How humans run on rough terrain

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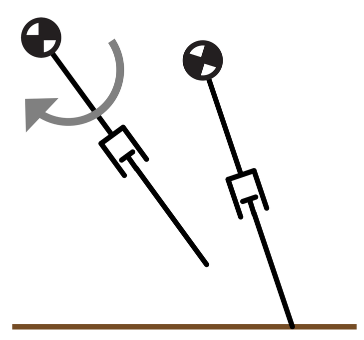
How do humans maintain stability on rough terrain?

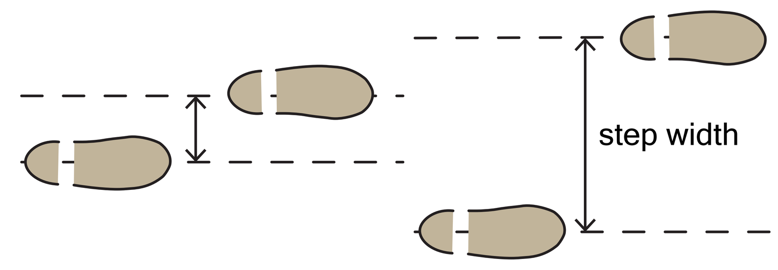
Most running experiments on flat/step-like terrain [1].

For stability on flat/step-like terrain:

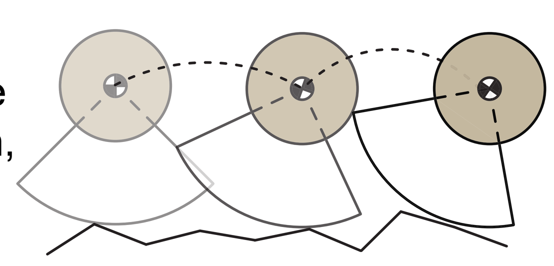
increase leg retraction rate [2].



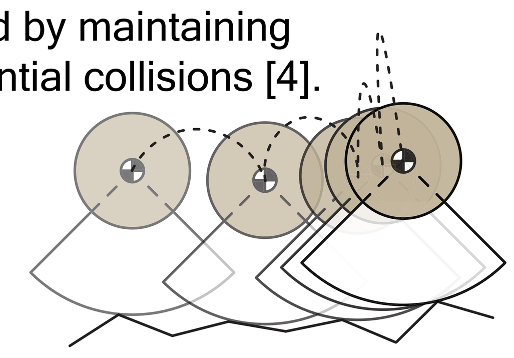
increase step width [3].



Open-loop strategies are stable on step-like terrain, but not if slopes vary [4].



Orientation can be stabilized by maintaining low tangential collisions [4].

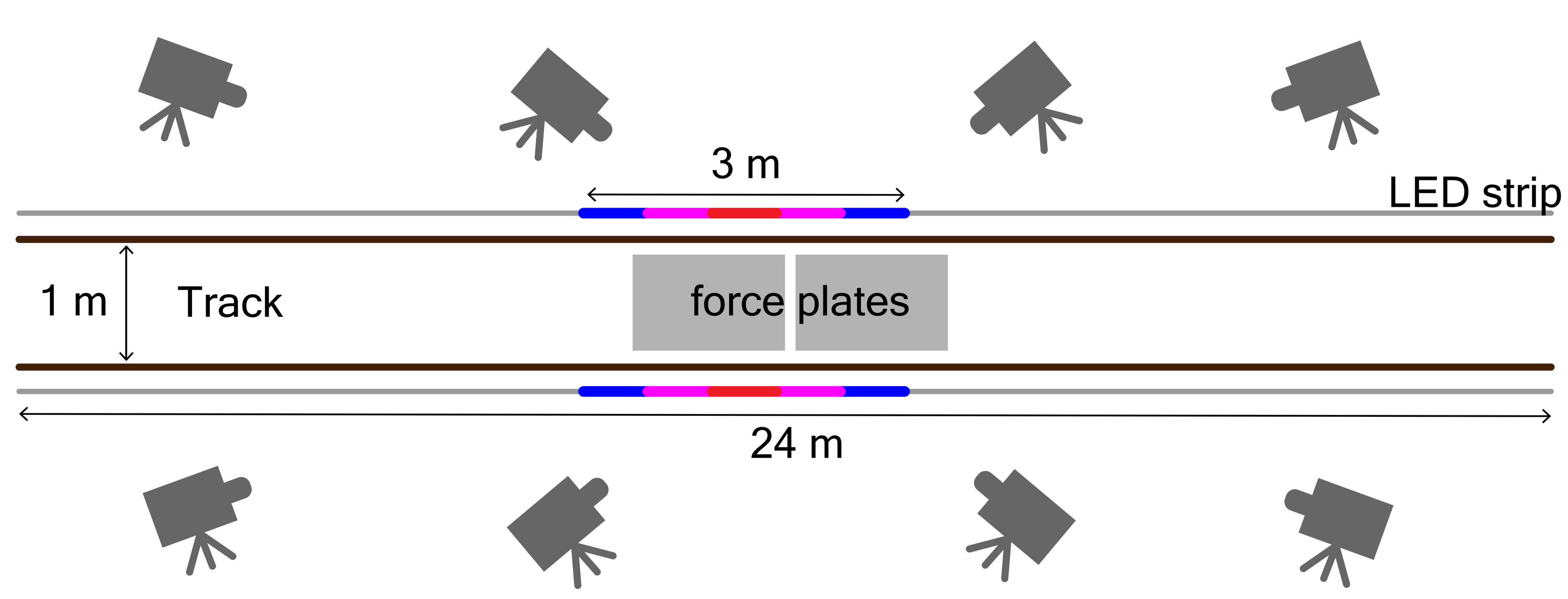


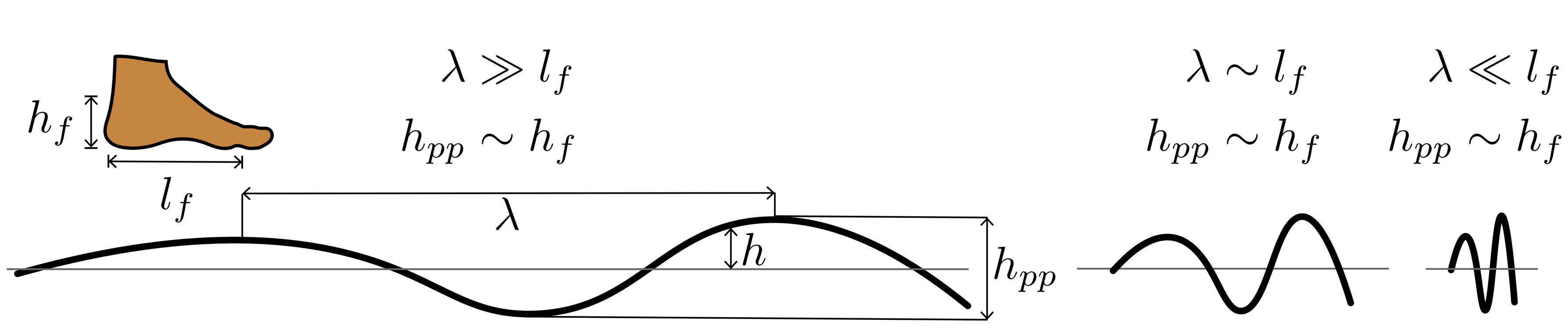
- For stable running on rough terrain, models [4] suggest that runners benefit from
  - maintaining low forward collision impulses using leg retraction to reduce forward foot speed and/or by maintaining compliant leg joints at landing.
  - landing their feet on lower slope regions of the terrain.

Experiment

Experiment

- 9 subjects ran at 3 m/s.
- 1 flat + 2 rough terrain (uneven I, uneven II), 24m long track.
- Data: O_2 consumption, foot and hip kinematics (300Hz), ground reaction forces (600Hz).
- Trial: 3 min standing followed by an ≈ 10 min run.





Conclusions

- Runners maintain low forward collisions using compliant leg joints at landing.
- Runners do not preferentially step on flatter regions of the terrain.

Acknowledgements

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References

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[2] A. Seyfarth, et al. Swing-leg retraction: a simple control model for stable running. *Journal of Exp. Biology*, 206:2547–2555, 2003.

[3] J. E. Seipel & P. Holmes. Running in three dimensions: Analysis of a point-mass sprung-leg model. *The Int'l Journal of Robotics Research*, 24:657–674, 2005.

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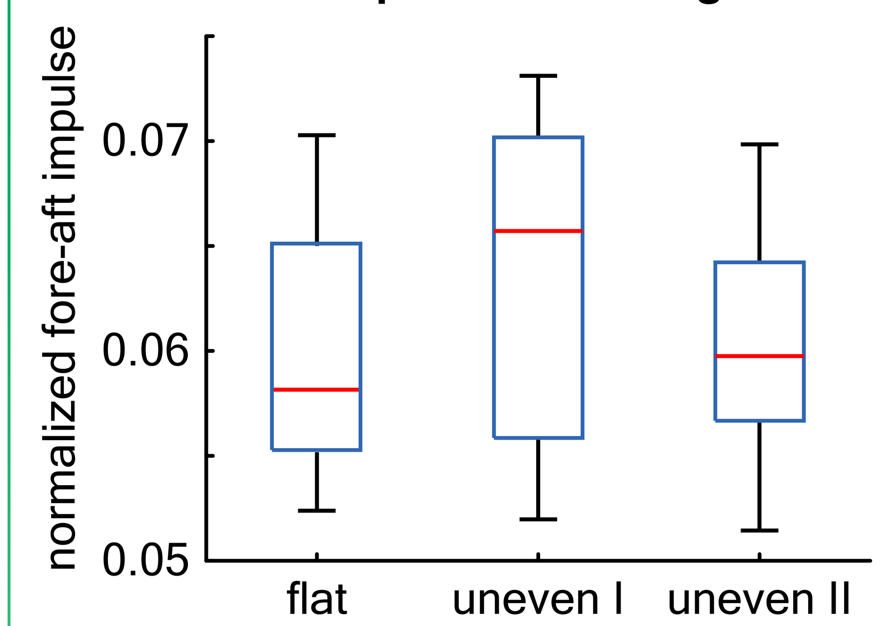
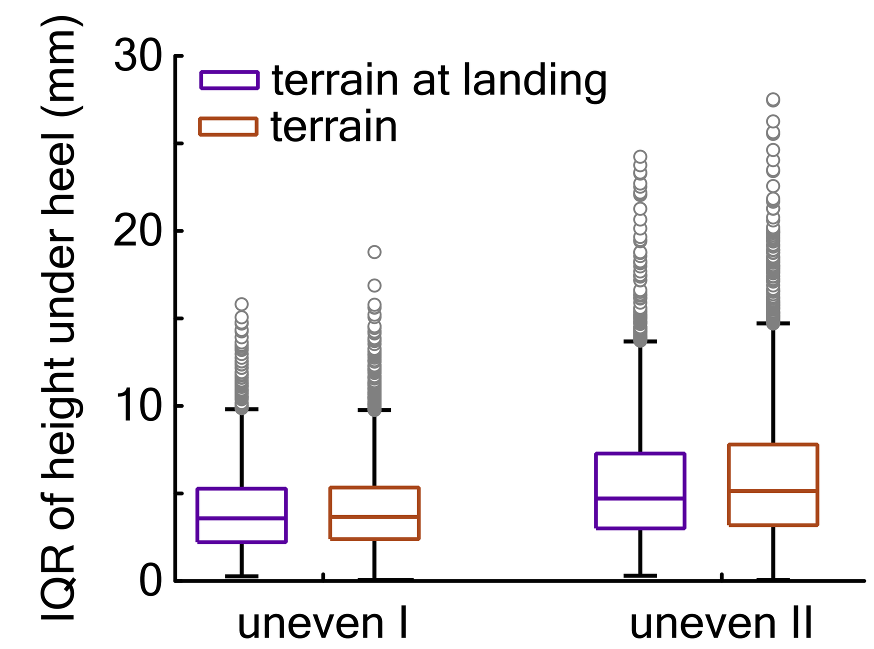
Results: Run with soft legs to reduce forward collisions

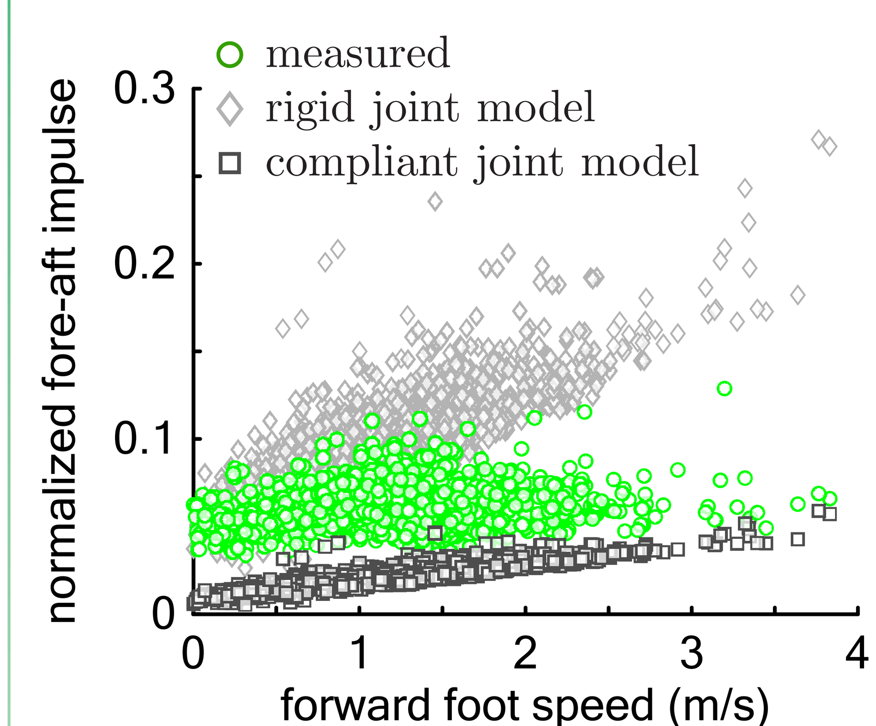
Around 6% of the forward momentum is dissipated at landing.

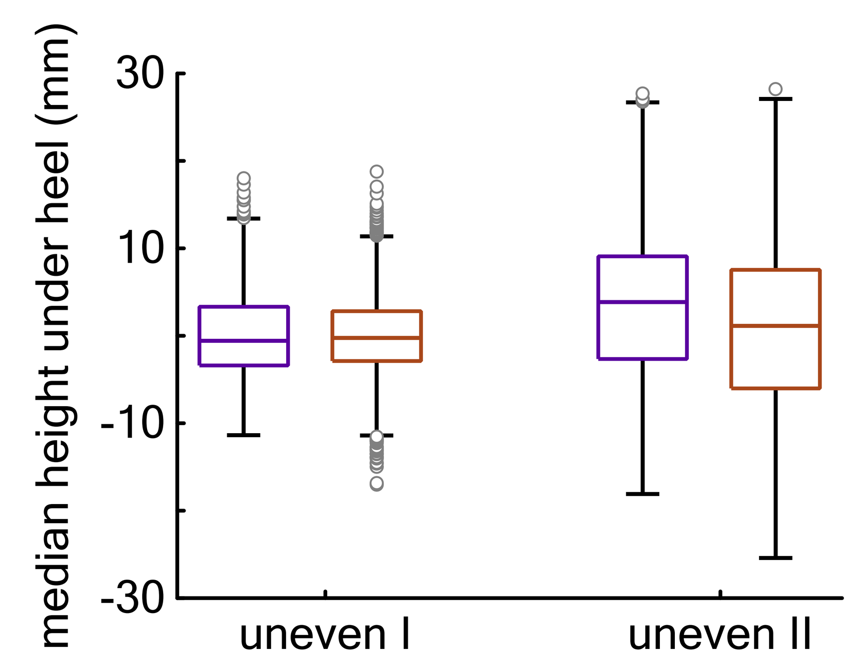


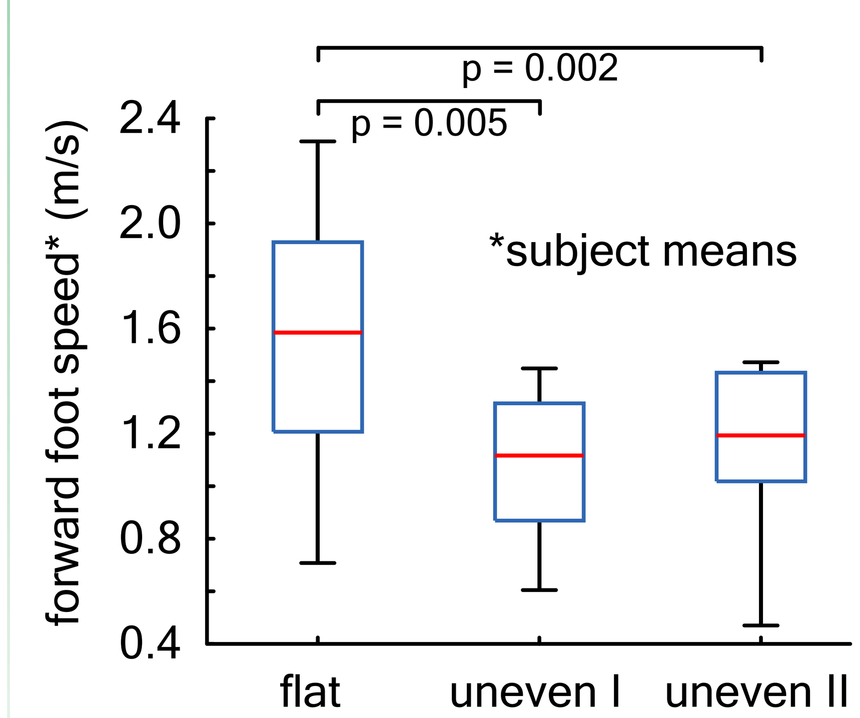
Terrain features at heel landing locations resemble those from a uniform random sample of the terrain.



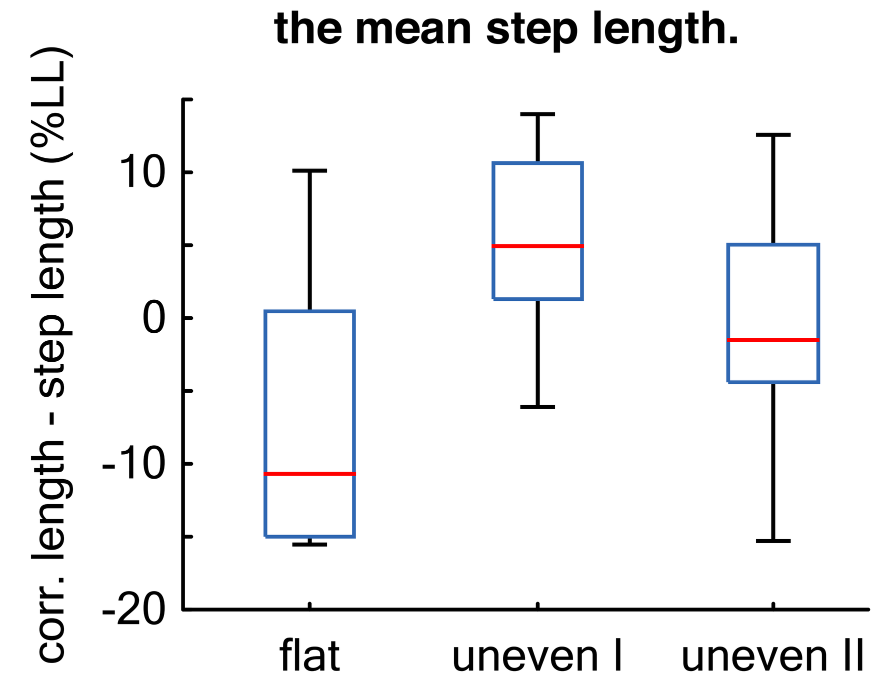
Leg compliance, not foot speed, predicts the collision impulse.







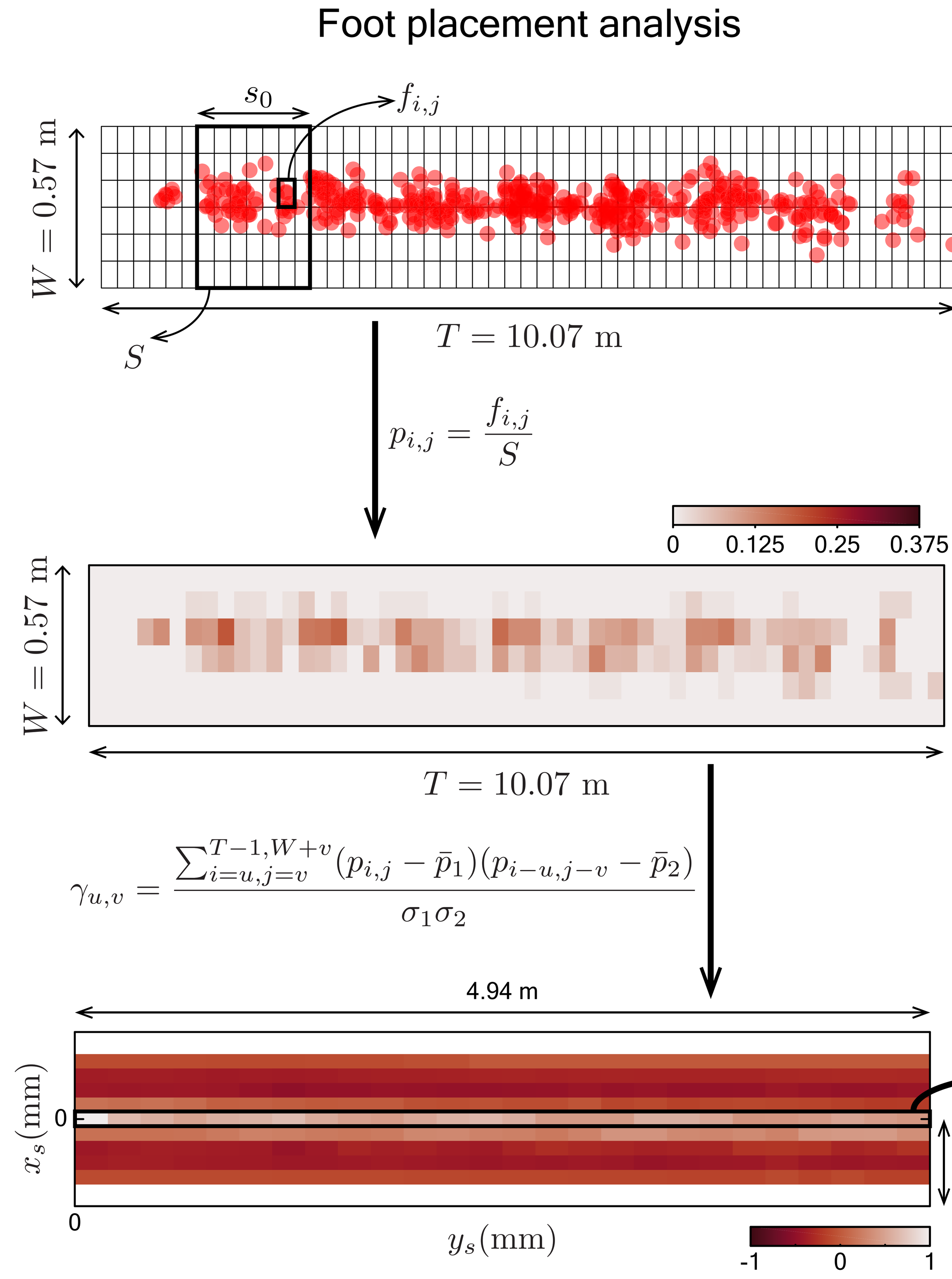
The correlation length of stepping patterns is likely the same as the mean step length.



- O_2 cost of transport higher by $6.8 \pm 2.5\%$ ($p = 0.04$) on uneven II compared to flat.
- Median step width higher by $13 \pm 3\%$ ($p = 0.03$) on uneven II compared to flat.
- Step width variability higher by $24 \pm 10\%$ ($p = 0.04$) on uneven II compared to flat.

Data analyses and modelling

Foot placement analysis



Collision analysis