Longitudinal bending stiffness of cycling footwear - What is stiff enough?

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Introduction

Research has shown that **increased longitudinal bending stiffness** of the cycling shoe soles **decreases** deflection of the cycling shoe - and hence the foot's **metatarsophalangeal angle (MTP)** (i.e. the angle between fore- and rearfoot) - during pedalling, thus reducing material deformation and **increasing power-transfer** [1, 2, 3, 5], ultimately leading to a higher performance.

However, **stiff shoes prevent a physiological motion of the foot during walking**. The objective of this work is to investigate whether longitudinal bending stiffness of **flat pedal cycling shoes** as well as the load intensity has an influence on the MTP- and the pedal-angle and hence **which stiffness is required to provide sufficient force transmission during riding and still allow enough flexibility for walking** (Figure 1).

Figure 1. Vaude's dualflex concept allowing MTP dorsalflexion during walking and preventing MTP plantarflexion during cycling (source: Vaude)

Aims

The **objective of this work** is to investigate whether

1. **longitudinal bending stiffness of flat pedal cycling shoes** as well as the **load intensity** has an **influence on the MTP- and the pedal-angle**.
2. and hence which stiffness is required to provide **sufficient force transmission and yet allow enough flexibility when walking** and what practical applications this has for industry.

Materials

- subjects: **12 healthy male experienced hobby cyclists** (S1…S12; age: 27.2 ± 2.6 yrs., weight: 72.3 ± 6.3 kg, height: 176.8 ± 5.2 cm)
- **cyclocross bicycle** mounted on an **Tacx indoor trainer** (Tacx B.V., Wassenaar, NED)
- **Power and cadence** were recorded using a Rotor 2INPOWER DM ROAD (Rotor Bike Components, Ajalvir, ESP) power meter and a Garmin Edge 530 head unit (Garmin Ltd., Schaffhausen, SUI)
- Three identical flat pedal shoe prototypes (Vaude, Tettnang, GER) with **different insoles and stiffness** (Table 1)

Table 1. Different insoles, insole material and stiffness properties.

label	material	stiffness
DF1	ethylenvinylacetat (EVA)	soft
DF2	nylon	stiff
DF3	nylon-carbon	stiffest

Methods

- saddle height 96% of trochanter major height
- cadence 80 rpm, four steady-state power levels at four gear ratios (I1…I4) and all-out standing start sprint (I5) until 80 rpm were reached (Table 2)
- shoes with five hemispherical markers to calculate MTP angle (Figure 3a) and pedal-ground angle (Figure 3b)
- eight camera Vicon Nexus (Vicon Motion Systems, Yarnton, GBR) infrared 3D motion capture system

Table 2. Power output (W) and gear-ratio of the five intensity levels (I1…I5).

label	power (W)	gear ratio
I1	100	50x22
I2	130	50x20
I3	170	50x18
I4	230	50x16
I5	max. 750	50x16

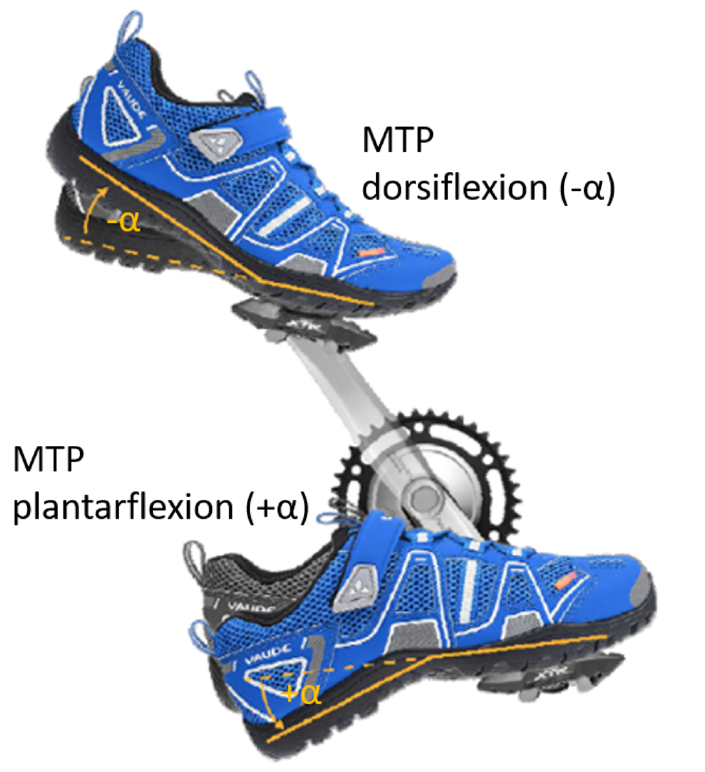

Figure 2. MTP dorsiflexion ($-\alpha$) and plantarflexion ($+\alpha$) (source: Vaude)

Figure 3. (a) Five markers were placed on each shoe. (b) Pedal-ground angle. Positive values (+) signify heel-up position (as shown in (b)), negative values (-) heel-down.

Data analysis

- using Matlab 2021a (The Mathworks, Natick, USA) single crank cycles were separated
- data were interpolated to 360°
- calculation of MTP- and pedal angle via marker trajectories
- 2-way ANOVA for statistical evaluation

Conflicts of Interest | Acknowledgements | Funding

Conflicts of Interest: Study design, interpretation of data and manuscript writing were done in collaboration with Vaude's R&D department (i-lab).

Funding: All shoes used in the research were provided by the company Vaude and returned after the trials.

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Results

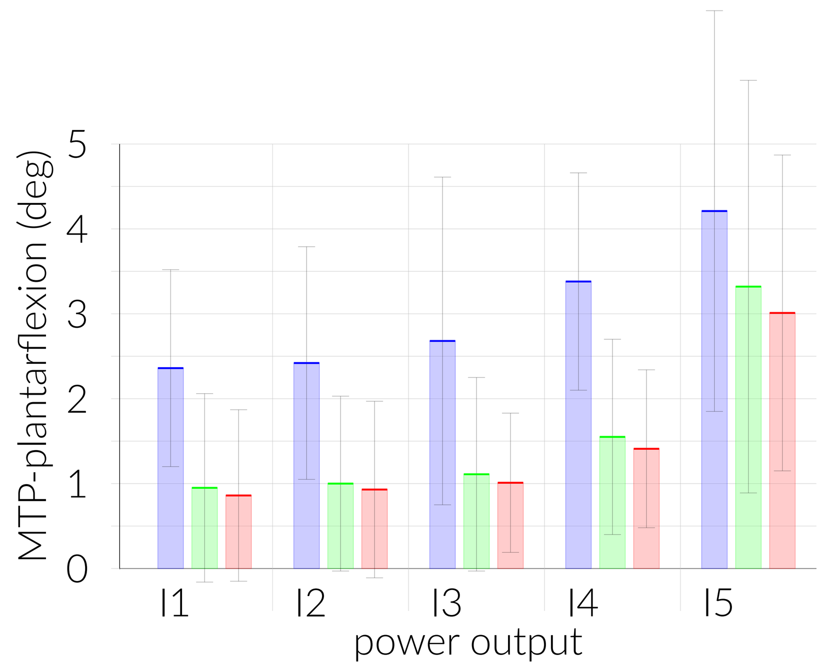

Figure 4. Mean maximal (± SD) MTP angle (α) between forefoot and rearfoot for the five power outputs (I1: 100W, I2: 130W, I3: 170W, I4: 230W and I5: sprint max. 750W) for all shoes (blue: DF1 - soft, green: DF2 - stiff, red: DF3 - stiffest).

MTP-angle over crank cycle

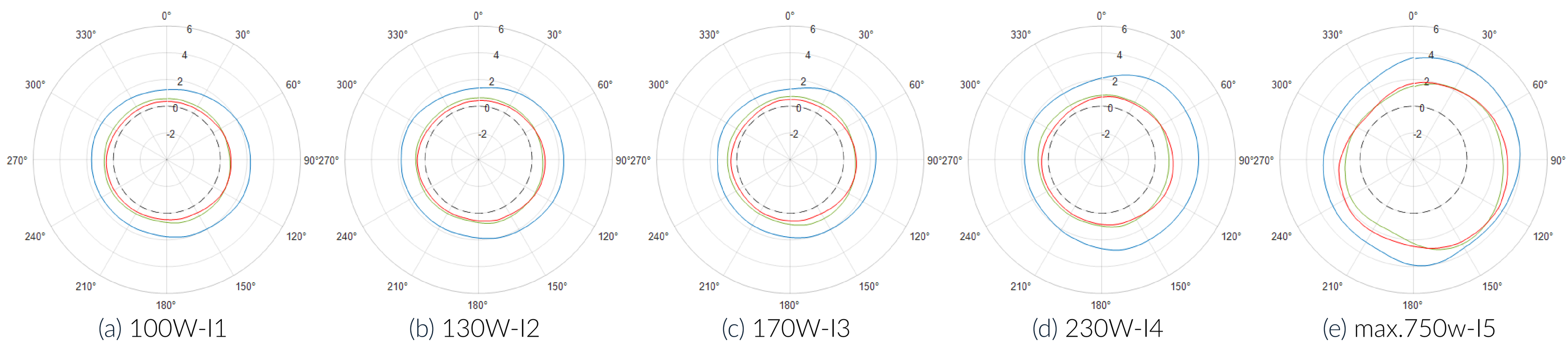

Figure 5. Comparison of the mean MTP-angle (α) for all subjectsan dall power-outputs (I1…I5) over a crank cycle for all shoes (black dashed line: α =0°, blue: DF1 - soft, green: DF2 - stiff, red: DF3 - stiffest)

Pedal-ground angle over crank cycle

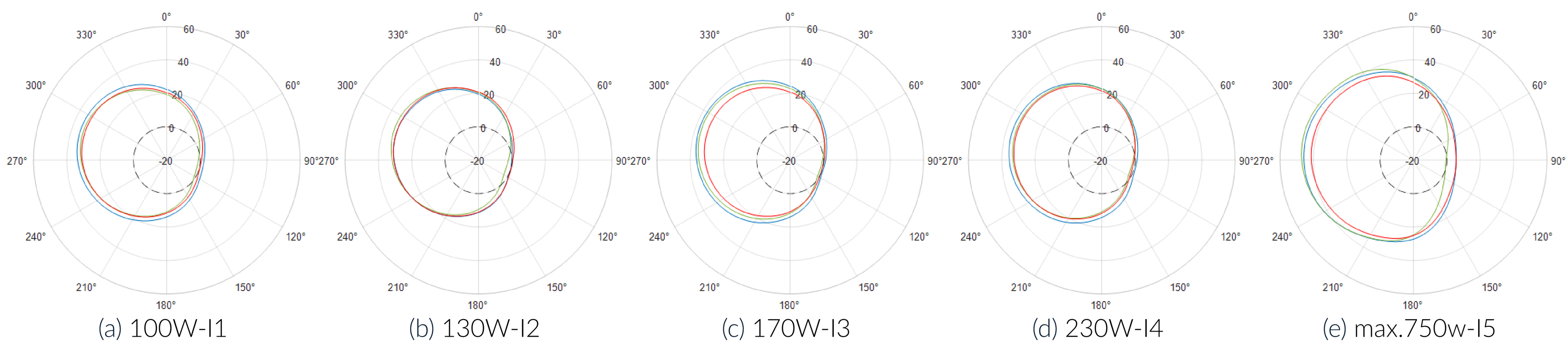

Figure 6. Comparison of the mean pedal-ground angle (**positive value = heel up**) for all subjects, and all power-outputs (I1…I5) over a crank cycle for all shoes (black dashed line: 0°, blue: DF1 - soft, green: DF2 - stiff, red: DF3 - stiffest)

Pedal-ground angle over crank cycle greatly differs for individual athletes

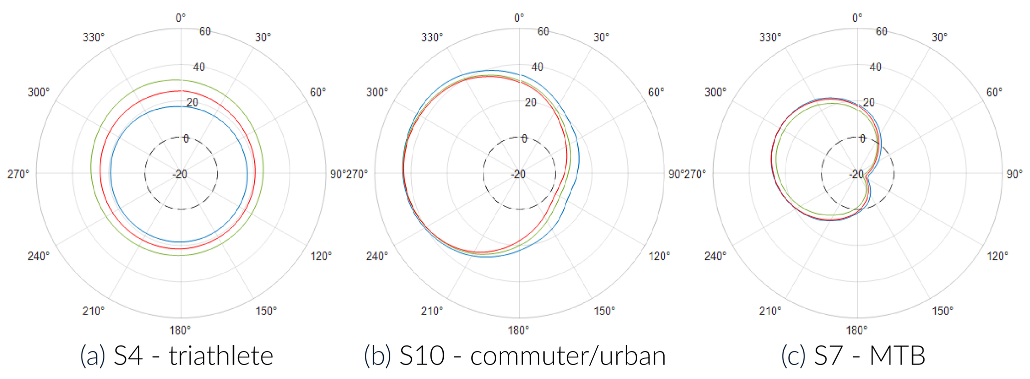

Figure 7. Individual examples for pedal-ground angle over the crank cycle for individual athletes (S4, S10, S7) with different sporting backgrounds showing distinct pedalling patterns (**positive value = heel up**). Results for all power-outputs (I1…I5) over a crank cycle for all shoes (black dashed line: 0°, blue: DF1 - soft, green: DF2 - stiff, red: DF3 - stiffest)

Main findings | Discussion

1. As expected **stiffer soles show a smaller MTP-angle** which **increases with increasing power output**, no MTP-dorsiflexion was observed in the sample (Figure 4, Figure 5). But other than expected there was **only a small difference between nylon and a carbon insole** even for high power output. **Pedal-ground angle is not influenced by shoe stiffness** (Figure 5) but shows distinct **individual differences** between single subjects independent of insole stiffness, which can - based on the given sample - be separated into three different groups: (a) constant heel-up (Figure 7a), (b) oscillating heel-up (Figure 7b), (c) oscillating heel-up/heel-down (Figure 7c).
2. **Practical Applications**
   For both leisure and competitive cycling conclusions can be drawn for industry. **Hybrid shoes** - according to the data acquired - **do not need to be extremely stiff to prevent excessive MTP-plantarflexion** - DF2 and DF3 have quite similar results. For leisure cycling **this would allow the construction of shoes for cycling and walking using comparatively cheap materials**. But using an EVA material (DF1) resulted in excessive plantar flexion during cycling and might not be suitable for such a shoe.
   Concerning **competitive cycling**, one practical application that might be of increased interest is **in triathlon racing** as **it could be a step towards the evidence-based construction of a hybrid cycling-running shoe** as already mentioned by [4].

Future research in this field should therefore focus to ascertain correlation of **specific stiffness and foot biomechanics for both cycling and walking/running.**

References

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