# Is the Foot Working With or Against the Ankle During Human Walking?

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# Is the <u>Beach</u> Working With or Against the Ankle During Human Walking?



**Turks & Caicos** 



# Sand dissipates energy during walking

#### 60-150% more biomechanical work, 110-150% higher metabolic cost



# Sand dissipates ankle Push-off



# Consensus: Push-off facilitates economical gait



# No consensus: primary function of ankle Push-off



### Good news: these are not mutually exclusive

Both are equally valid descriptions



#### Push-off primarily contributes to leg swing & COM kinetics



# Consensus: Push-off facilitates economical gait



# Consensus: Push-off is good

Corollary: dissipating Push-off is bad (for gait economy)



# Is the Foot Working With or Against the Ankle (Push-off) During Human Walking?

# Feet are complex, contain 25% of bones in body



#### Foot kinetics estimated using deformable body model



#### Foot kinetics estimated using deformable body model



# Foot\* absorbs energy during push-off, returns little

\*everything distal to the ankle joint



# Foot\* absorbs energy during push-off, returns little





#### Foot\* absorption partly due to negative toe joint work

#### \*everything distal to the ankle joint



#### EMGs provide supplemental perspective



#### Negative toe work during active muscle contractions

foot absorption not simply the result of passive deformation



# Consensus: Push-off is good

#### Corollary: dissipating Push-off is bad (for gait economy)

------ Sand (Lejeune, Willems & Heglund 1998)



# What is going on with the foot?

3 Possibilities...

Why does it matter?

Example: implications for prosthetic foot design

# Possibility 1: Foot is working <u>against</u> the ankle

Foot absorption detrimental to gait economy, perhaps beneficial for other reasons (e.g., adaptability)? Song & Geyer 2011, Song, Collins & Geyer 2013

![](_page_22_Figure_2.jpeg)

## Possibility 1: Foot is working <u>against</u> the ankle

Foot absorption detrimental to gait economy, perhaps beneficial for other reasons (e.g., adaptability)?

Song & Geyer 2011; Song, Collins & Geyer 2013

#### **Prosthetic Foot Implication 1: Avoid Biomimicry**

If goal is to improve amputee walking economy, then don't mimic wasteful foot behavior.

Fatigue & increased metabolic demands are common problems for amputees.

![](_page_23_Picture_6.jpeg)

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Fatigue & increased metabolic demands are common problems for amputees.

#### **Prosthetic Foot Implication 2: Actuation Not Required**

Ankle+foot work is <u>not</u> net positive. Powered prostheses may not be needed to emulate ankle+foot function during gait. Takahashi & Stanhope 2013; Zelik, Takahashi & Sawicki 2015

#### Possibility 2: Foot is working with the ankle

Foot absorption itself is bad, but may enable calf muscles to operate at more favorable length or velocity (e.g., Carrier et al. 1994) or extend time duration of Push-off (e.g., clapskates, Houdijk et al. 2000), etc.

# Possibility 2: Foot is working with the ankle

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**Prosthetic Foot Implication 1: Avoid Biomimicry (probably)** If foot behavior enables calf muscles to operate more effectively, then not applicable to amputees/prosthetics.

**Prosthetic Foot Implication 2: Actuation Not Required** Ankle+foot work is <u>not</u> net positive. Powered prostheses may not be needed to emulate ankle+foot function during gait. Takahashi & Stanhope 2013; Zelik, Takahashi & Sawicki 2015

#### **Relevant (upcoming) talks**

- Shreyas Mandre foot stiffness
- Keonyoung Oh toe joint function
- Matt Yandell shod vs. barefoot gait

# Possibility 3: Foot is working with the ankle, BUT...

our conventional biomechanical estimates fail to measure it (e.g., due to neglecting multiarticular muscles) Zelik et al. 2015 EJAP; Zelik, Takahashi & Sawicki 2015 JEB

#### Thought expt: multiarticular muscle acting isometrically

![](_page_28_Picture_1.jpeg)

#### Thought expt: multiarticular muscle acting isometrically

![](_page_29_Figure_1.jpeg)

![](_page_30_Picture_1.jpeg)

![](_page_31_Figure_1.jpeg)

![](_page_34_Figure_1.jpeg)

#### Push-off $\rightarrow$ multiarticular muscle moments

![](_page_35_Figure_1.jpeg)

#### Inverse dynamics $\rightarrow$ apparent negative foot work

![](_page_36_Figure_1.jpeg)

#### Inverse dynamics $\rightarrow$ apparent positive ankle work

![](_page_37_Figure_1.jpeg)

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![](_page_38_Figure_2.jpeg)

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**Prosthetic Foot Implication: Avoid Mimicking Current Estimates** We need better empirical estimates to understand & restore normal ankle-foot function.

#### **Relevant talks & posters**

- Eric Honert (poster 54) accounting for multiarticular ankle-foot muscles
- Ryan Riddick modeling & estimating foot kinetics

#### Concluding Remarks

1. Thank you DW committee (for session on feet)

- 2. Encourage everyone to think more about feet
  - not to a creepy fetish level, but to a level reflective of foot's importance
    ignoring foot is akin to ignoring knee during gait

![](_page_40_Figure_4.jpeg)

#### **Concluding Remarks**

1. Thank you DW committee (for session on feet)

- 2. Encourage everyone to think more about feet
  - not to a creepy fetish level, but to a level reflective of foot's importance
    ignoring foot is akin to ignoring knee during gait (Zelik, Takahashi & Sawicki 2015)
- 3. Request feedback, thoughts, new perspectives... Is the foot working with or against the ankle during human walking?

# Is the Foot Working With or Against the Ankle During Human Walking?

![](_page_42_Figure_1.jpeg)