Midsole bending stiffness of running shoes & muscle-tendon unit mechanics

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Introduction

- Multiple compliances of the foot-shoe interface (e.g., plantar aponeurosis, Achilles tendon, shoe) were suggested to store and release energy during running[1-3].
- The midsole bending stiffness (MBS) of a running shoe is an external compliance that can be manufactured to increase athletic performance[4].
- One mechanism as to why increased MBS can improve athletic performance was suggested to be its ability to alter the mechanics of muscle-tendon units (MTUs) of the foot-shoe interface[5].

Purpose

The purpose of this project was to investigate how compliances of the foot-shoe interface are affected during running when the MBS of a sport shoe is increased. Specifically, the behaviour of the plantar (pMTU) and shank muscle-tendon units (sMTU) were of interest.

Hypothesis

It was hypothesized that the positive work performed by the pMTU will be reduced in the stiff condition because it's shortening will be limited due to the windlass mechanism. Also, it was hypothesized that the sMTU mechanics will be altered by increasing the MBS of running shoes.

Methods

Participants

N = 13
Male, recreational runners
30 seconds running
Speed: 3.5 m/s

Conditions

Control
Nike Free 5.0 k = 1.2 N/mm

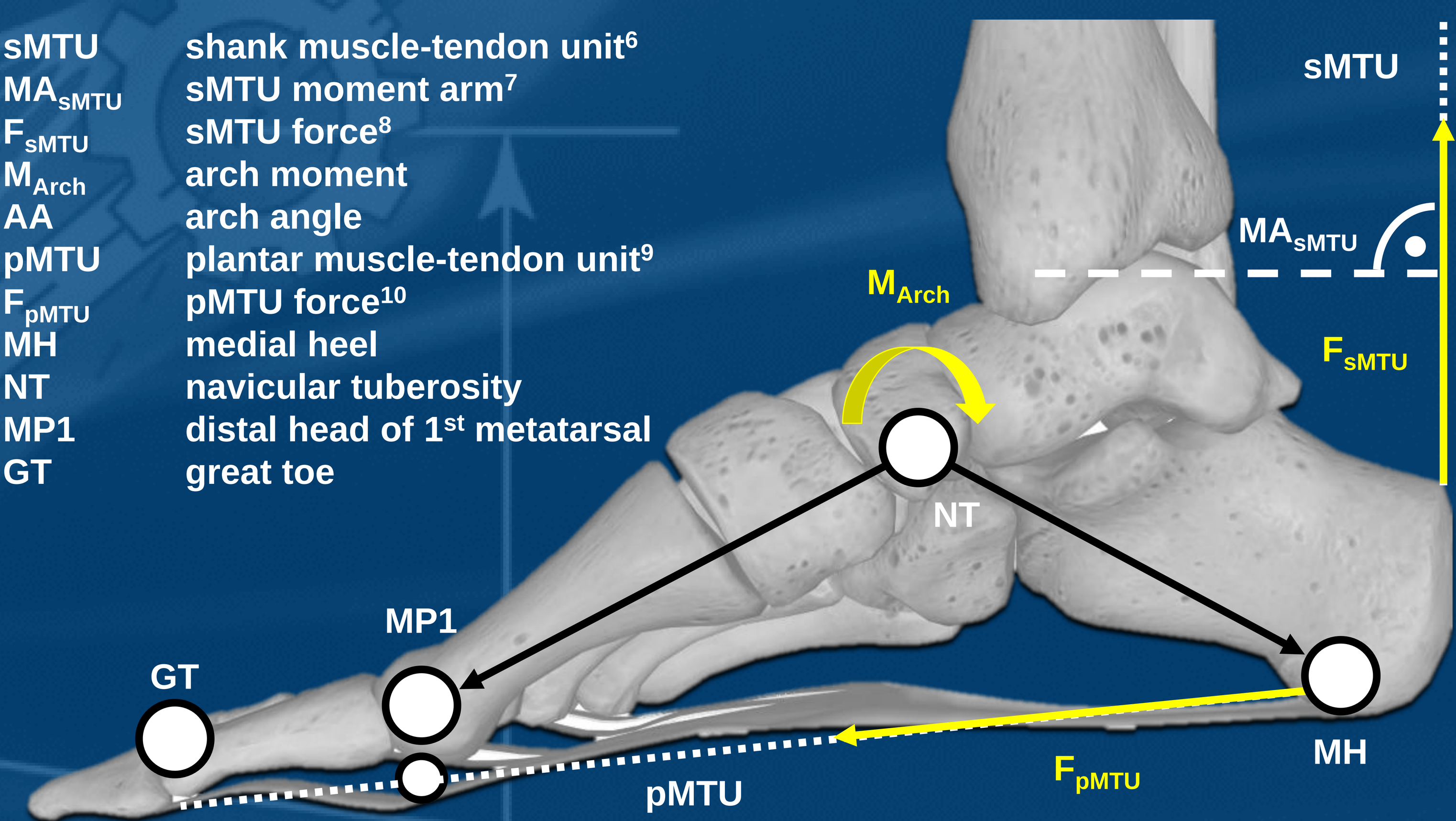
Stiff
Nike Free 5.0 + Carbon fibre plate
k = 11.9 N/mm

Equipment

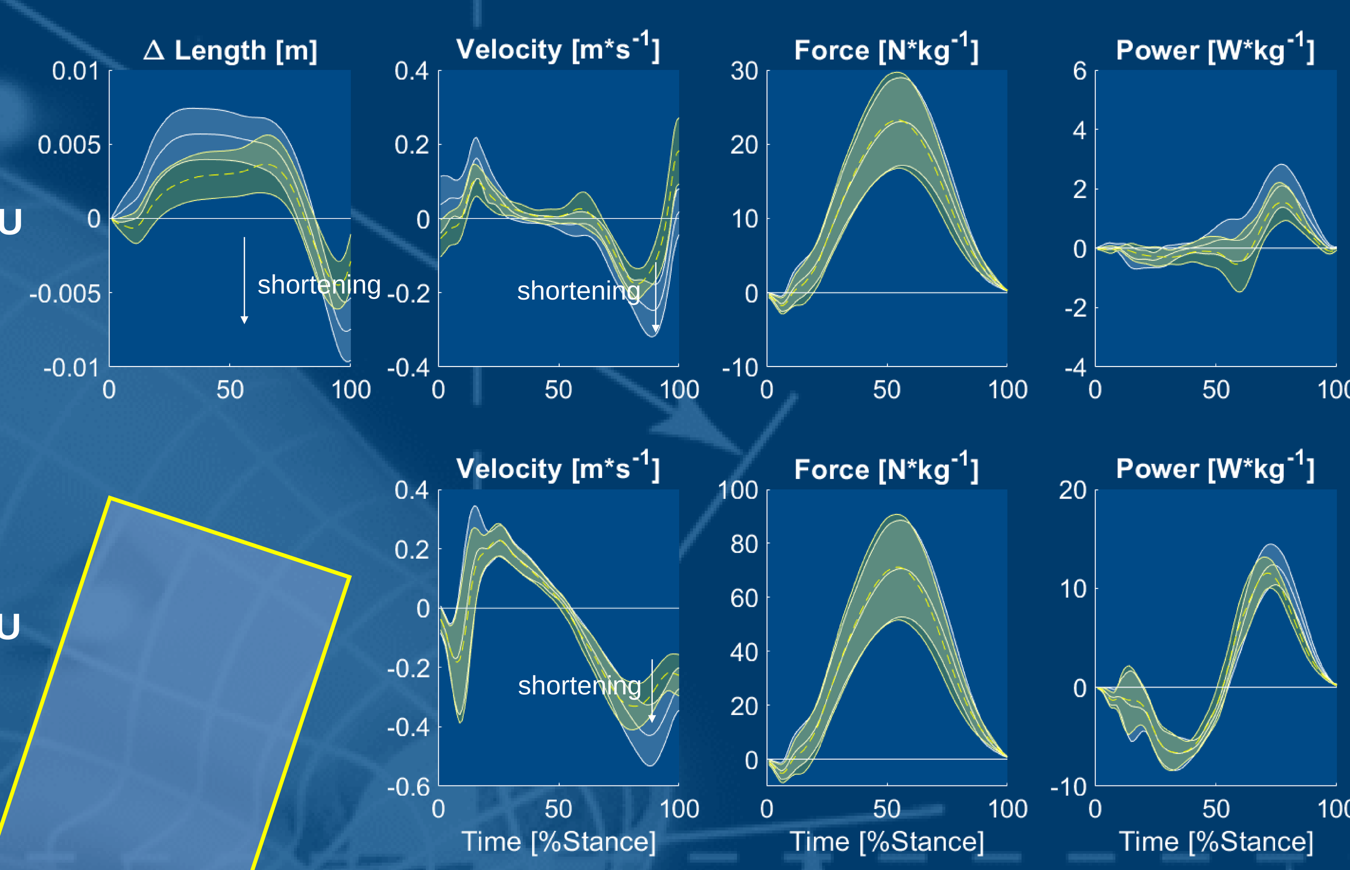
- 8 camera motion capture system
- Force-instrumented treadmill
- Ultrasound
- Dynamometry

MTU models

sMTU shank muscle-tendon unit[6]
MA_{sMTU} sMTU moment arm[7]
F_{sMTU} sMTU force[8]
M_{Arch} arch moment
AA arch angle
pMTU plantar muscle-tendon unit[9]
F_{pMTU} pMTU force[10]
MH medial heel
NT navicular tuberosity
MP1 distal head of 1st metatarsal
GT great toe



Results



	Pos. Work [J*kg-1]		Neg. Work [J*kg-1]		Net Work [J*kg-1]	
	Control	Stiff	Control	Stiff	Control	Stiff
pMTU	0.13 (0.04)	0.09* (0.03)	-0.04 (0.02)	-0.06* (0.03)	0.10 (0.05)	0.03* (0.04)
sMTU	0.76 (0.13)	0.73 (0.11)	-0.45 (0.11)	-0.45 (0.10)	0.31 (0.14)	0.28* (0.10)

* Represents a significant ($\alpha < 0.05$) difference between footwear conditions

Discussion

- Increasing the stiffness of the external compliance (i.e., MBS of shoe) resulted in:
  → Less stretch of the pMTU
  → Less shortening of the pMTU
  → Slower shortening of the pMTU
  → Less positive and net work performed by the pMTU
  → More negative work performed by the pMTU

  → Slower shortening of the sMTU
  → Less net work performed by the sMTU
- Differences in work between shoe conditions were due to velocities, not forces
  → amount/velocity of MTU deformation was reduced but mechanical load remained the same
- Significantly longer ground contact times in the stiff condition could have allowed the MTUs to generate the same amount of force at slower velocities
  → muscular compartment of the MTUs operated more economically

Conclusion

- If slower shortening velocities of the MTUs are attributed to the muscle
  → Could be related to lower metabolic cost of running
- If slower shortening velocities are attributed to the tendon
  → Could be indicative of reduced energy return capacities of the tendon
- Deformation of linear compliances (i.e., pMTU) was reduced when running with increased MBS of a shoe; however, mechanical load remained the same
  → Apparent stiffness of this compliance was increased with greater MBS
  → The foot-shoe interface could then be modelled as multiple springs that act in series:

$$k_{foot/shoe} = \left(\frac{1}{k_{foot}} + \frac{1}{k_{shoe}}\right)^{-1}$$