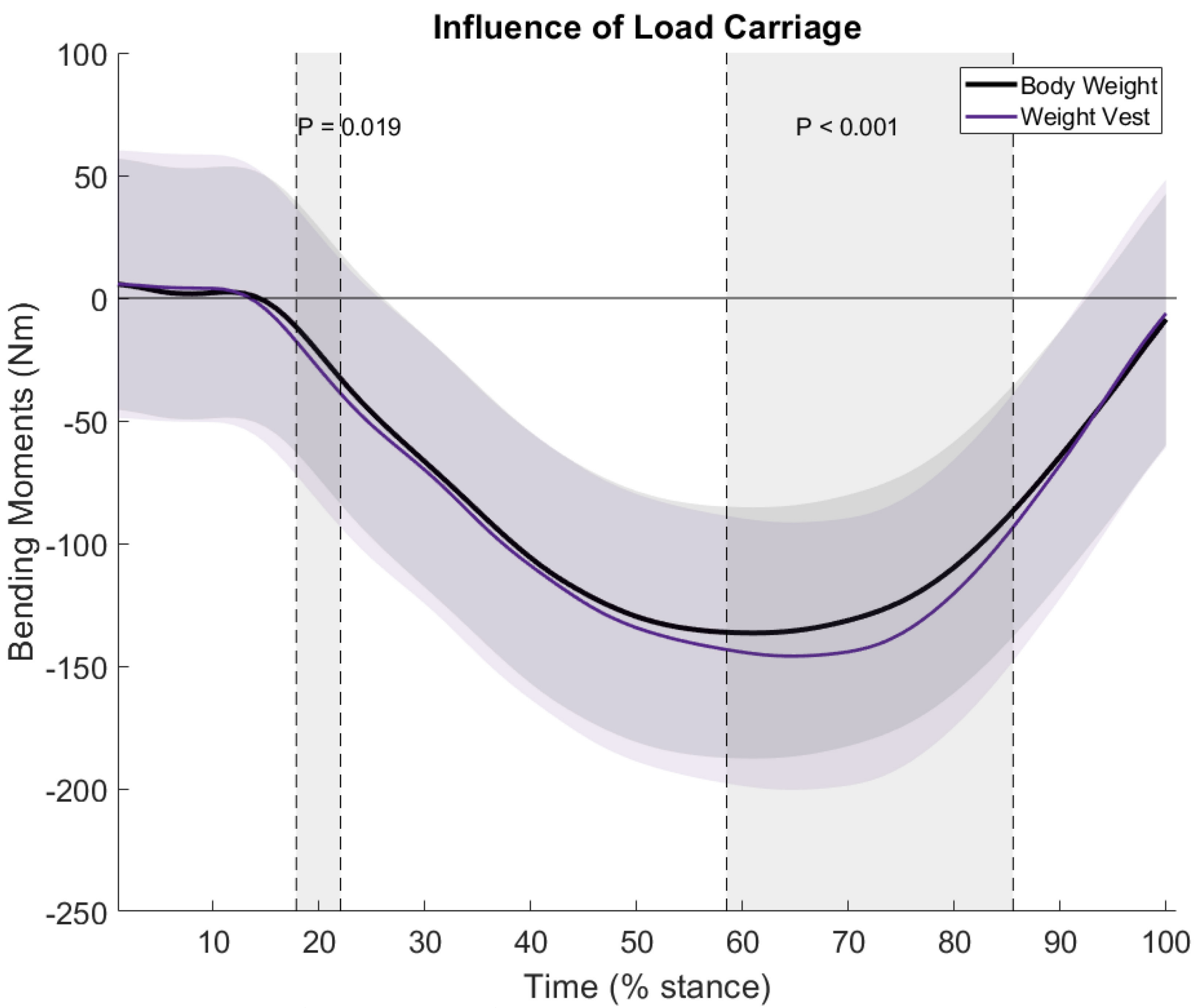
Main effect for added weight



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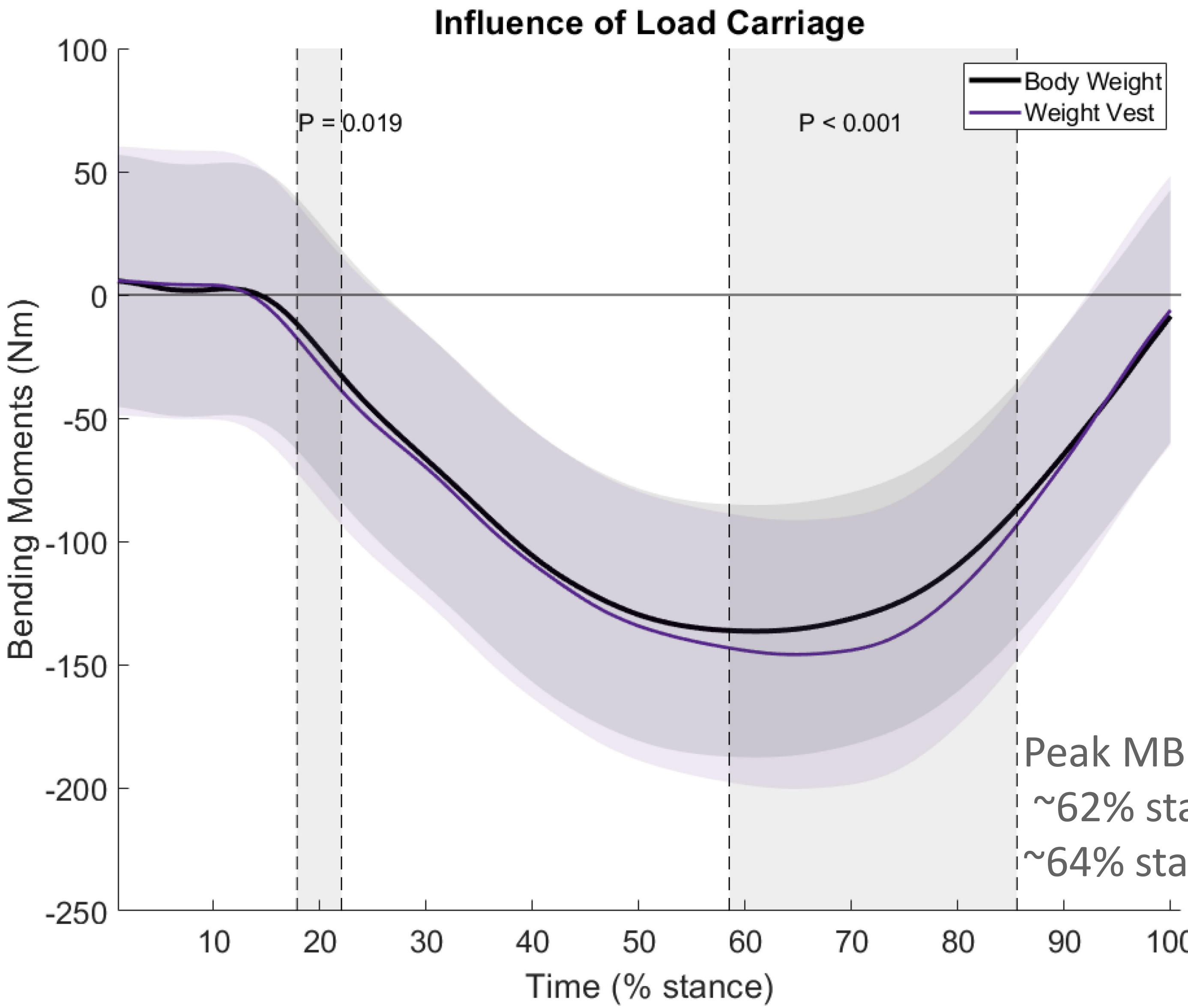
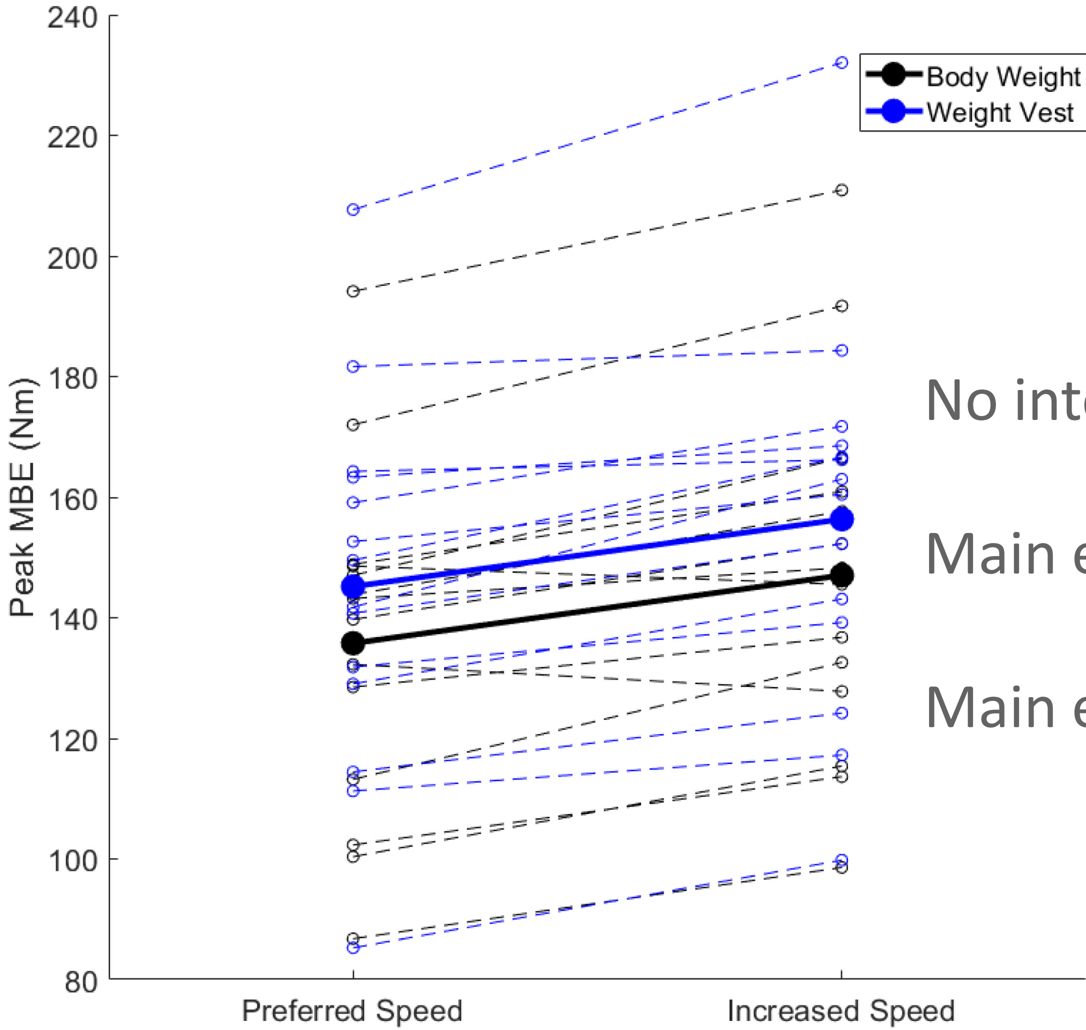
Main effect for added weight



Peak MBE:
~62% stance without load
~64% stance with load

Rice, Seynnes,…, Werkhausen (*in preparation*)

Discrete Results - Peak Bending Moment



No interaction effect ($p = 0.967$)

Main effect for speed ($p < 0.001$)

Main effect for weight ($p < 0.001$)

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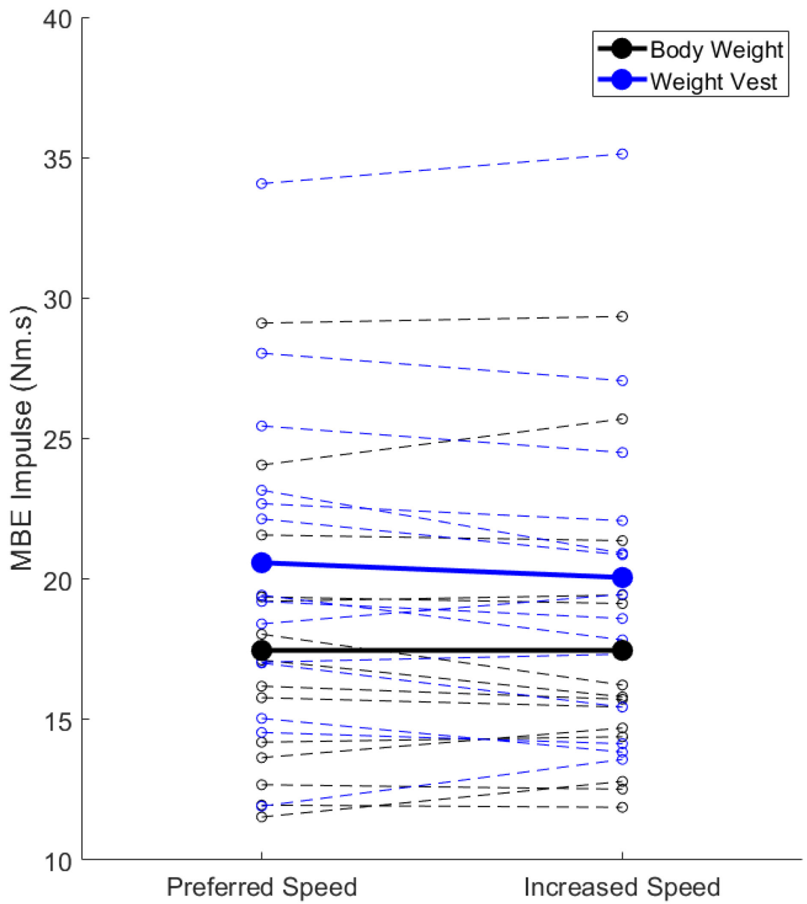
Cumulative Loading per step



No interaction effect (p = 0.246)

No main effect for speed (p = 0.166)

Main effect for weight (p < 0.001)

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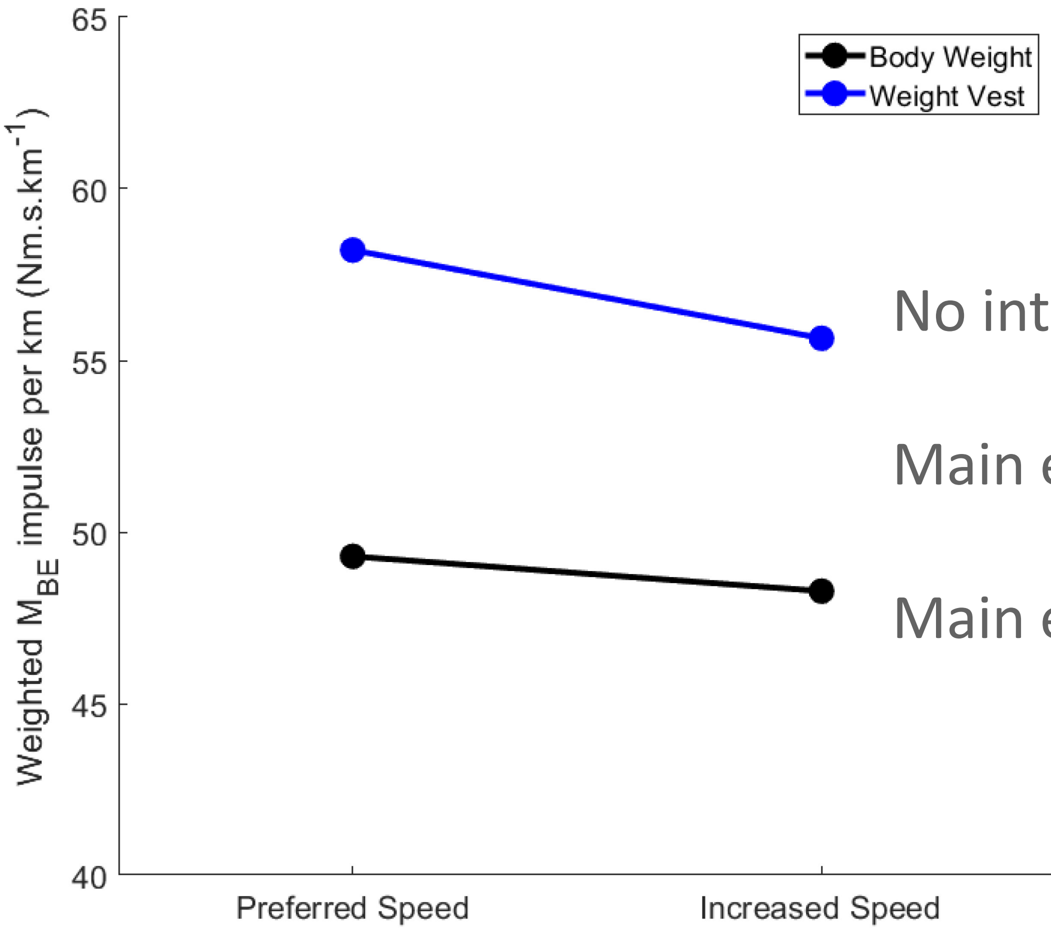
Weighted Cumulative Loading per km



No interaction effect ($p = 0.204$)

Main effect for speed ($p = 0.002$)

Main effect for weight ($p < 0.001$)

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Tibial stress during loaded running at two different speeds

Increased running speed and weight carriage independently increase *peak* tibial loading

However, with increasing speed contact time decreases and fewer steps are required per distance

Therefore cumulative loading decreases per km with increasing speed, but is higher with greater weight carriage

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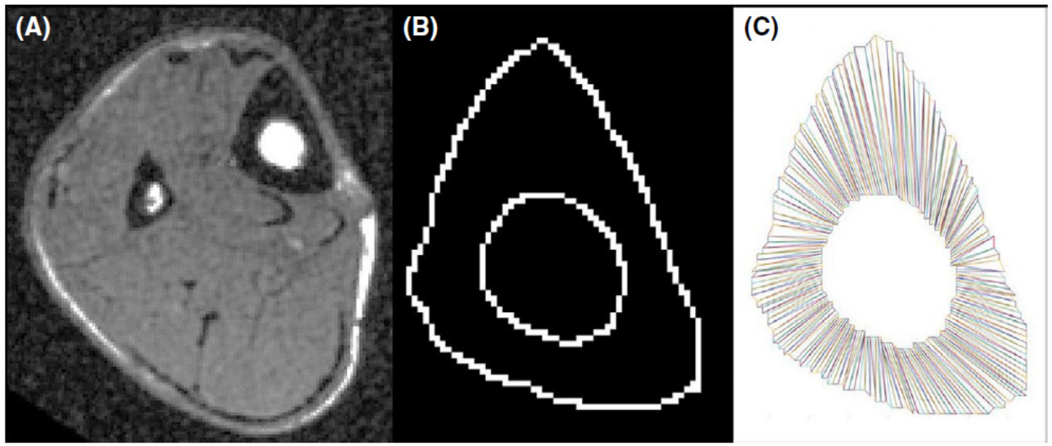
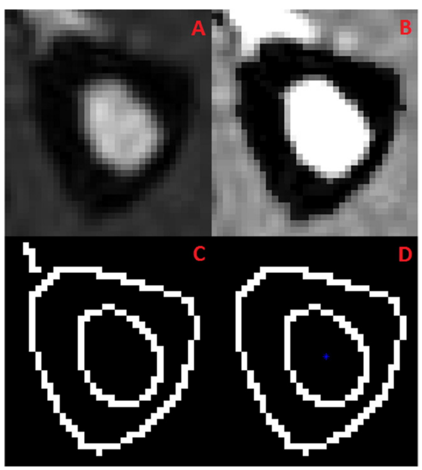
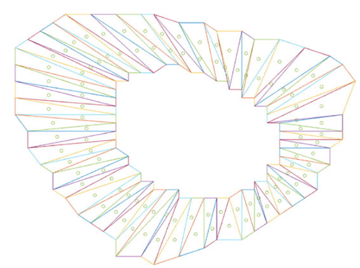
Participant-specific estimates?



Rice et al., 2020





Ellison et al., 2020

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Foot strike and metatarsal stress

Aim: to quantify second metatarsal stress during running when landing with a habitual rearfoot or non-rearfoot strike

Ellison et al., 2020

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Foot strike and metatarsal stress

Barefoot running 3.6 $m.s^{-1}$
Synchronised motion capture and kinetics including
RSscan plantar pressure plate
MRI

Ellison et al., 2020

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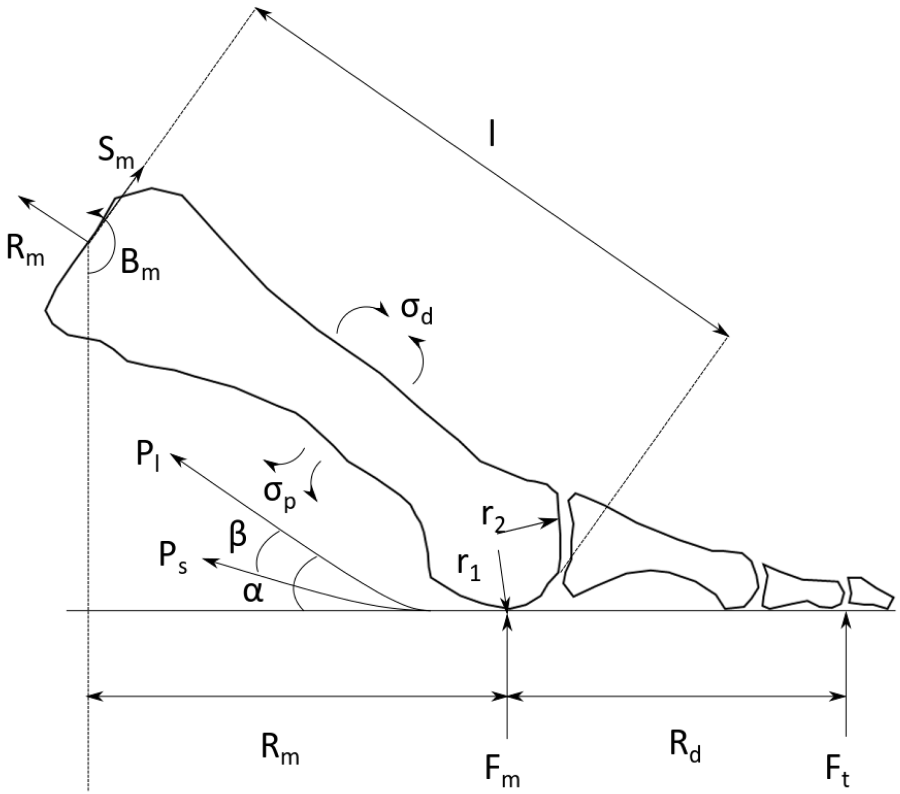
Foot strike and metatarsal stress



Similar peak stresses between groups despite greater peak external loading under the metatarsal head of non-rearfoot strikers

Ellison et al., 2020

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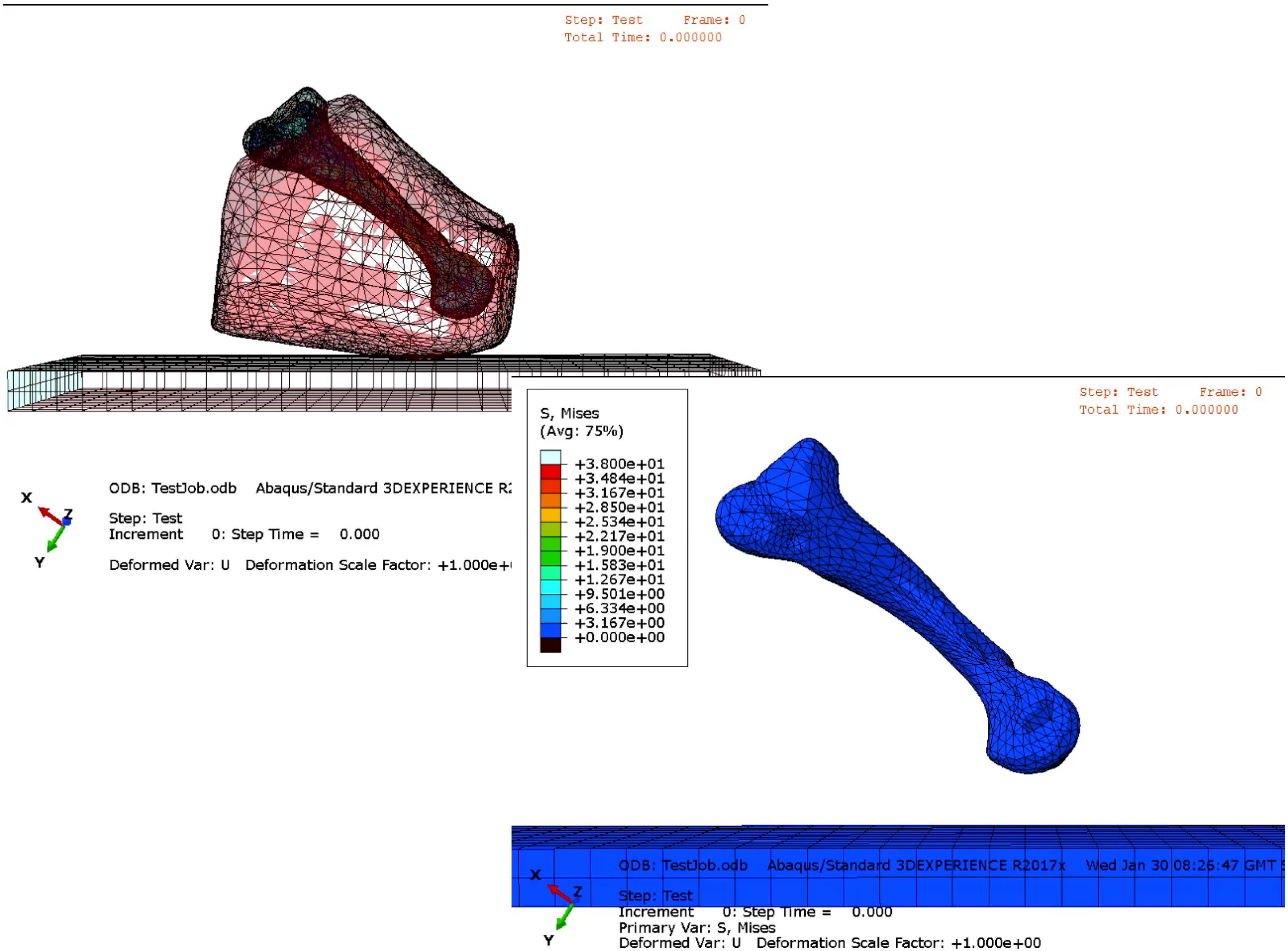
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S, Mises
(Avg: 75%)
+3.800e+01
+3.484e+01
+3.167e+01
+2.850e+01
+2.534e+01
+2.217e+01
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+9.501e+00
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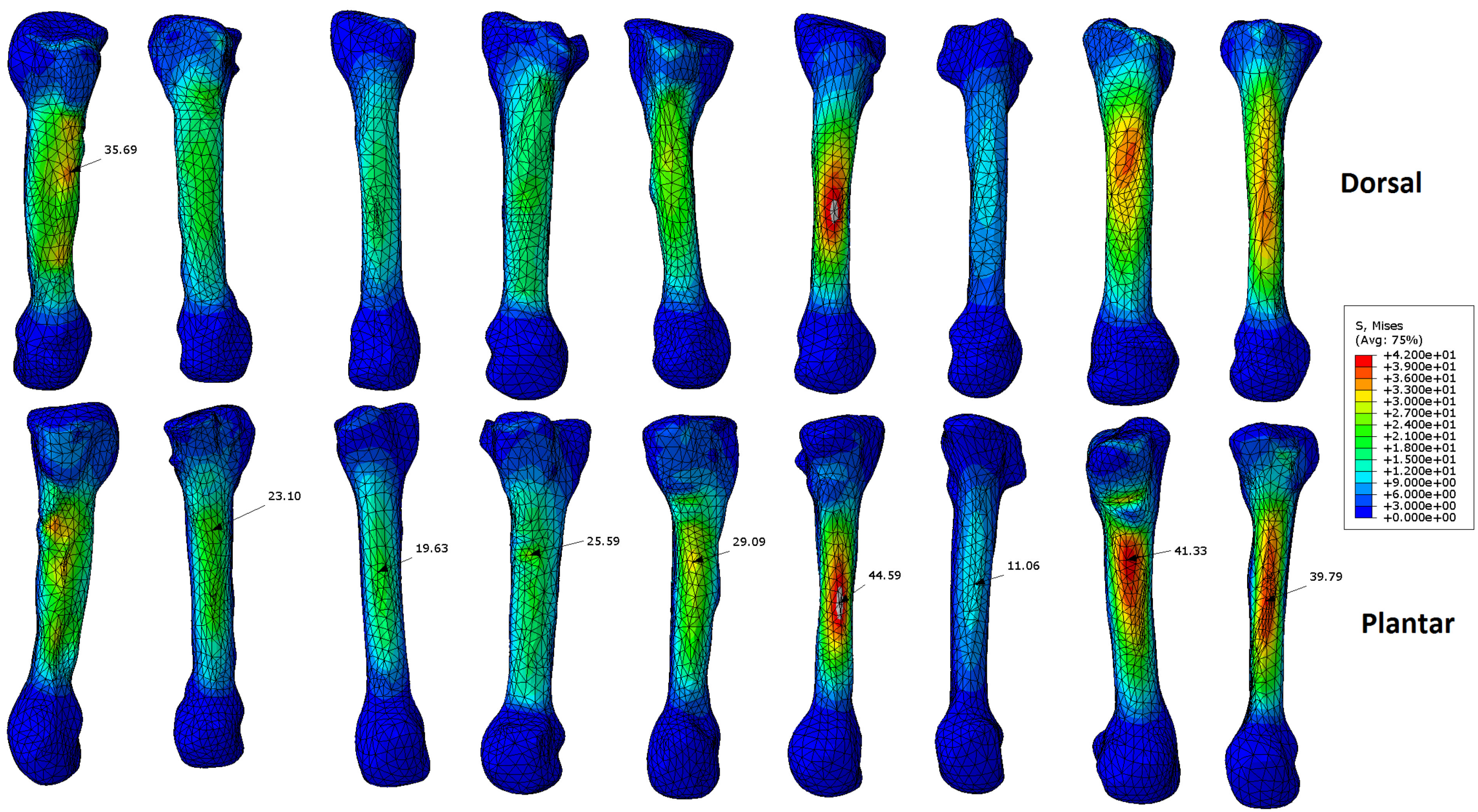
Foot strike and metatarsal stress

No difference in maximum stress between rearfoot strikers and non-rearfoot strikers during running



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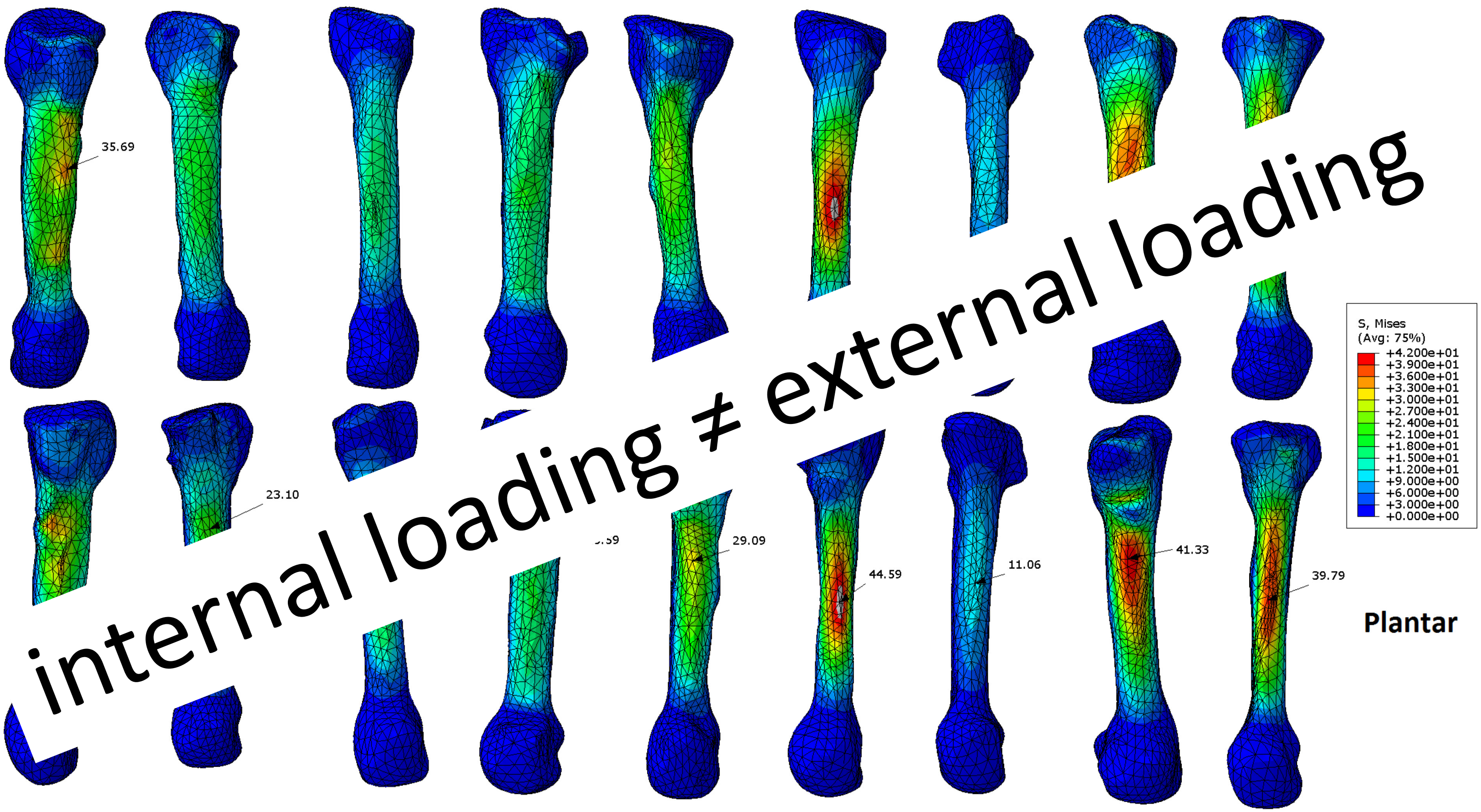
Foot strike and metatarsal stress

No difference in maximum stress between rearfoot strikers and non-rearfoot strikers during running



internal loading ≠ external loading

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Estimating Bone Loading in Real-time

- Robustness and validity of equipment to measure position, force, pressure…
- Real-time estimates of joint moments?
- Static optimisation time-consuming

Estimating Bone Loading in Real-time

- Is CT/MRI required?
    - Participant-specific not needed to detect change in loading
- Can a simpler model be used?
    - Consider predictive modelling

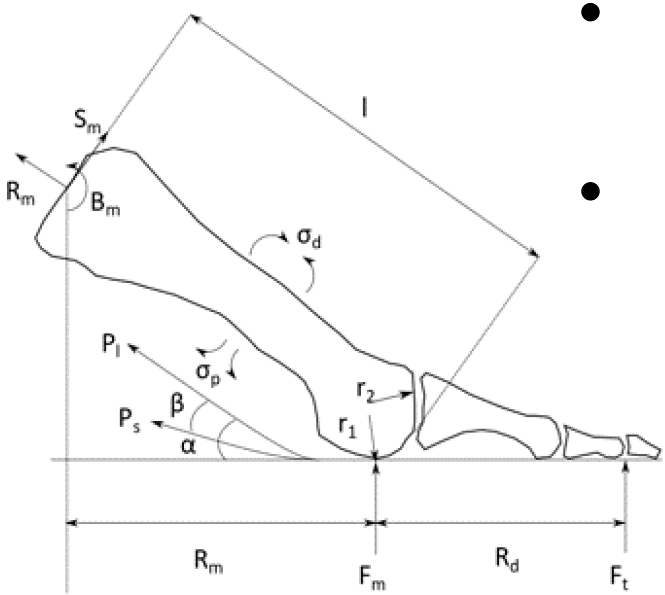
Validation

- not truly validated
- comparison with strain gauge
- bone pin studies and direction of bending

Ultimately need injury outcomes

Where do we go next?

- Application to other movements
- Increasing ability to measure in-field
- Model improvement
- Model validation



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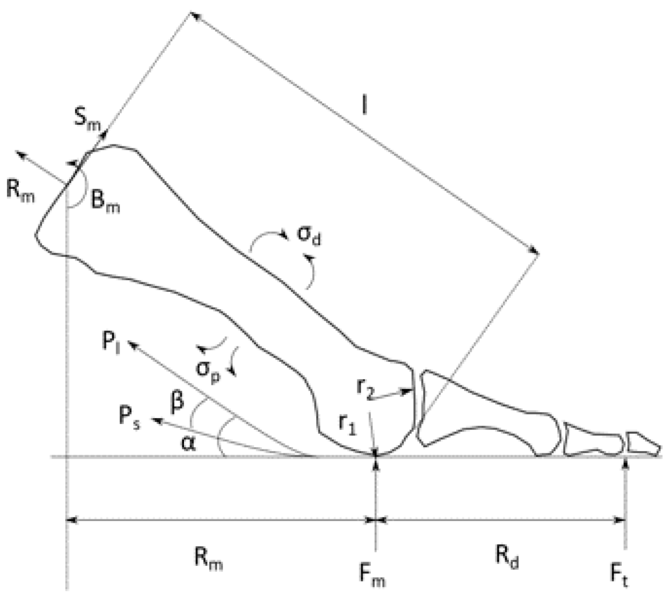
Conclusions

- Exciting potential to quantify bone loading in-field, in real-time
- Implications for many
- Technology and modelling development is increasing at a fast pace



We need to understand it, not just measure it

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Acknowledgements

Matthew Ellison

Tim Derrick

Joe Hamill

Gill Weir

Stacey Meardon

Jo Fallowfield

Sharon Dixon

Olivier Seynnes

Amelie Werkhausen

Jon Fulford

Steffen Willwacher

Patrick Mai

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Thank you!

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