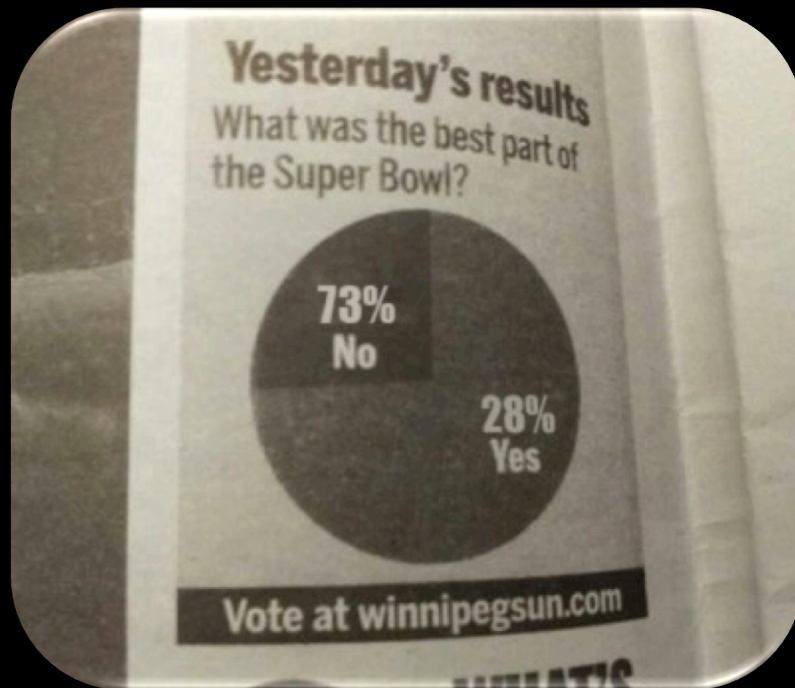


Improved empirical estimates of work production in human walking motivate updated theory of step-to-step transition

Karl E. Zelik

Laboratory of Neuromotor Physiology, Santa Lucia Foundation, Italy (until July)
Department of Mechanical Engineering, Vanderbilt University (from August)



Bad Pie Charts & Dennis Rodman

Karl E. Zelik

Laboratory of Neuromotor Physiology, Santa Lucia Foundation, Italy (until July)
Department of Mechanical Engineering, Vanderbilt University (from August)

1. We all make bad pie charts (in biomechanics)

... but we don't have to



2. Why Rebound?

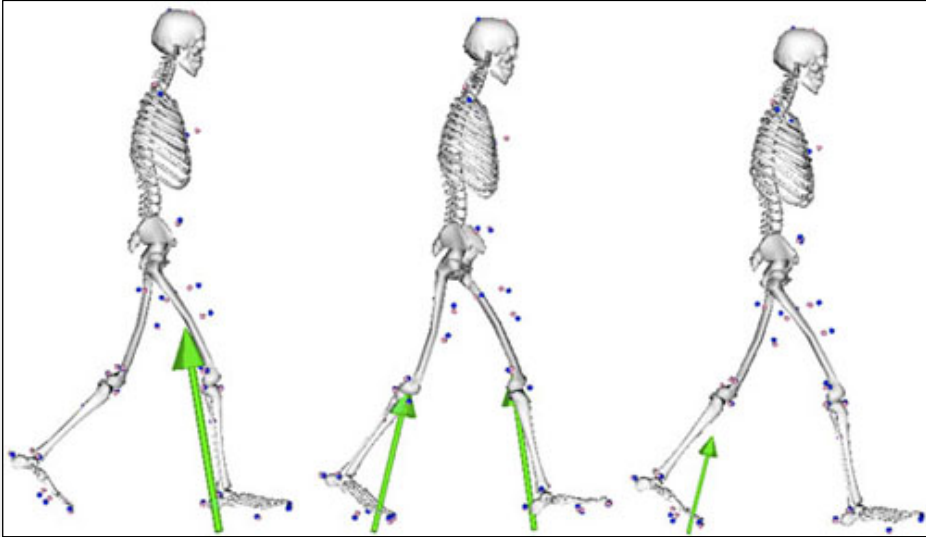
analogous reasons for basketball & walking?



7x NBA Rebounding Champion (1992-98)

SOCIETAL SIGNIFICANCE

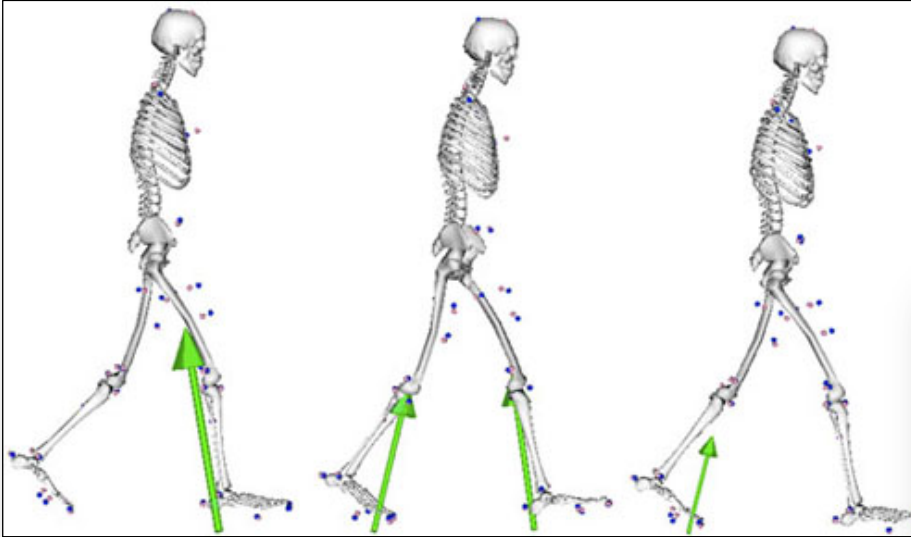
Biomechanical measures → science



engineering.pitt.edu/SubSites/HMBL

SOCIETAL SIGNIFICANCE

Biomechanical measures → science, tech



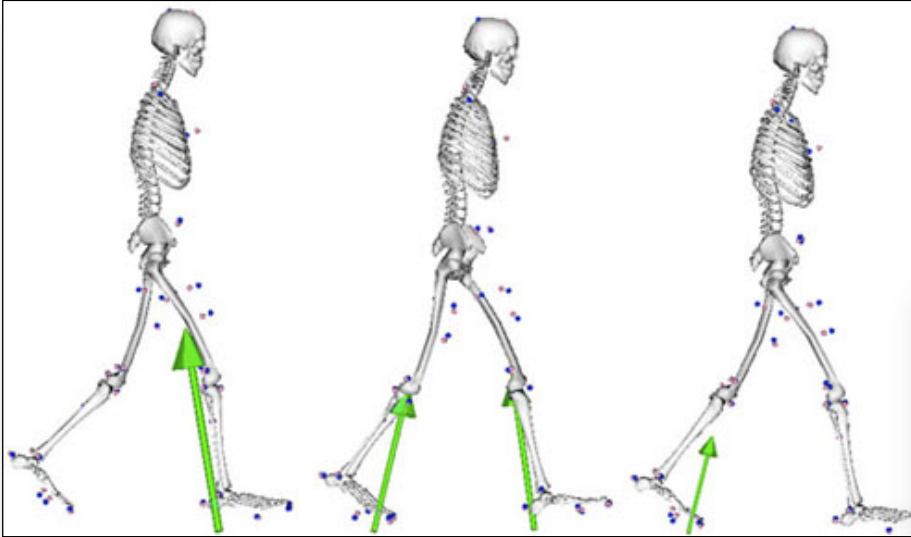
engineering.pitt.edu/SubSites/HMBL



Farris, Quintero & Goldfarb 2011

SOCIETAL SIGNIFICANCE

Biomechanical measures → science, tech & medicine



engineering.pitt.edu/SubSites/HMBL



Gage 1994, Wren et al. 2011



Farris, Quintero & Goldfarb 2011

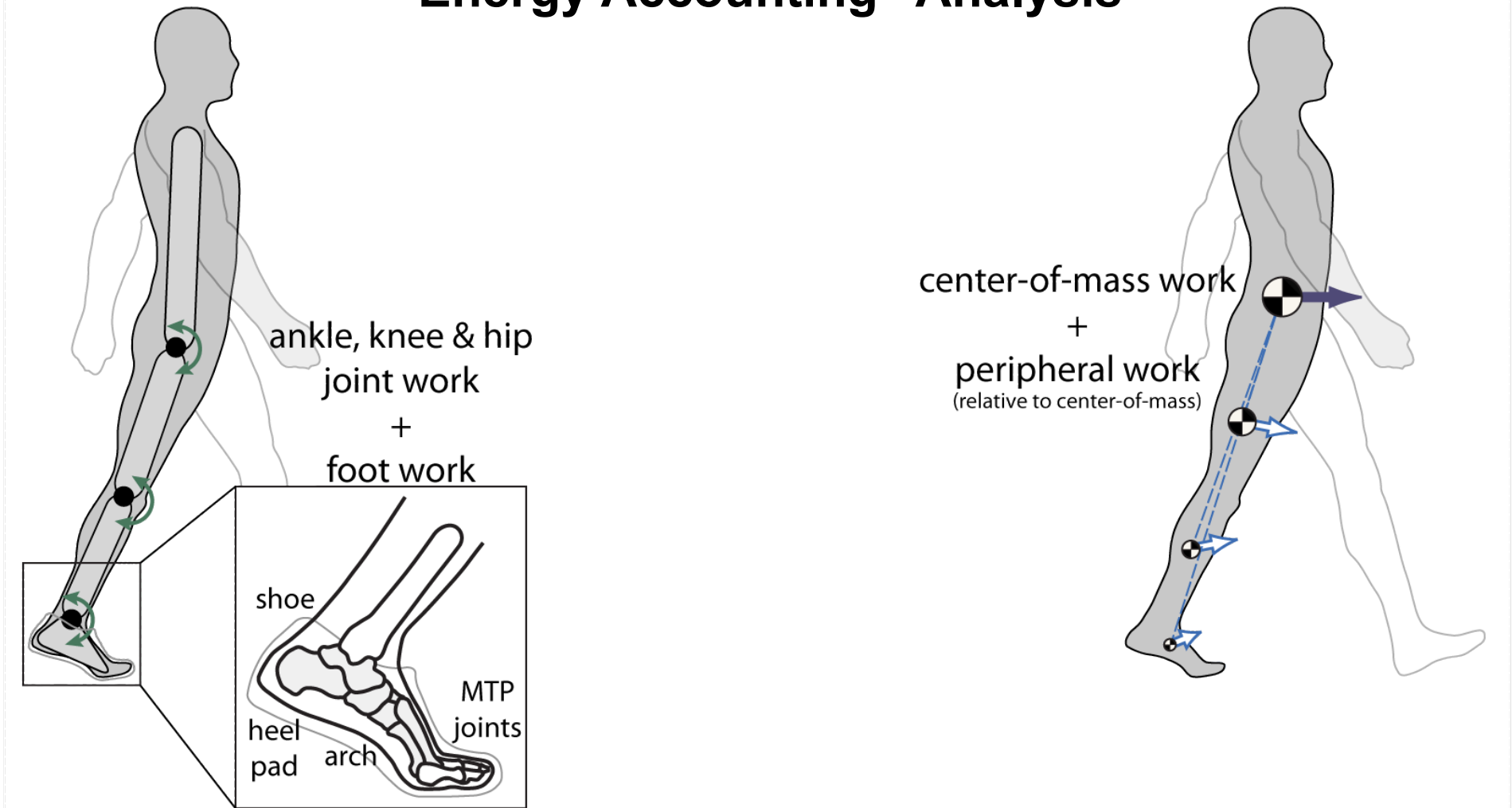
QUESTION

How good are our biomechanical measures?

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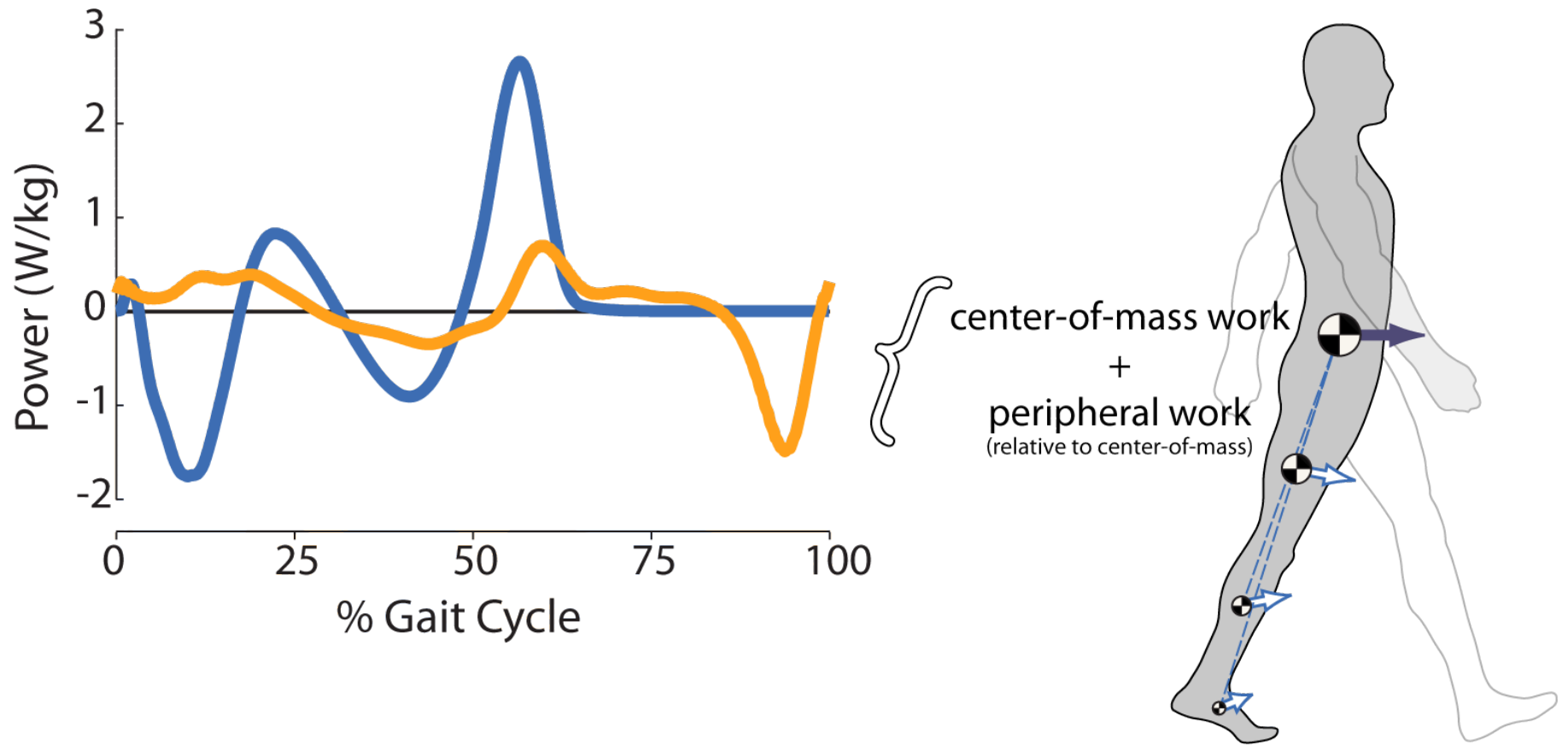
“Energy Accounting” Analysis



Joint-Segment Estimates vs. COM-Based Work Estimates

QUESTION

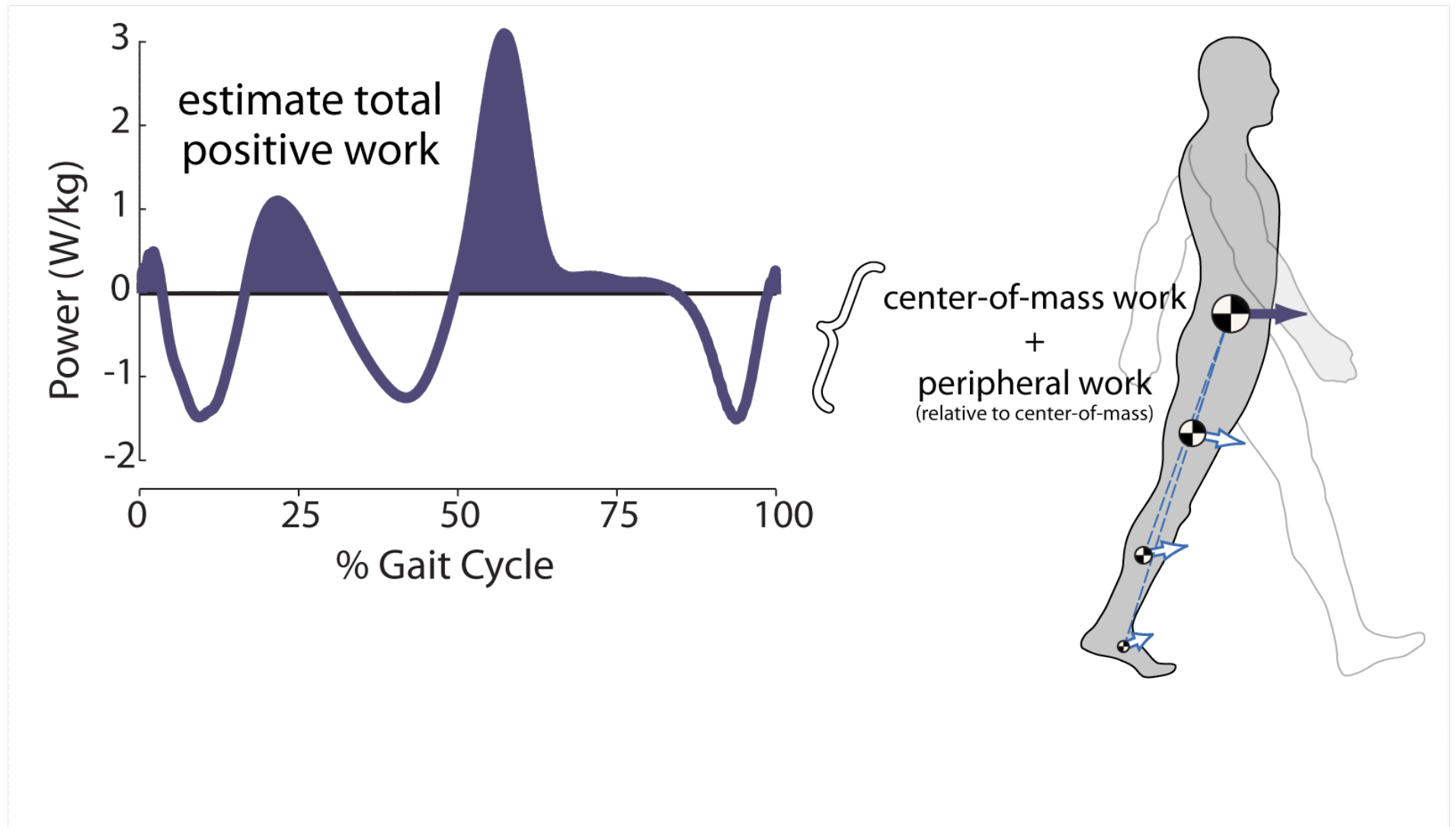
How good are our biomechanical measures?



COM-Based Work Estimates

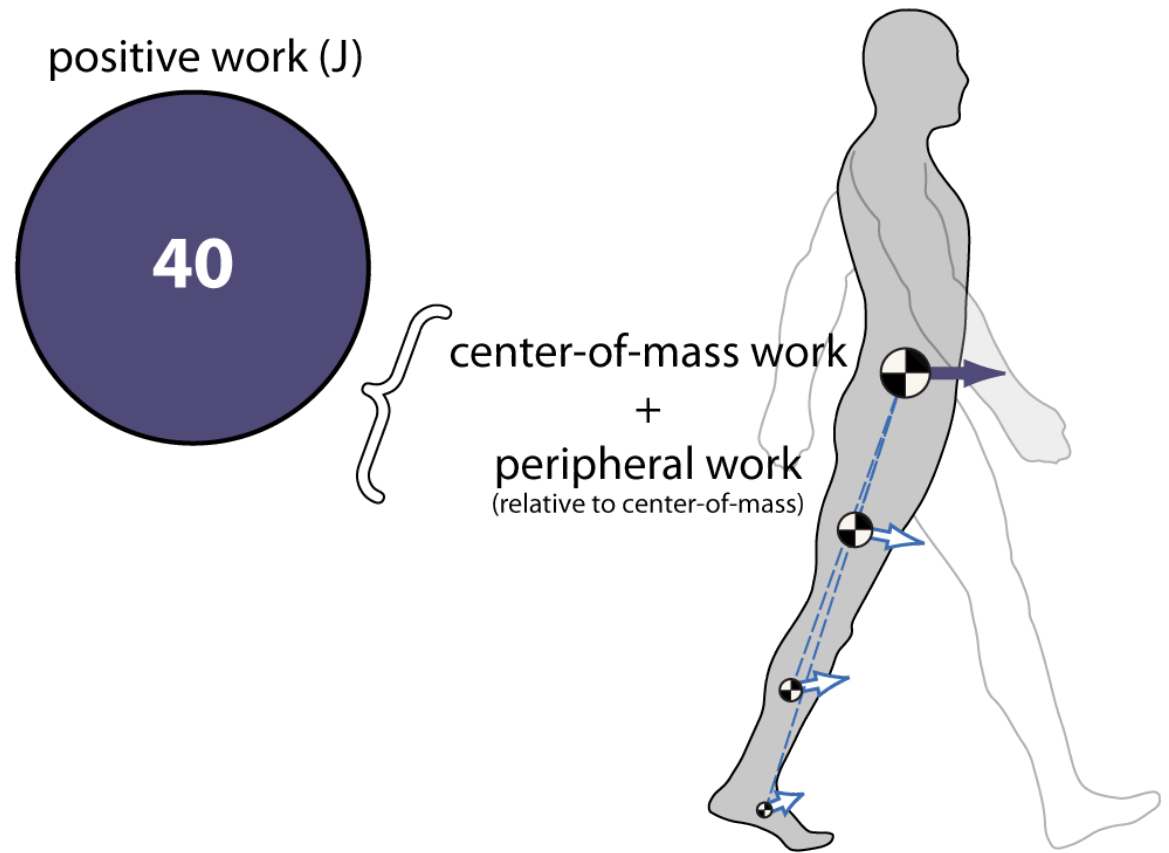
QUESTION

How good are our biomechanical measures?



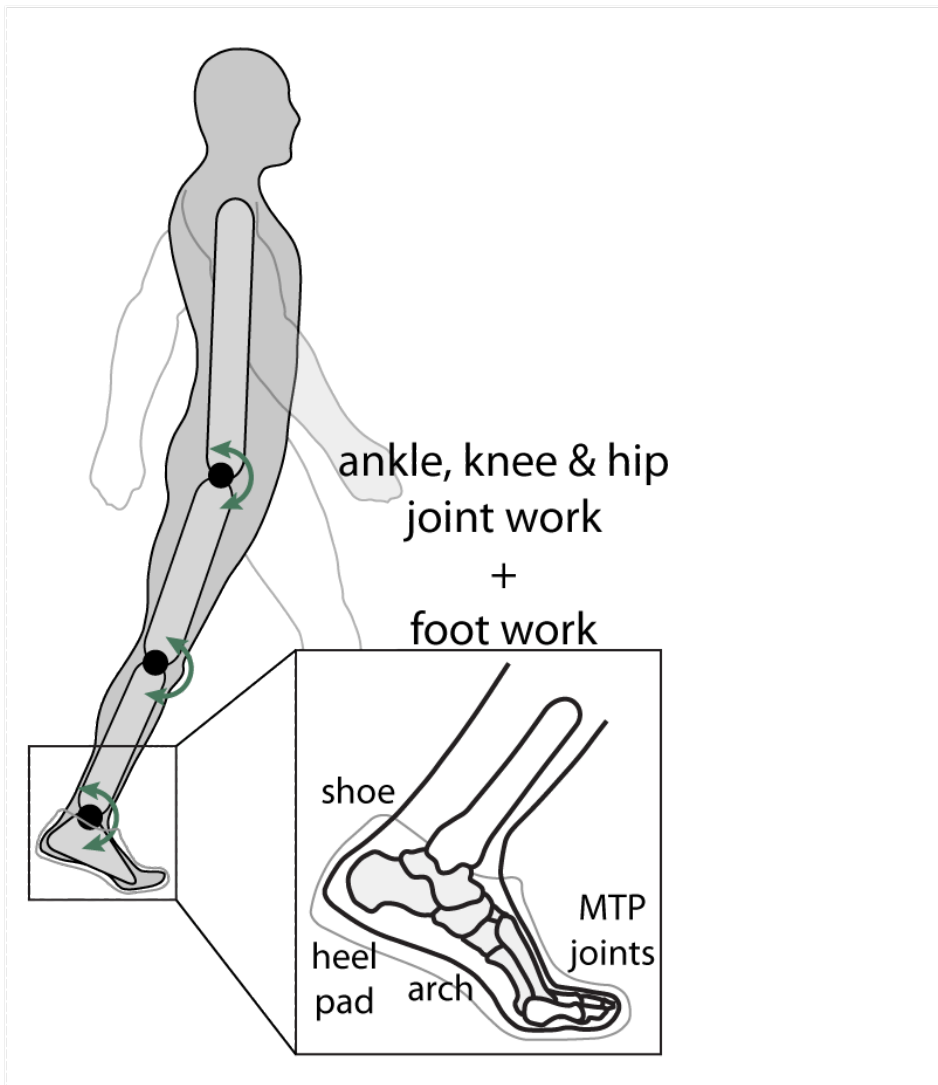
COM-Based Work Estimates

Total positive work ~40 J



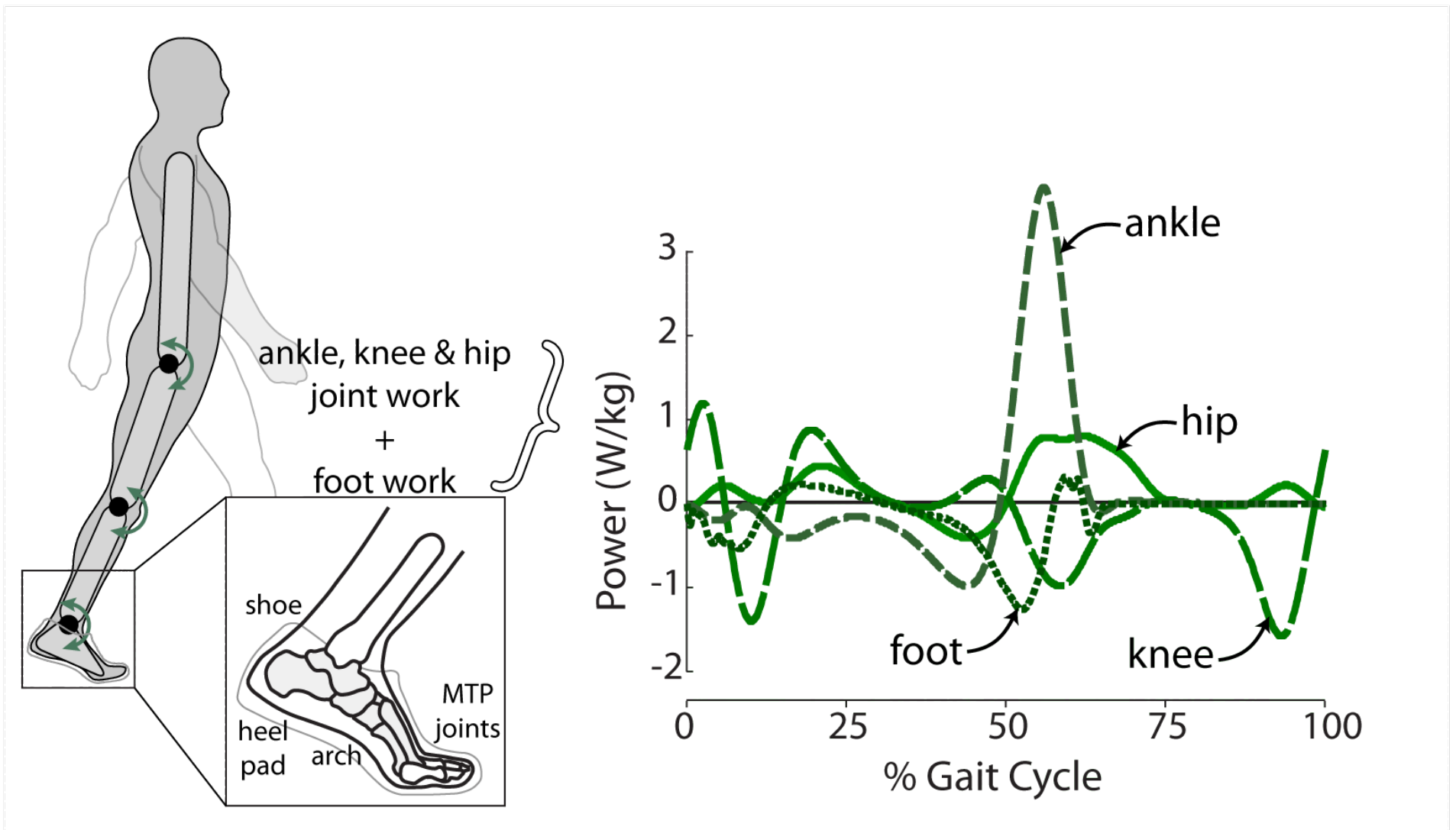
walking at 1.4 m/s

Joint-segment work



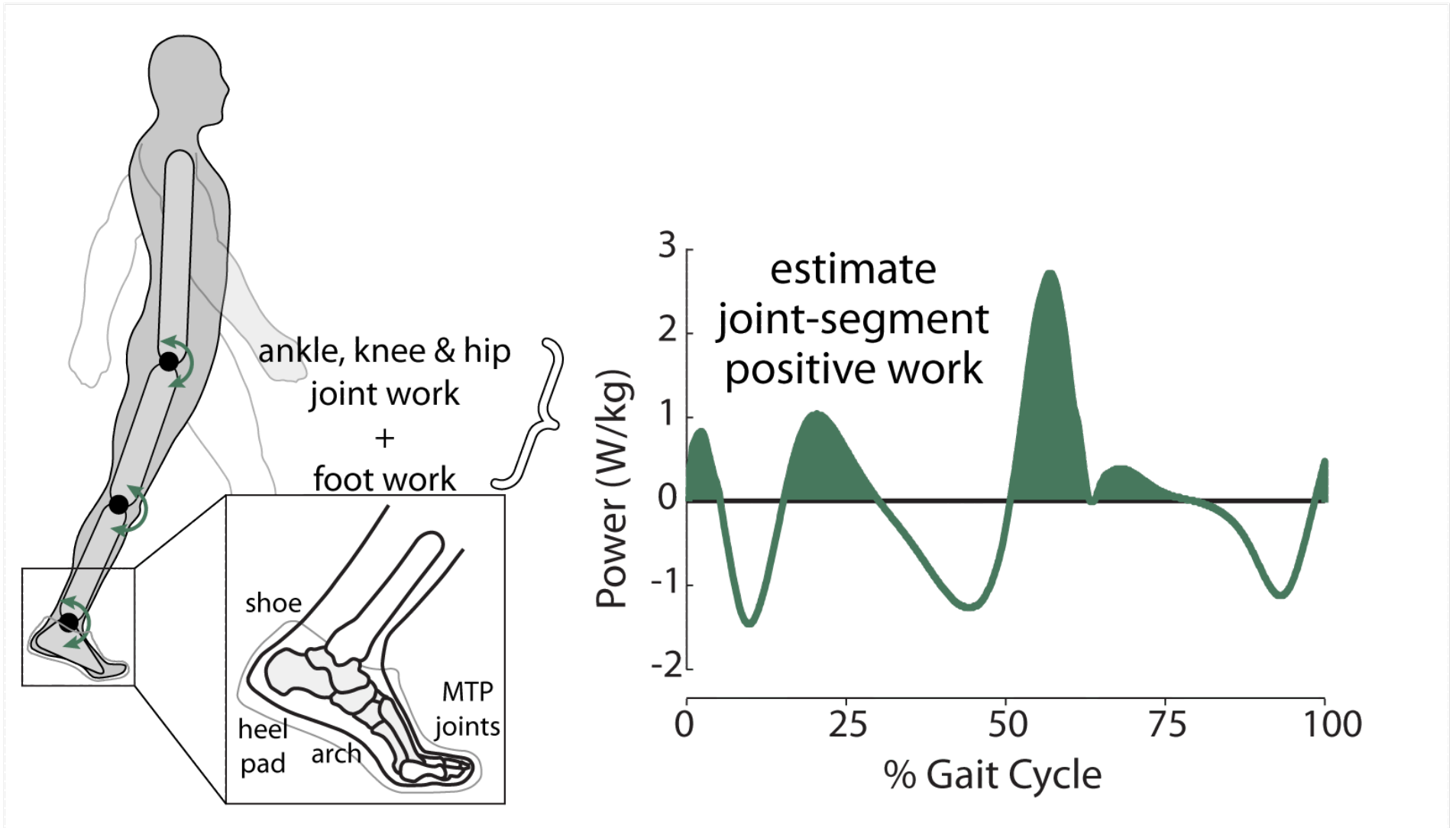
Joint-Segment Estimates

Joint-segment work



Joint-Segment Estimates

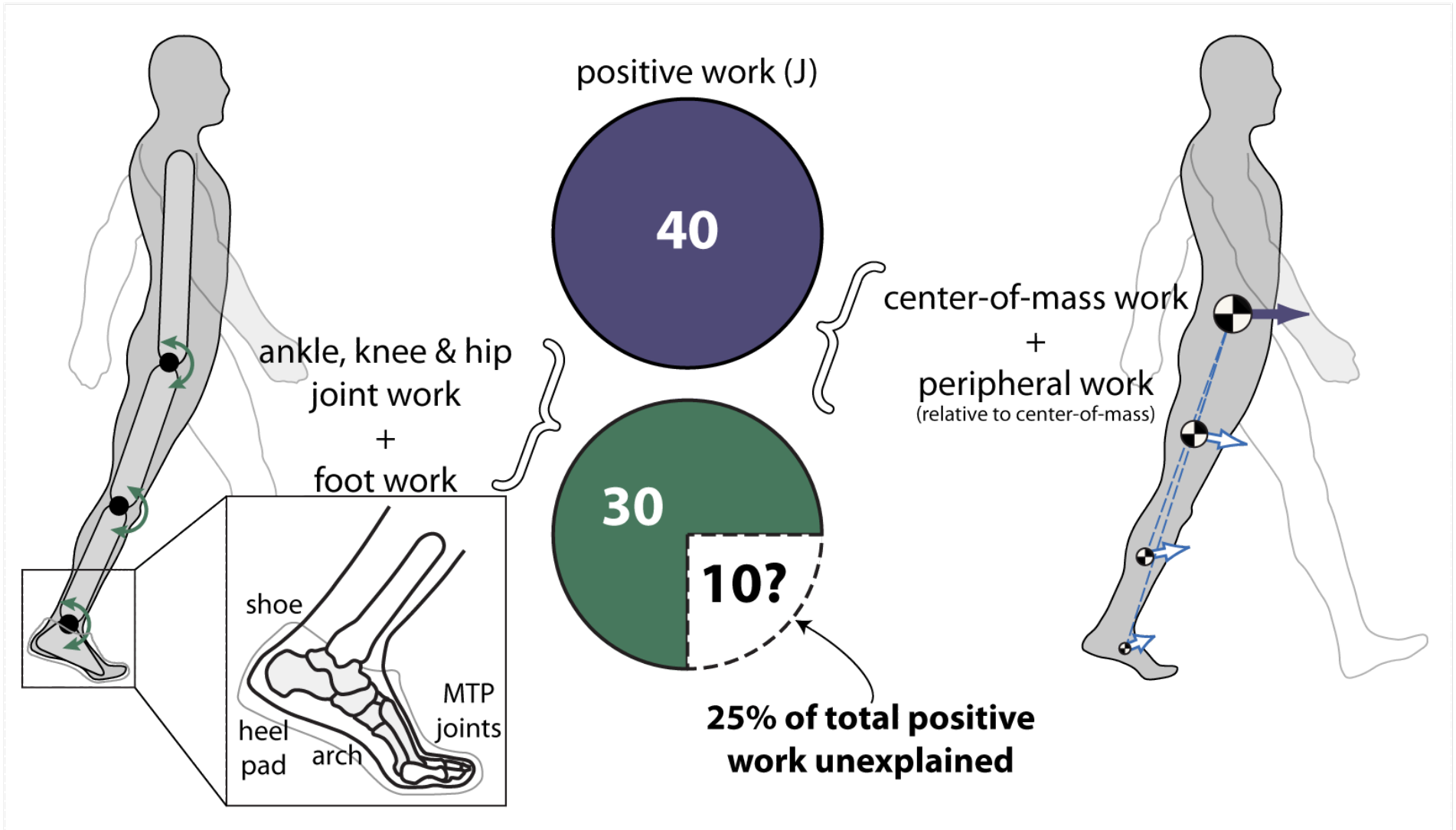
Summed joint-segment work



Joint-Segment Estimates

PROBLEM

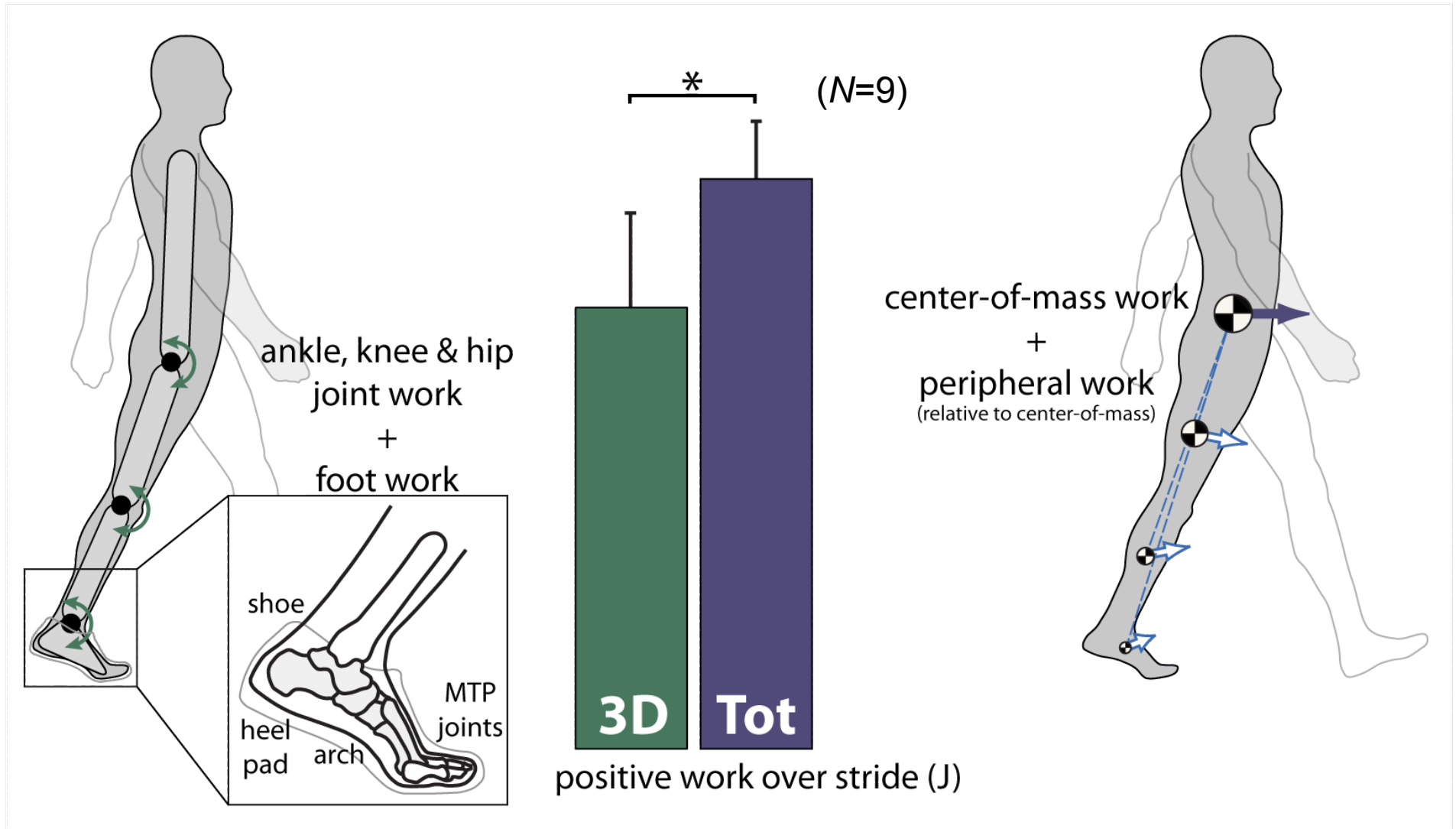
Conventional joint-segment measures miss 25% of work



PROBLEM

Conventional joint-segment measures miss 25% of work

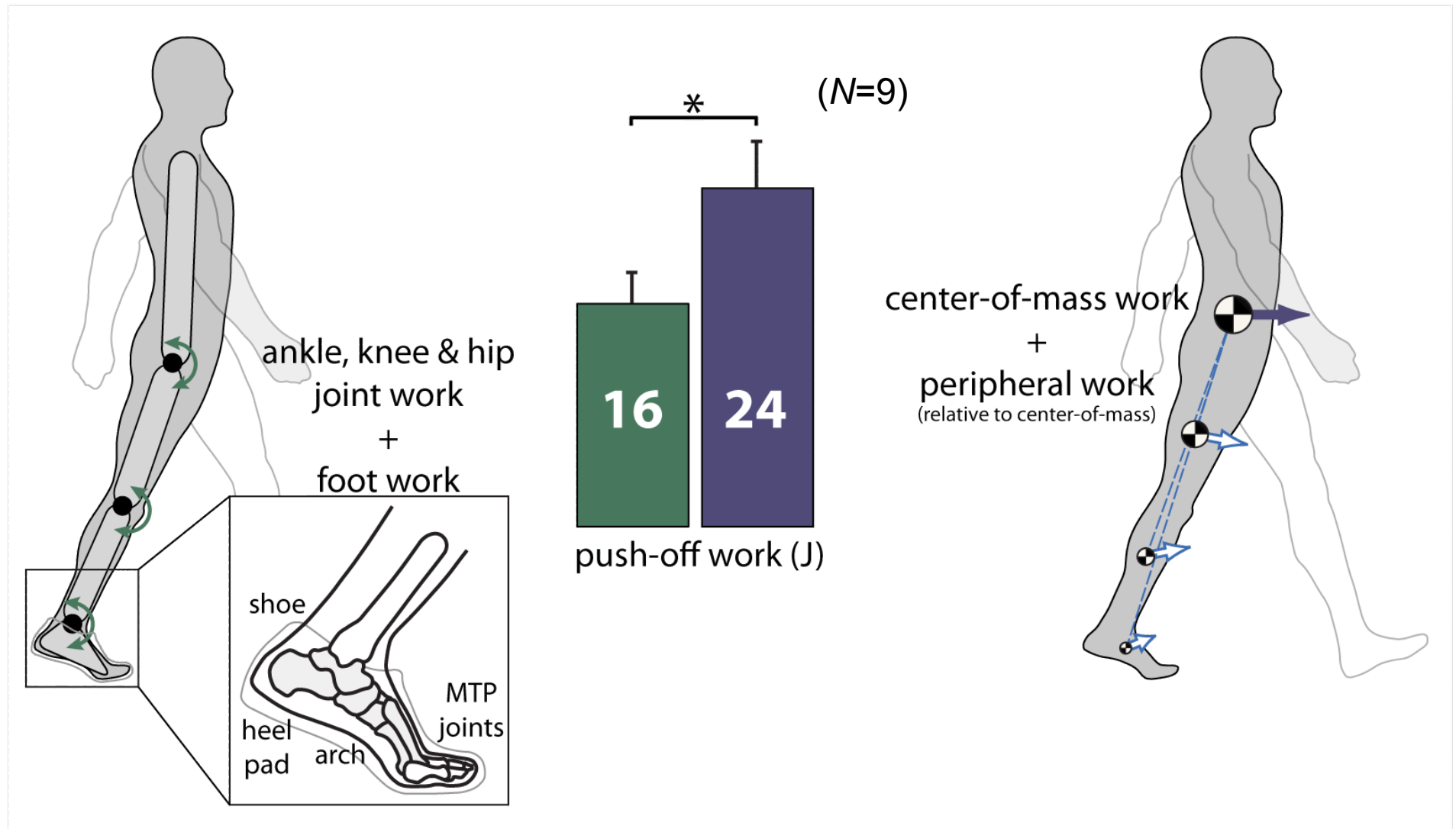
Zelik, Takahashi & Sawicki 2014 (in review)



PROBLEM

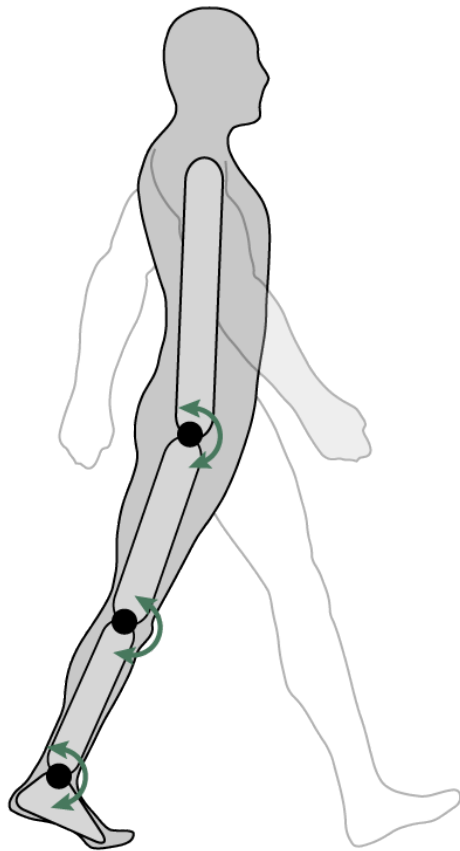
Joint-segment estimates miss even more of Push-off (33%)

Zelik, Takahashi & Sawicki 2014 (in review)



walking at 1.4 m/s

Reconsider current “gold-ish standard”



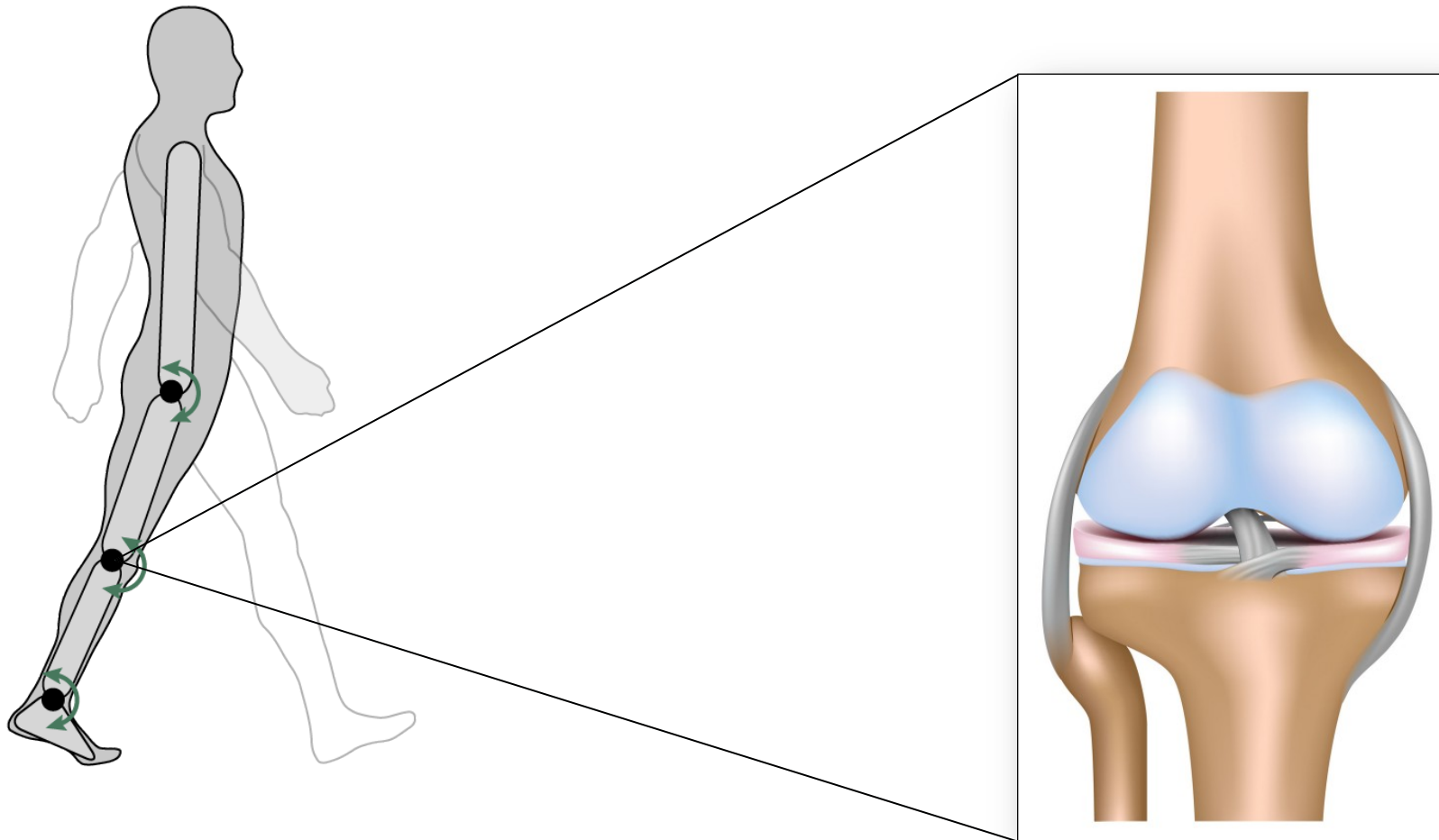
3D inverse dynamics

How much work to rotate body segments?

$$W_{joint} = \int (M_{joint} \omega_{joint}) dt$$

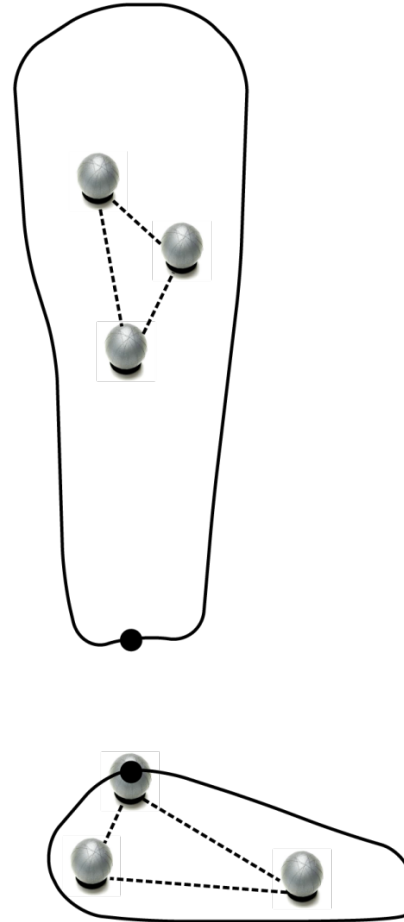
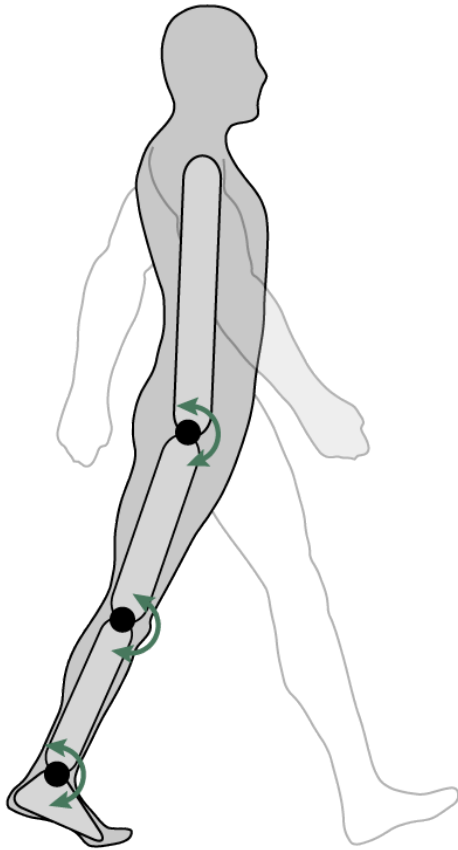
Conventional estimates ignore translational work

due to joint compression



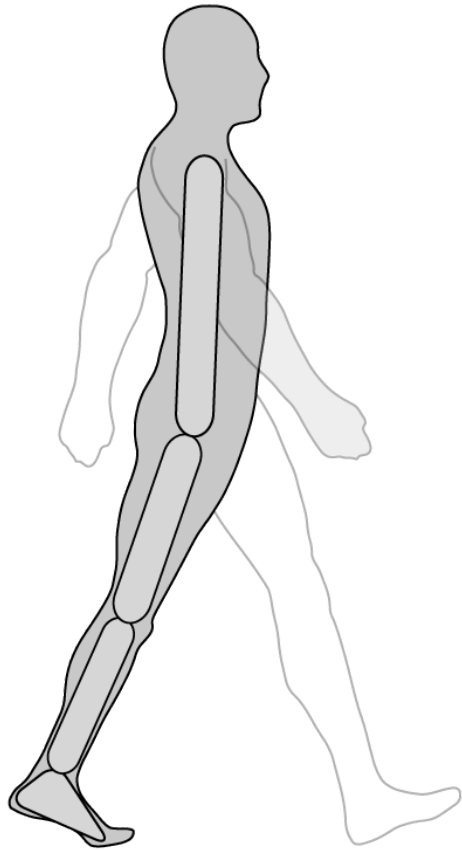
Conventional estimates ignore translational work

or due to measurement limitations



HYPOTHESIS

6D estimates would explain missing work



6D inverse dynamics

How much work to
move body segments?

$$W_{joint} = \int \left(M_{joint} \omega_{joint} + F_{joint} \Delta v_{joint} \right) dt$$

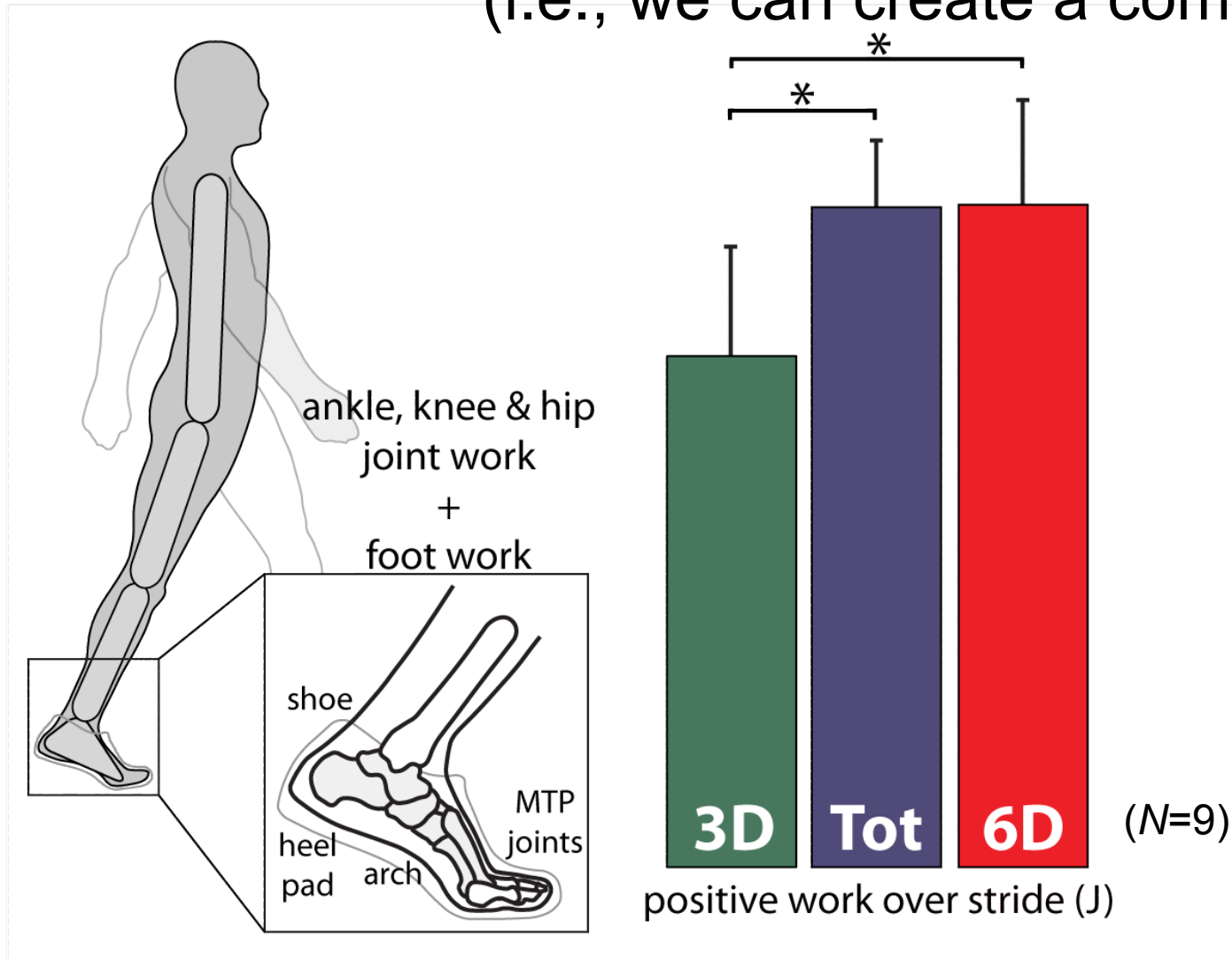
rotational work + translational work

Buczek 1994, Duncan 1997

KEY FINDING 1

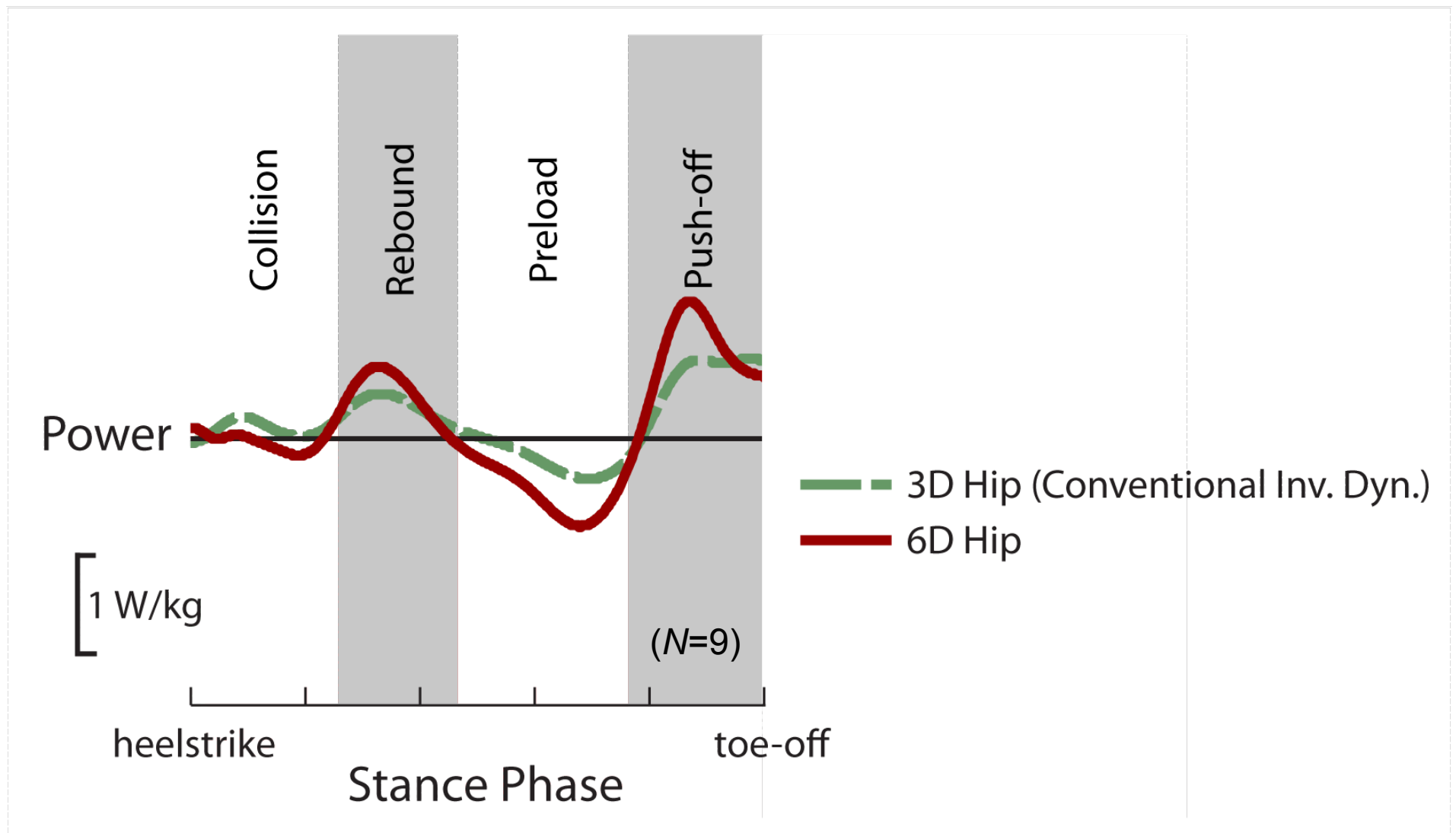
6D analysis explains positive work across stride

(i.e., we can create a complete pie chart)



KEY FINDING 2

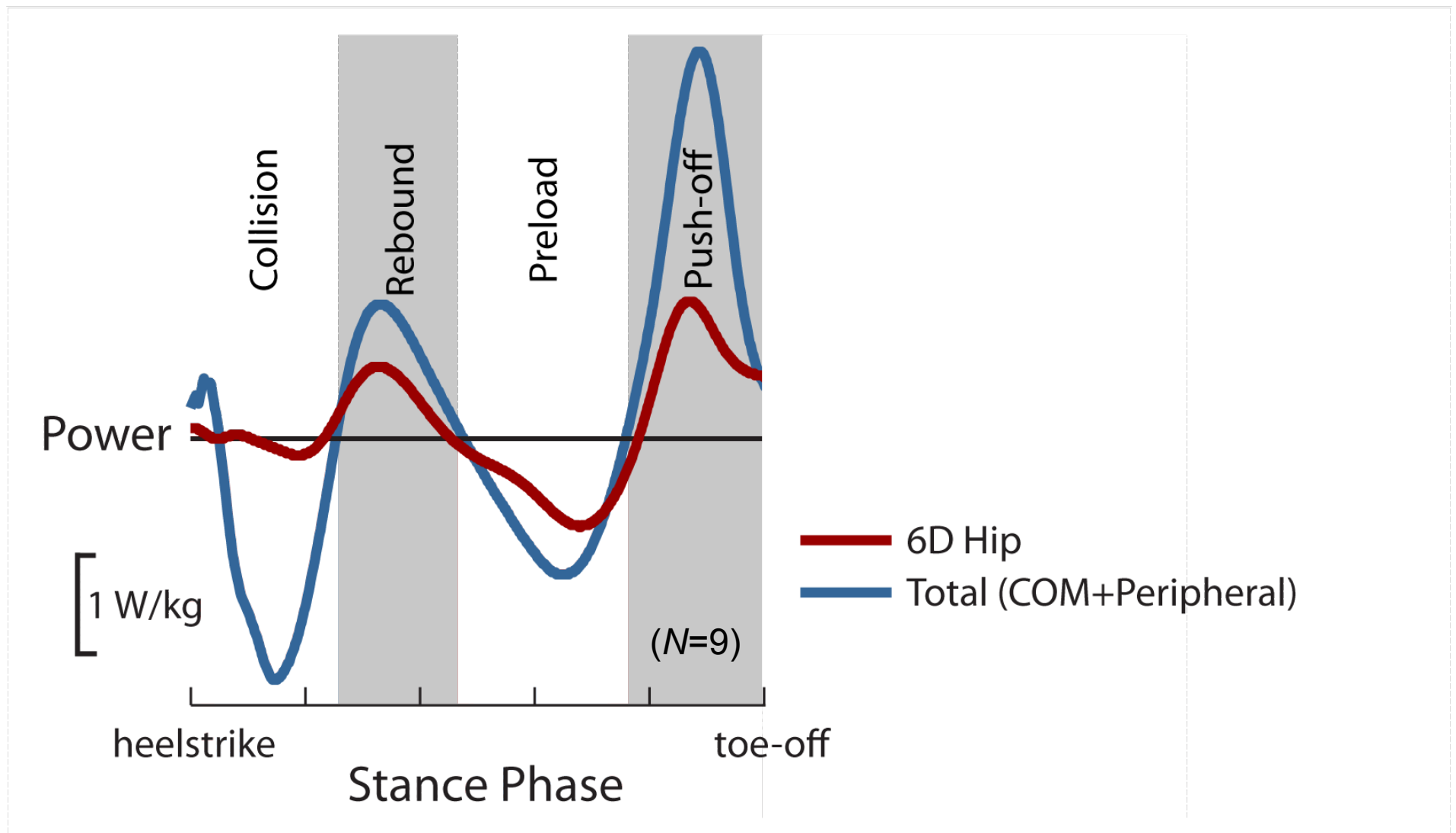
6D analysis reveals more hip work



Zelik, Takahashi & Sawicki 2014 (in review)

KEY FINDING 2

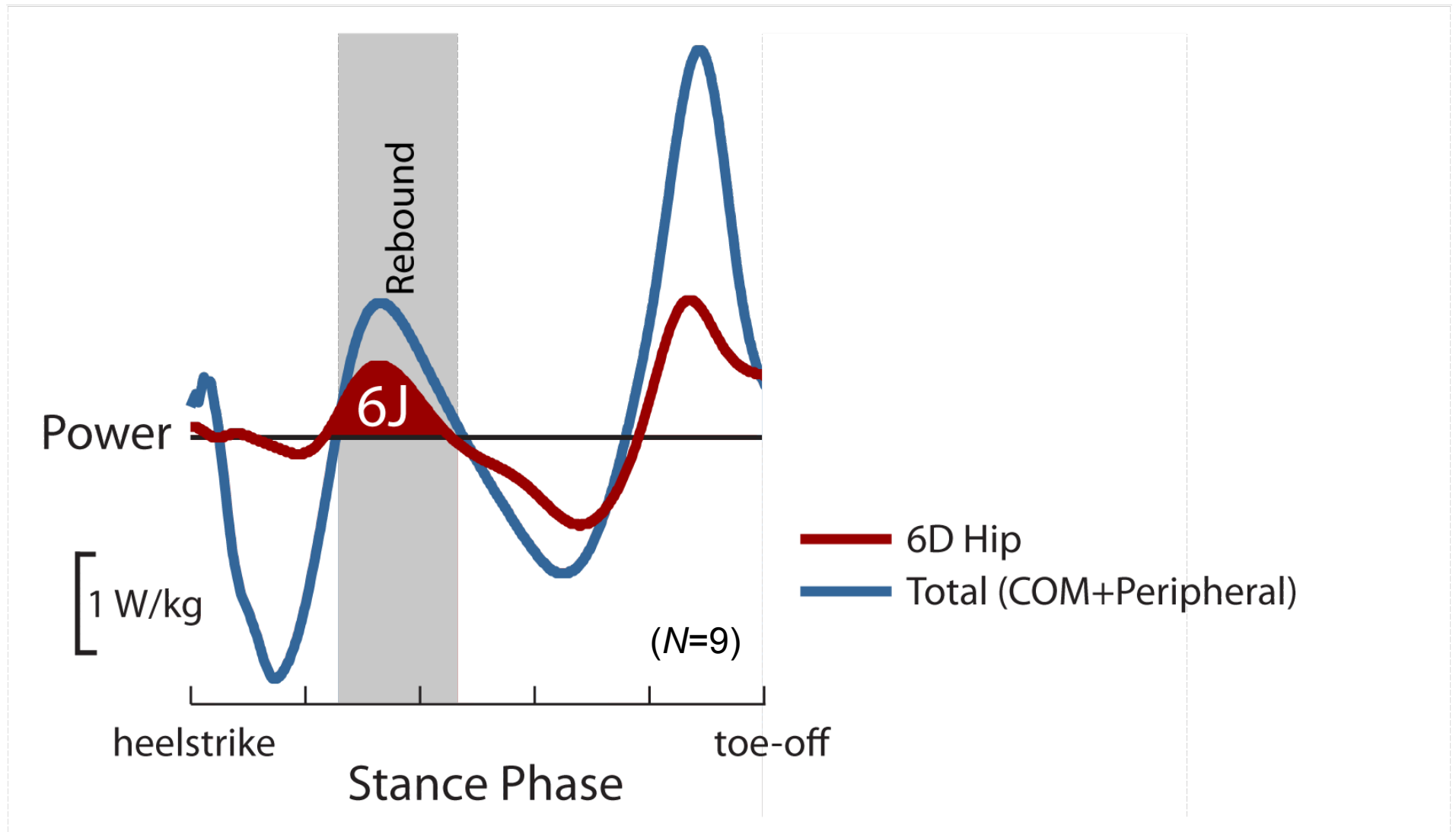
6D analysis reveals more hip work



Zelik, Takahashi & Sawicki 2014 (in review)

QUESTION

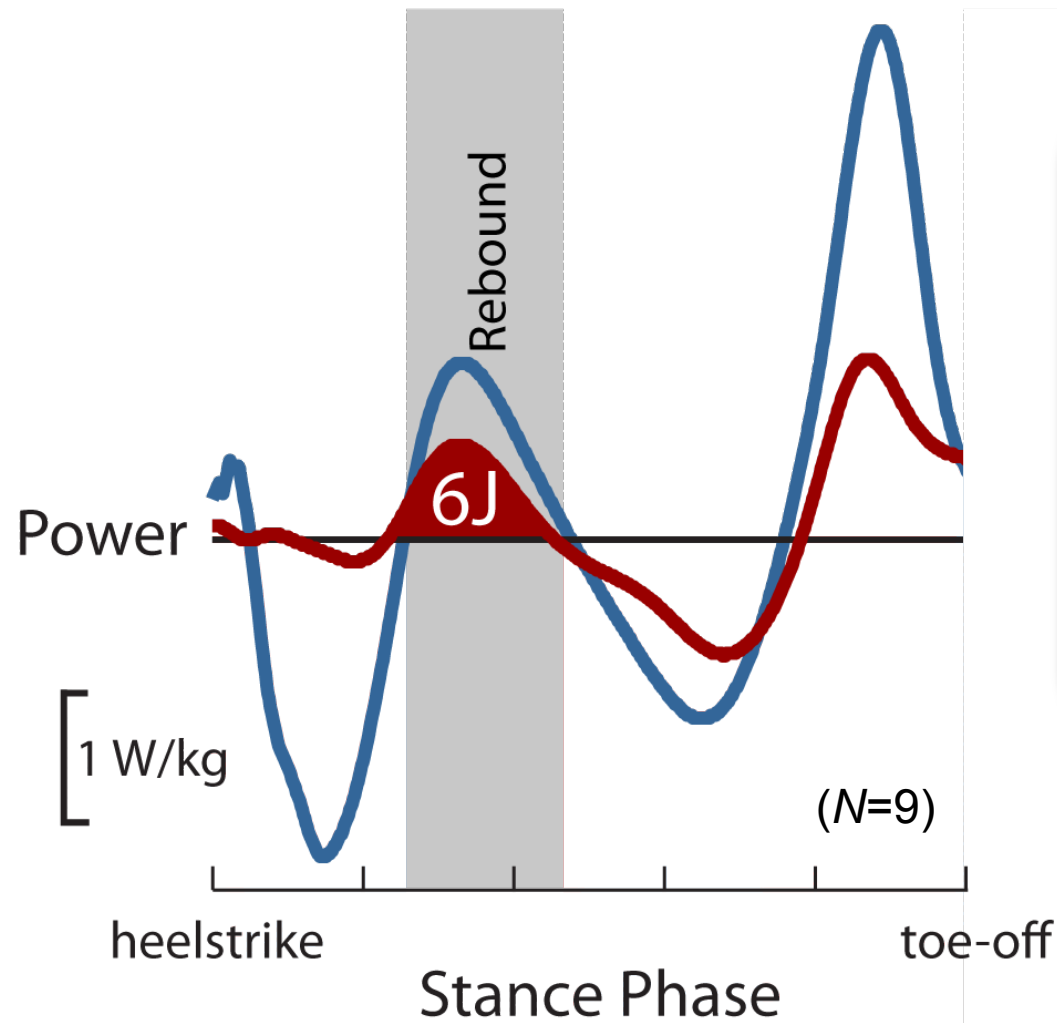
Why (active) Rebound?



Zelik, Takahashi & Sawicki 2014 (in review)

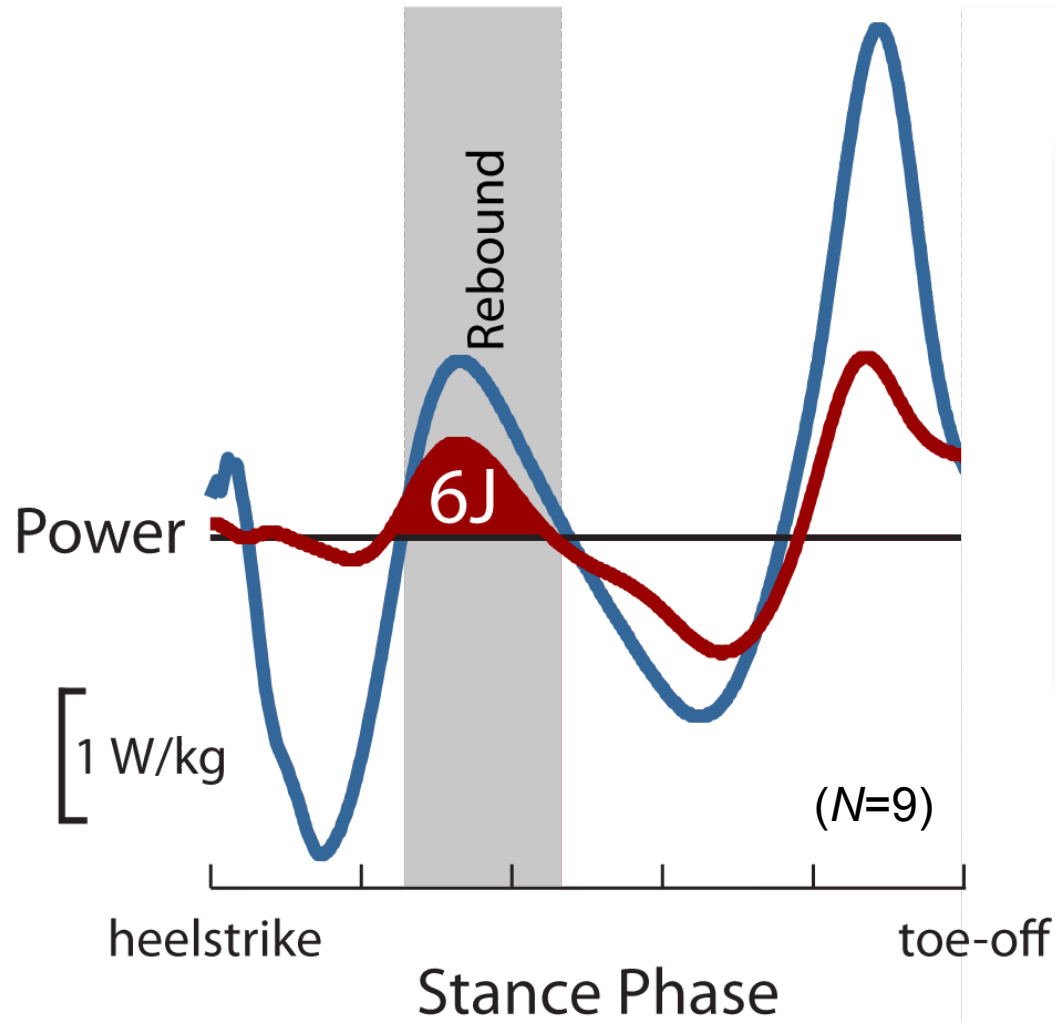
QUESTION

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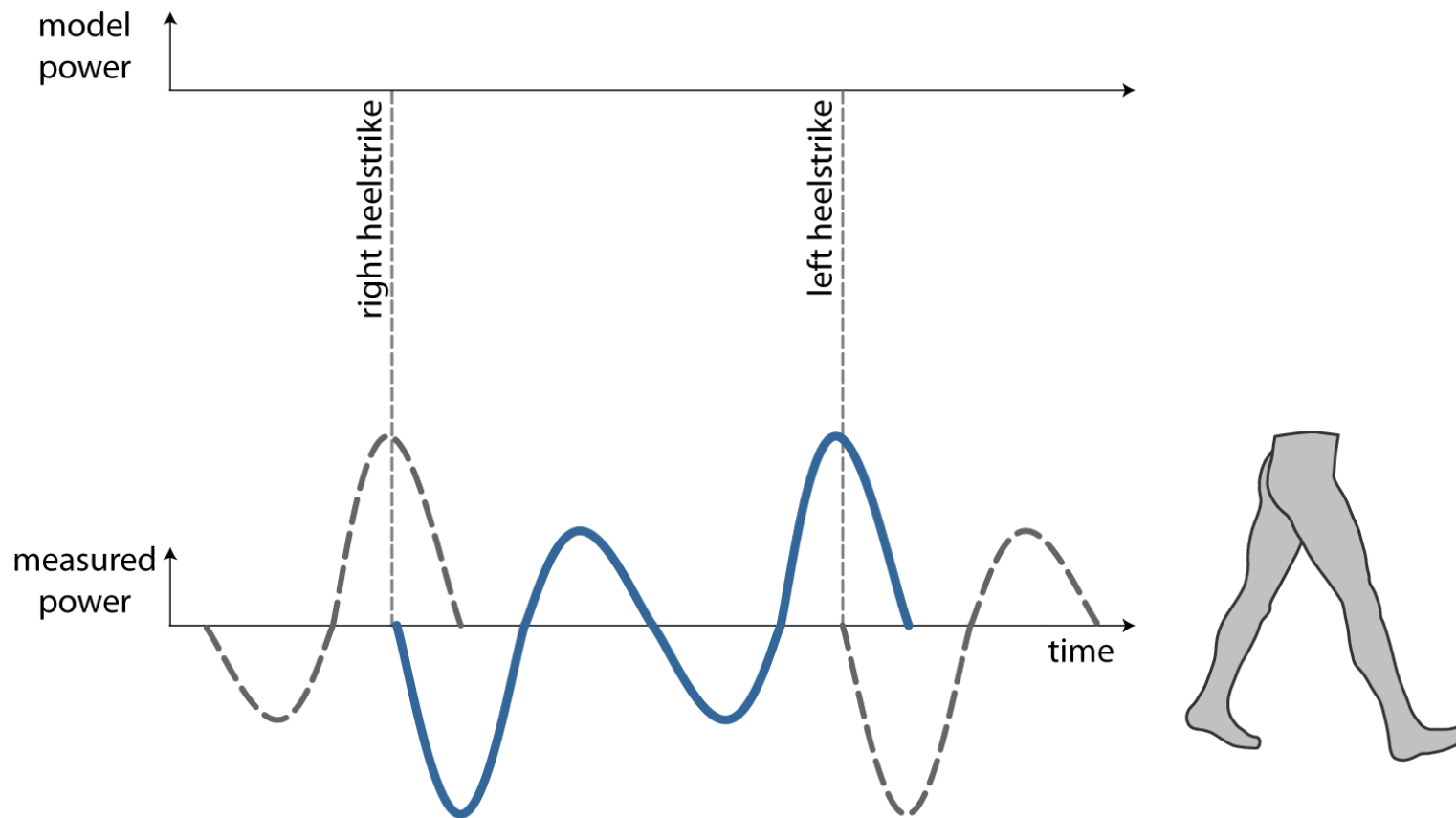


Not all shots go in

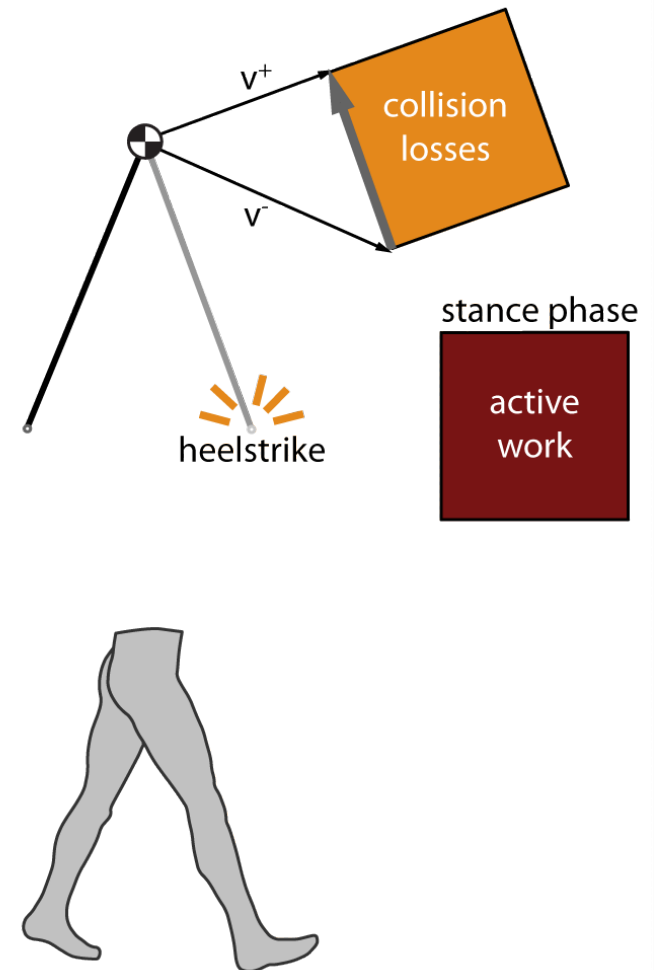
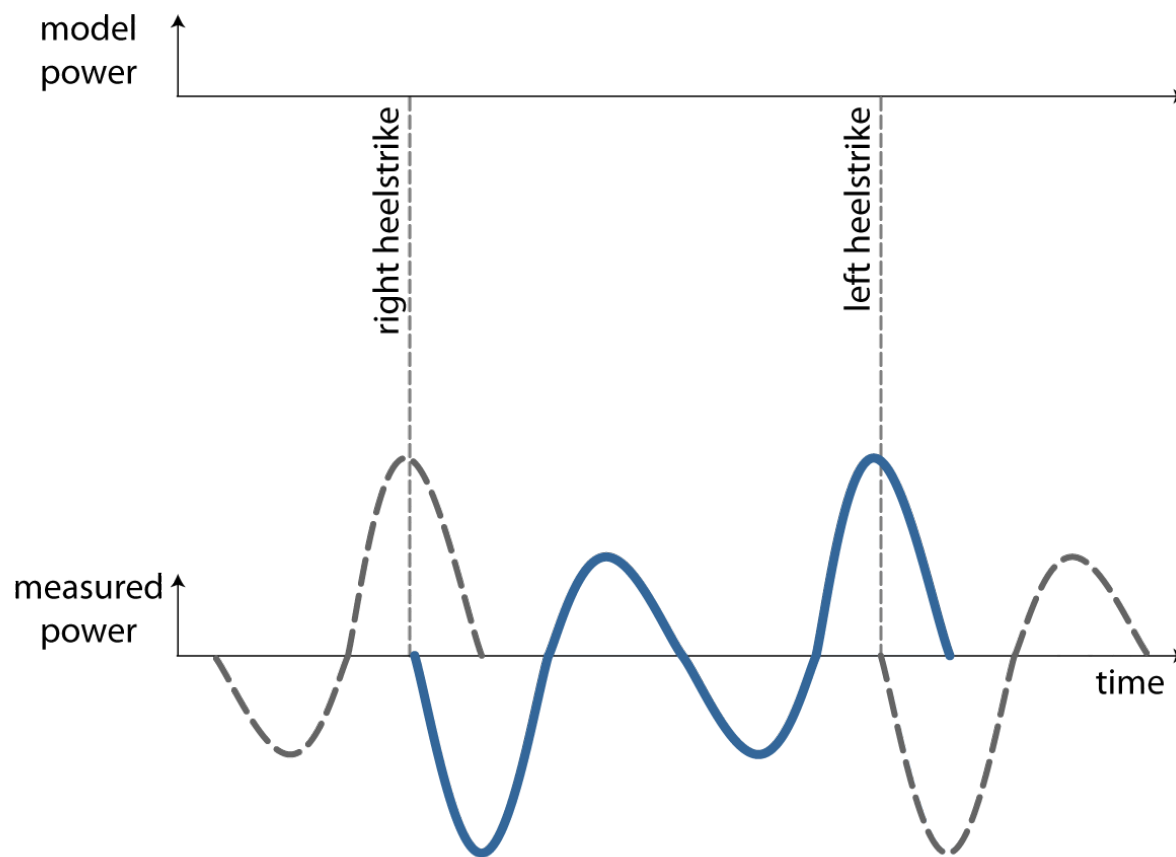


APPROACH

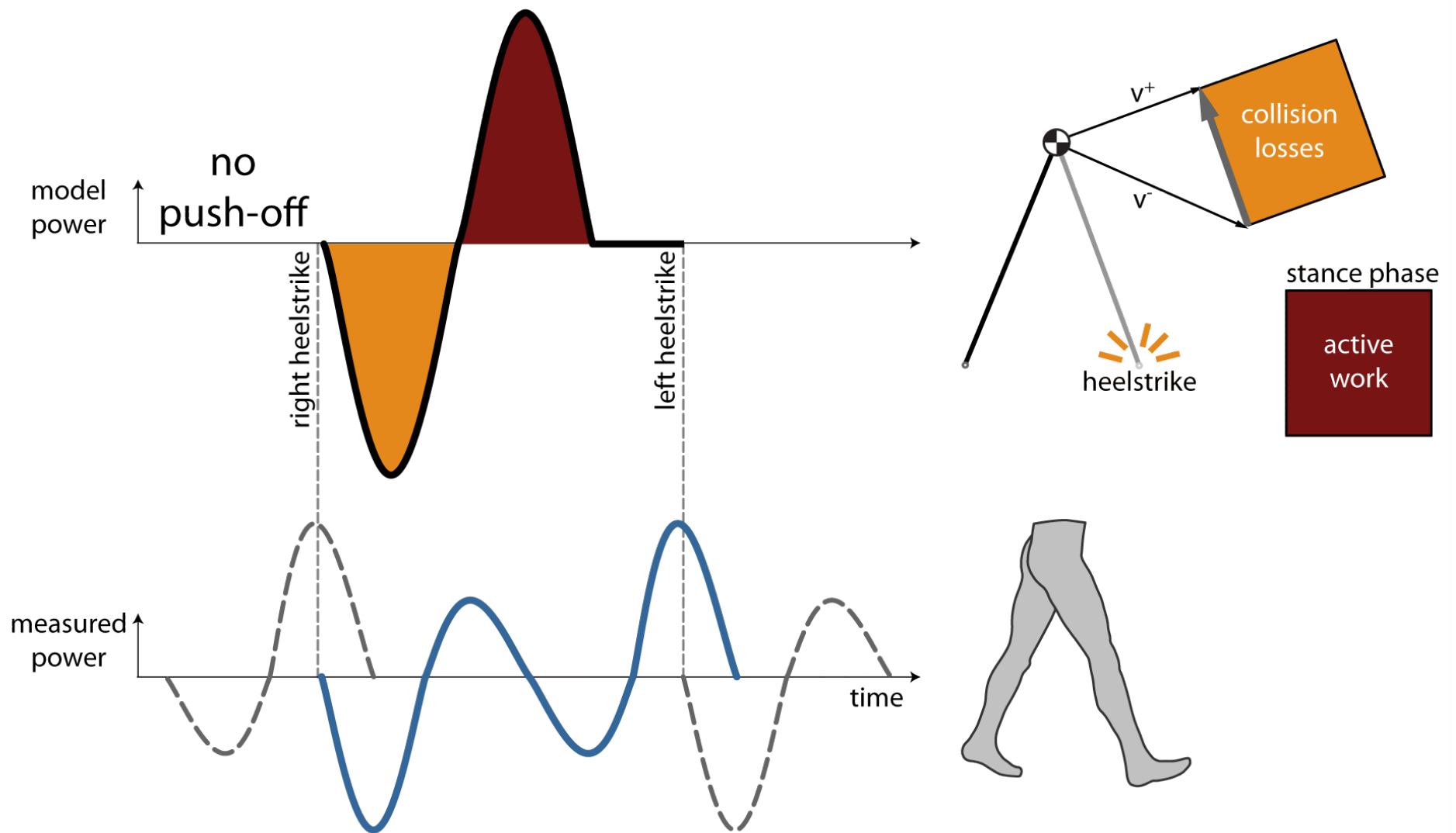
Build up from Dynamic Walking perspective...



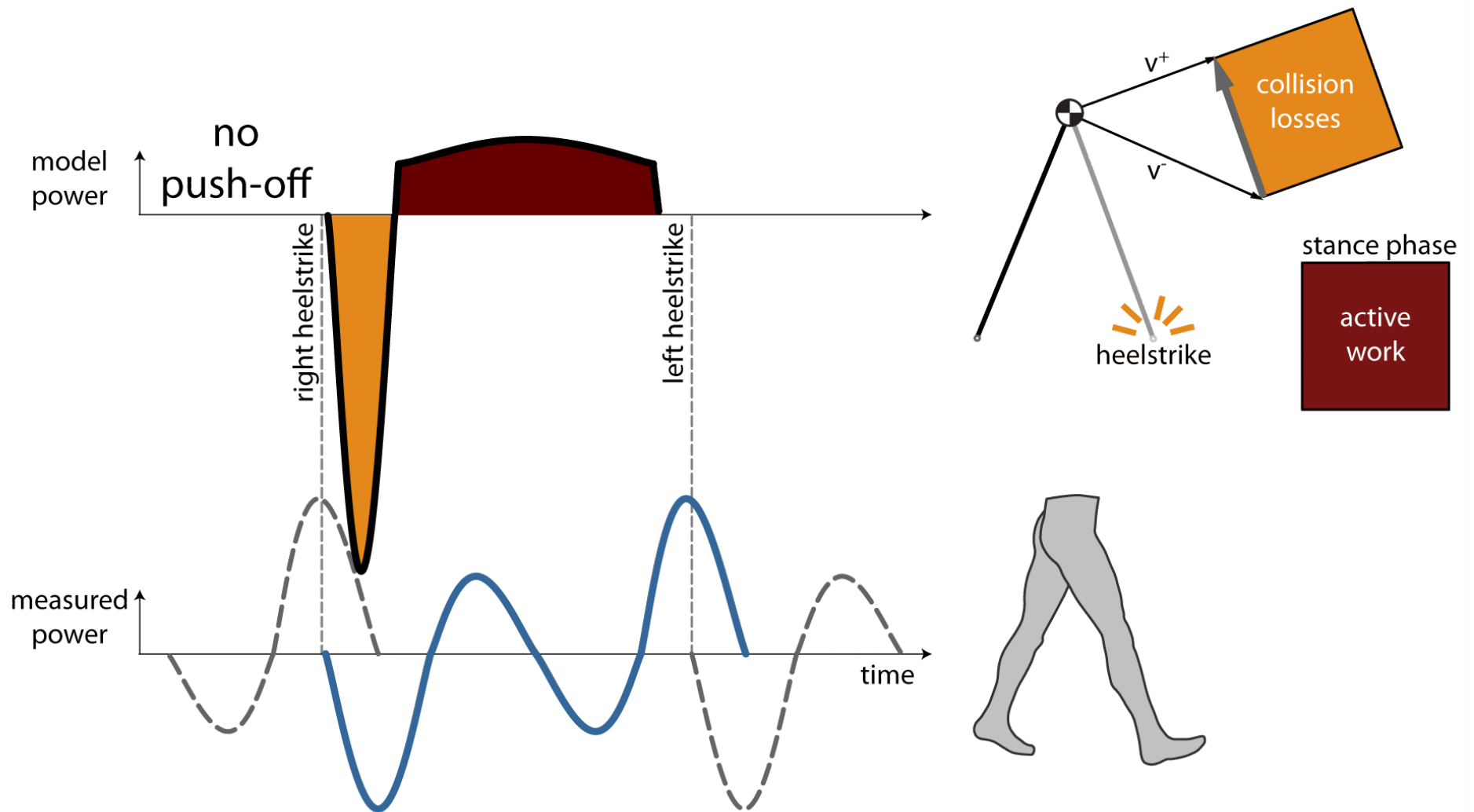
Simplest (No Push-off) Model



Simplest (No Push-off) Model

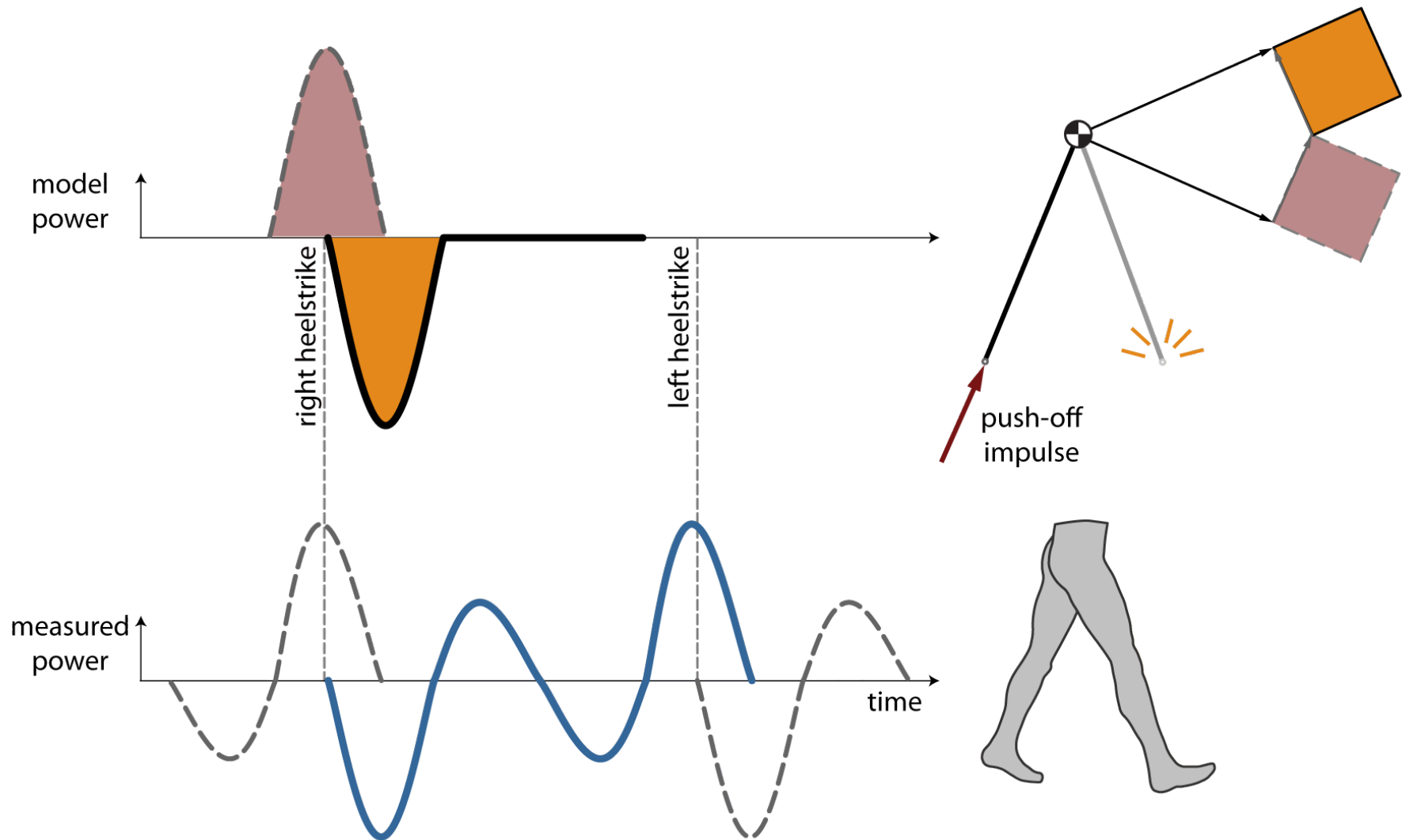


Simplest (No Push-off) Model



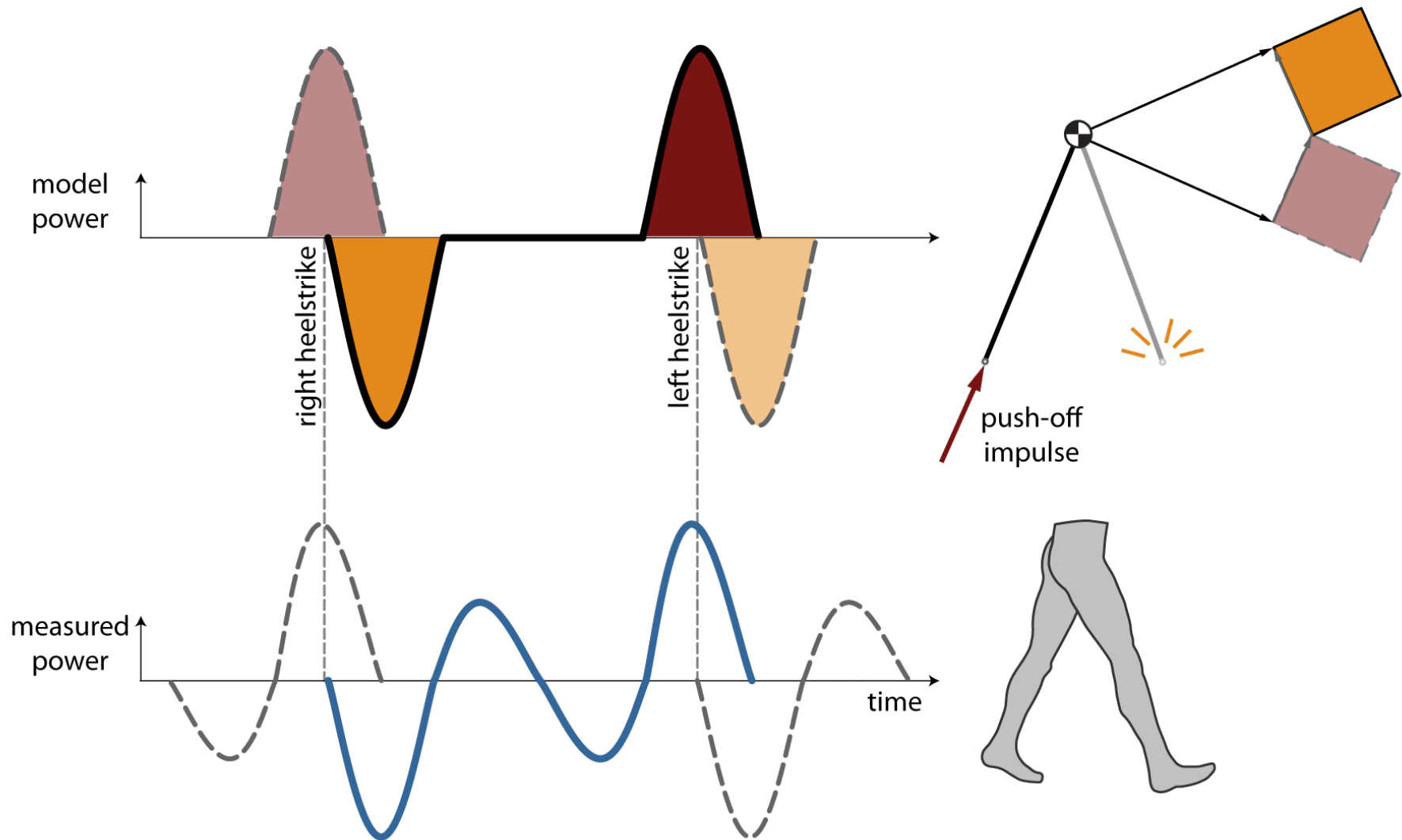
Optimal Active Push-off

Push-off = Collision

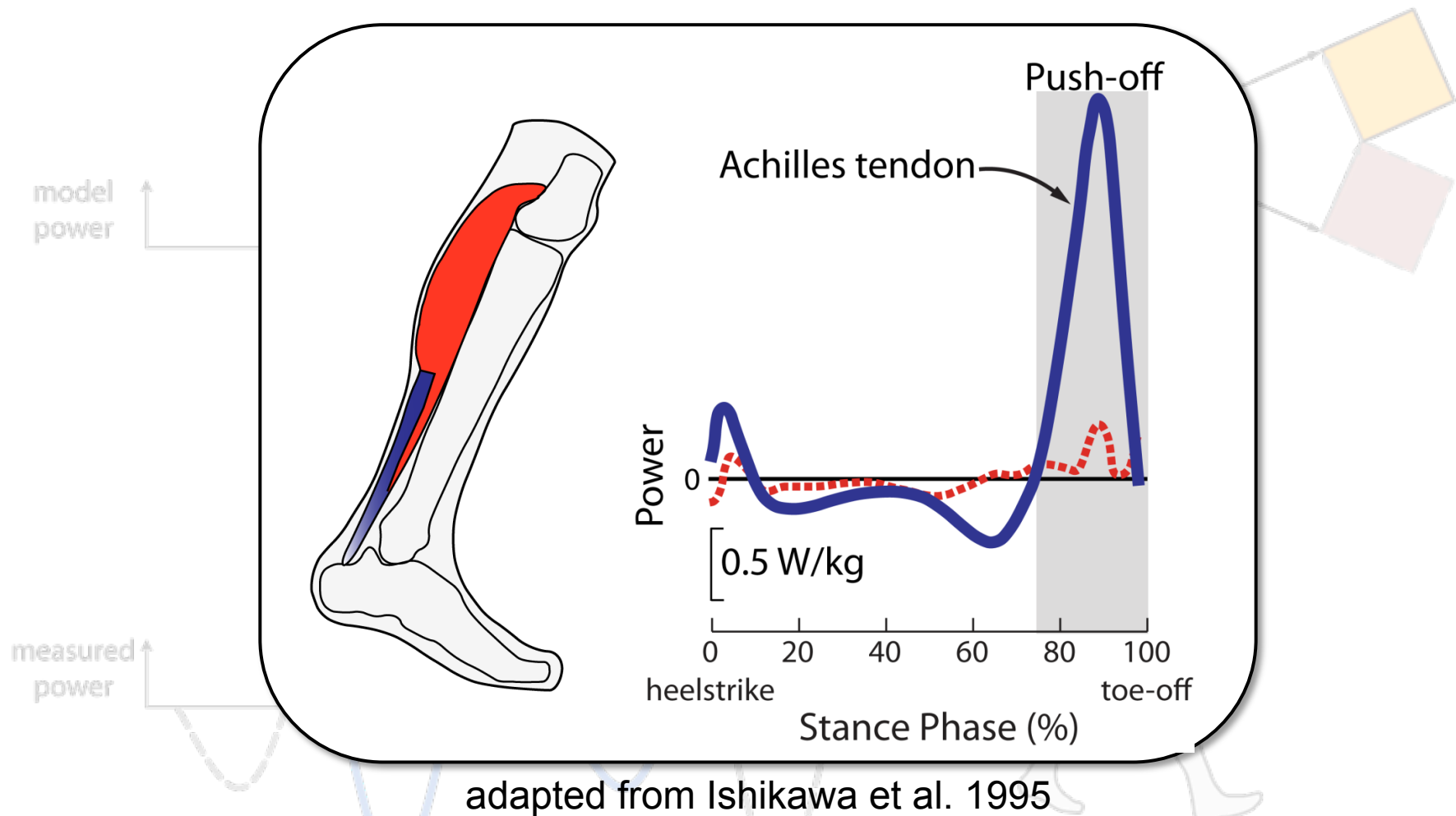


Optimal Active Push-off

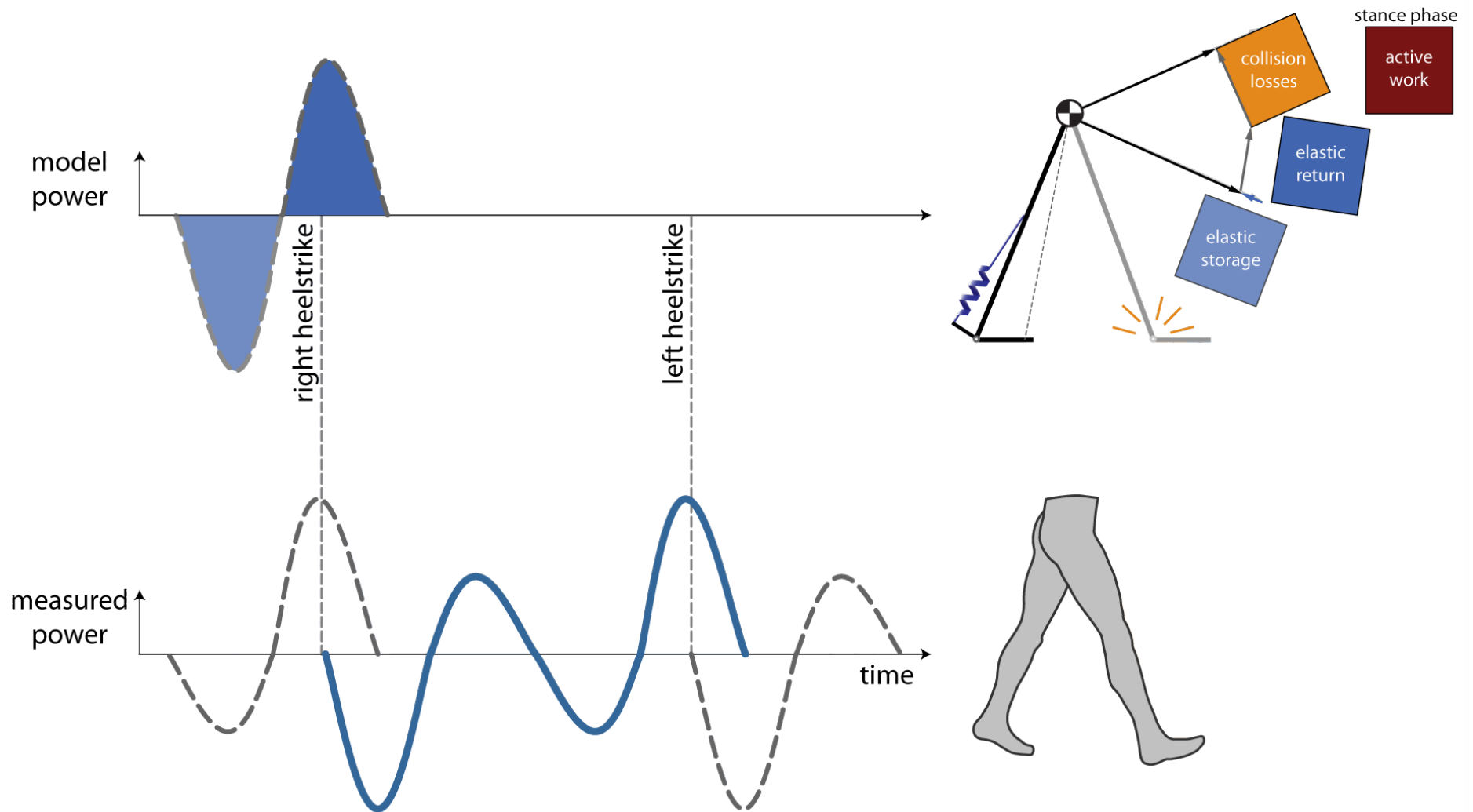
Push-off = Collision



Humans: Push-off largely due to elastic recoil of Achilles

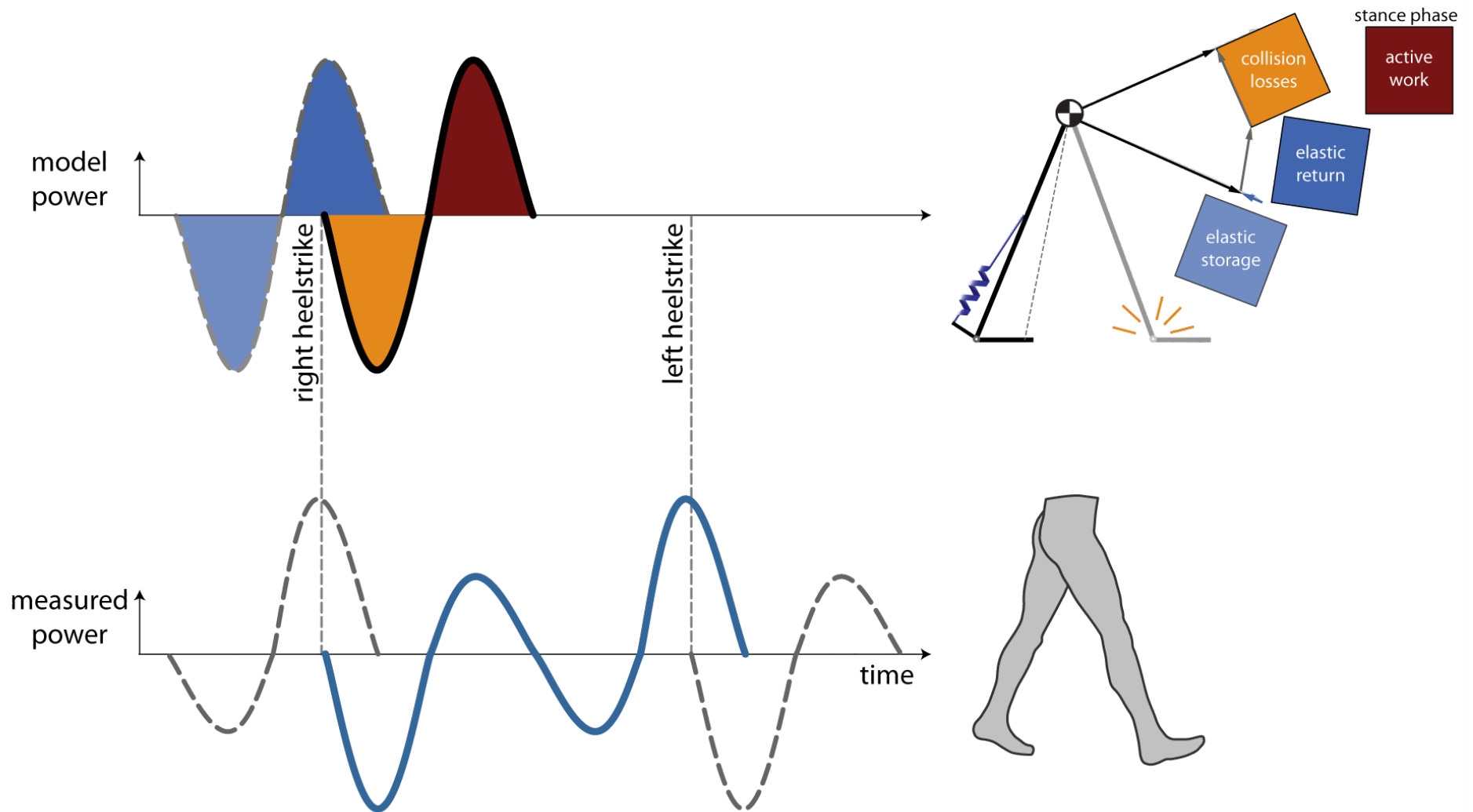


Passive Push-off (from elastic ankle)



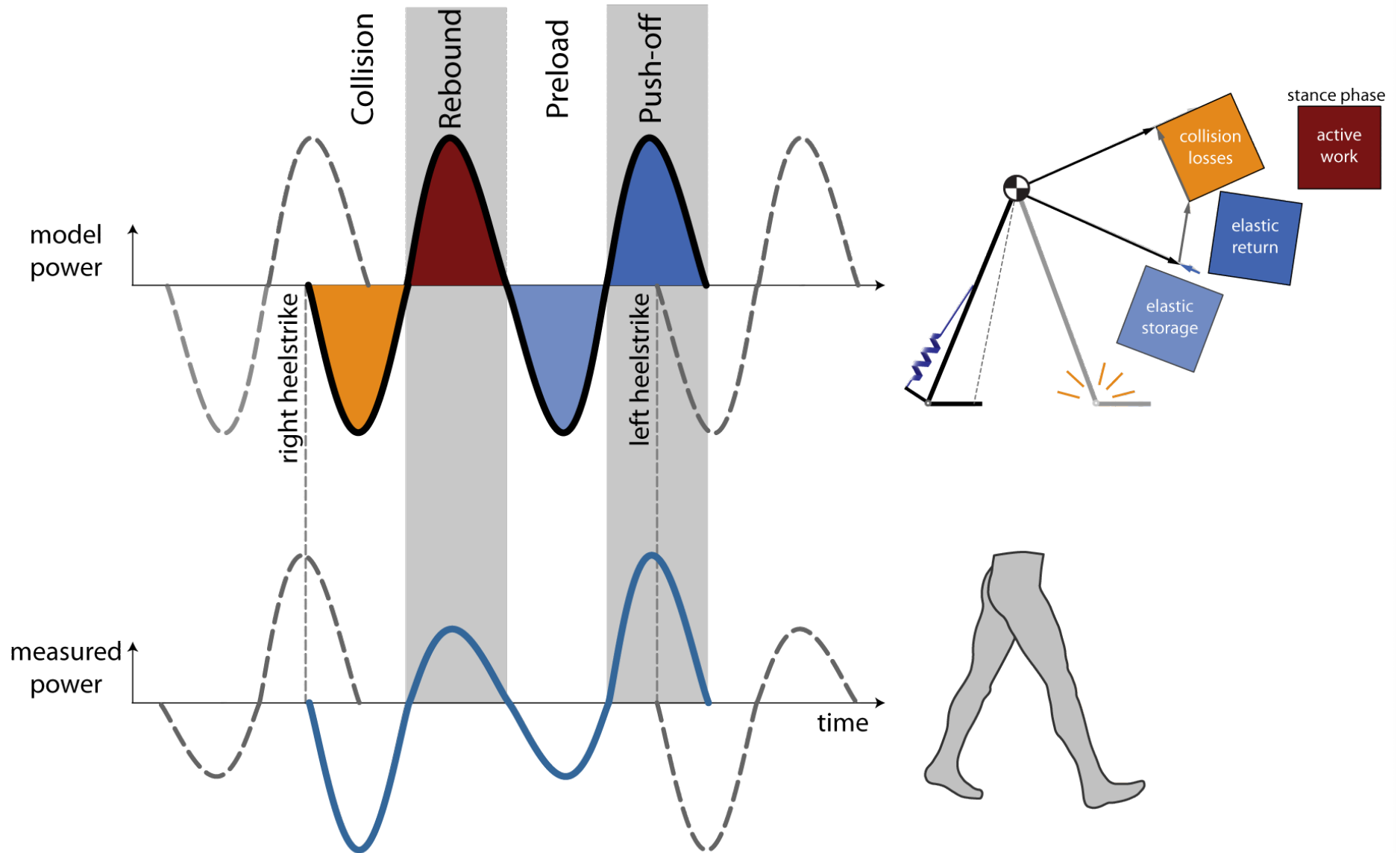
KEY FINDING 1

Passive Push-off predicts active Rebound work



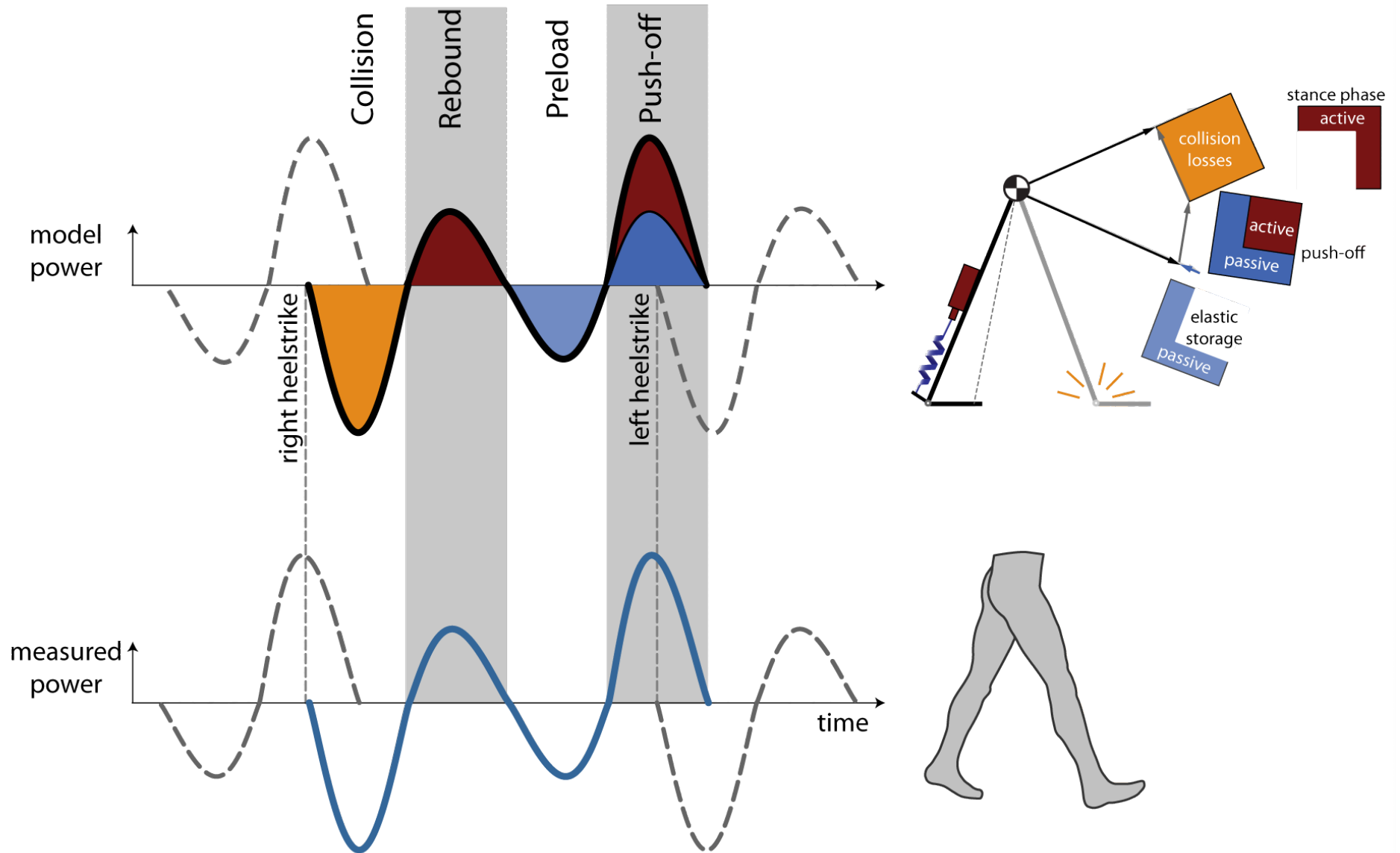
KEY FINDING 1

Passive Push-off predicts active Rebound work



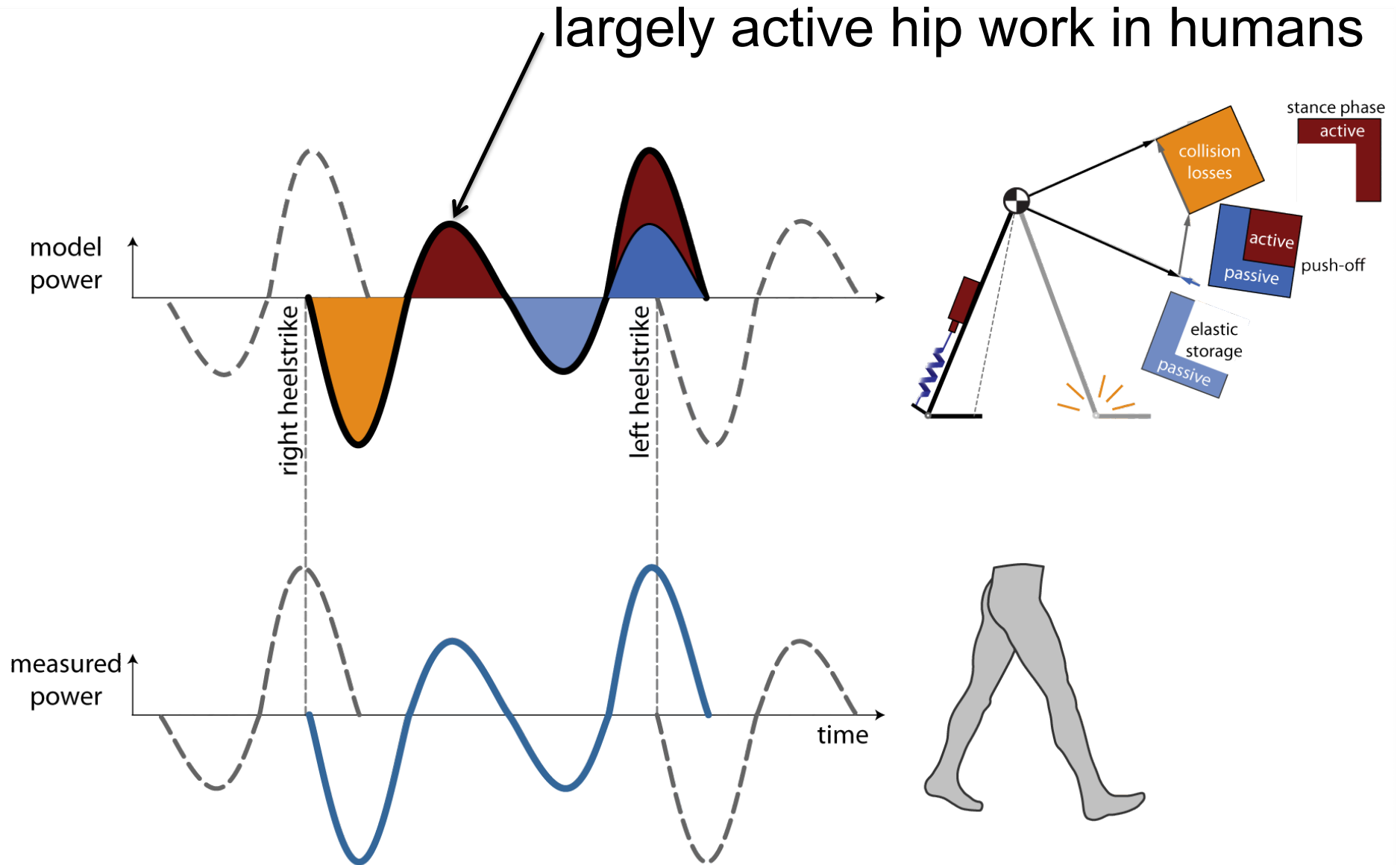
KEY FINDING 2

Passive & Active Push-off explains all phases



QUESTION

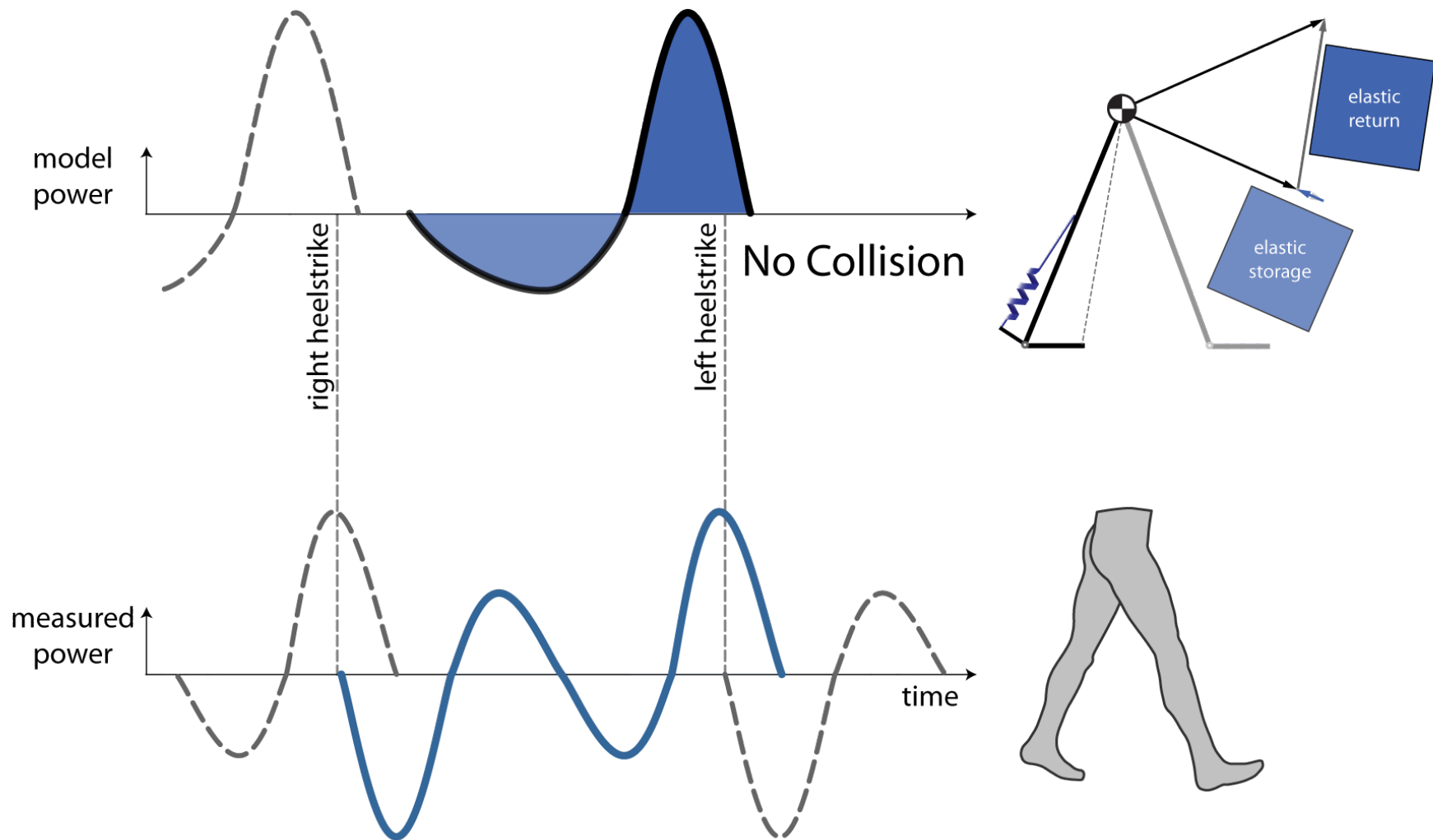
Can we avoid need for active Rebound work?



KEY FINDING 3

Passive Push-off can remove need for active work

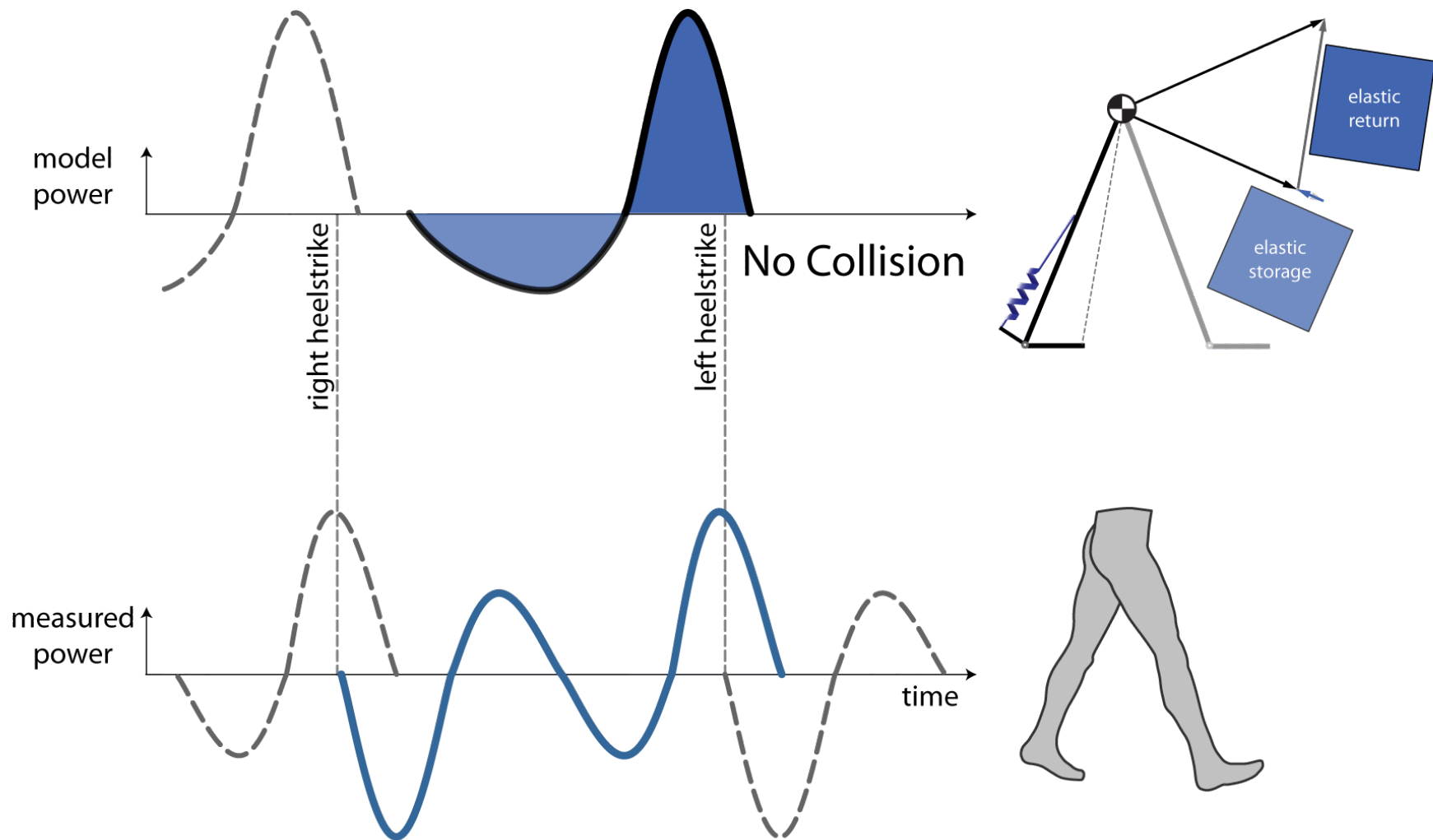
(theoretically no need to perform Rebound work)



QUESTION (CLIFFHANGER)

Why don't humans walk more like this model?

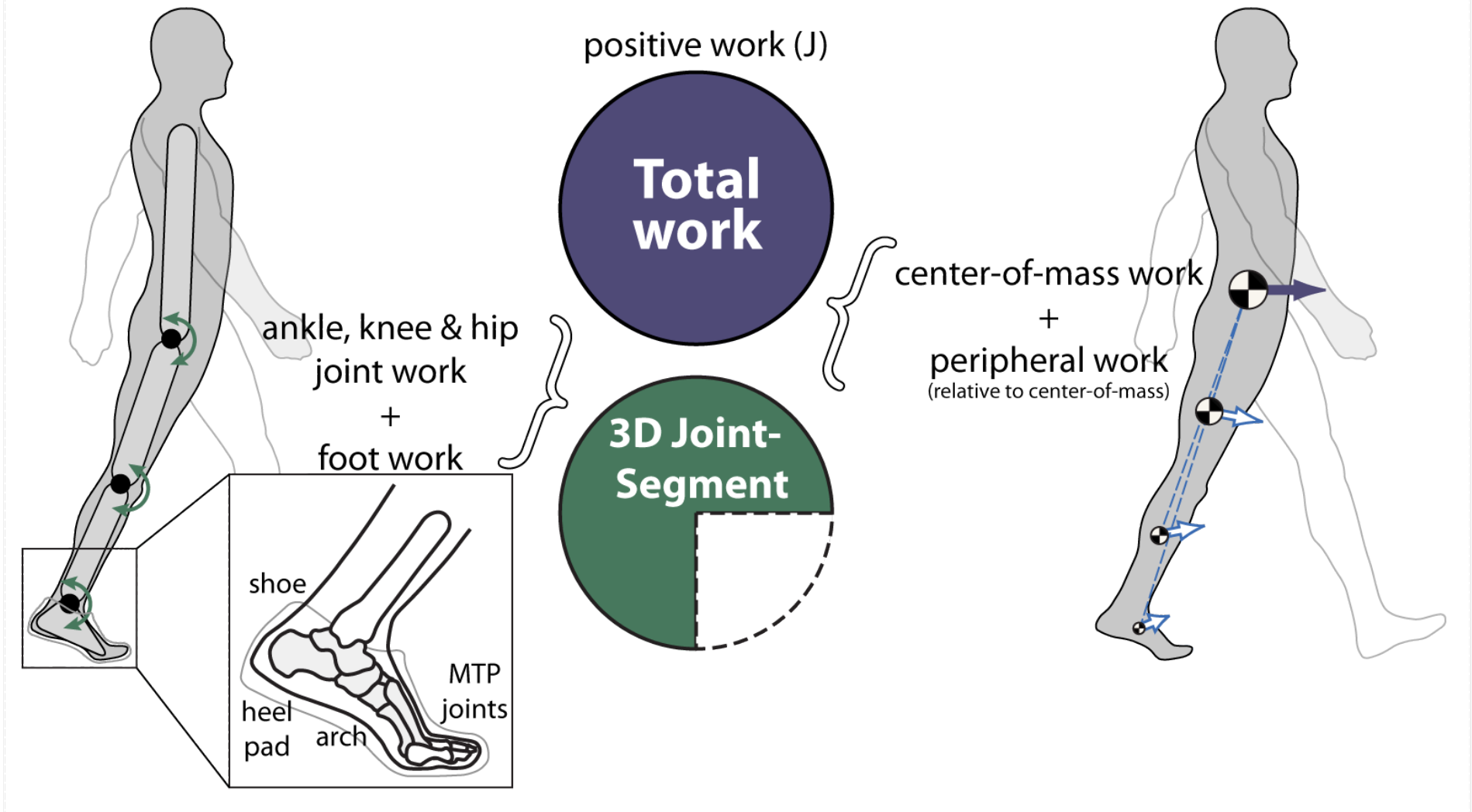
Corollary: should assistive devices aspire to this model?



SUMMARY

1. We all make bad pie charts (in biomechanics)

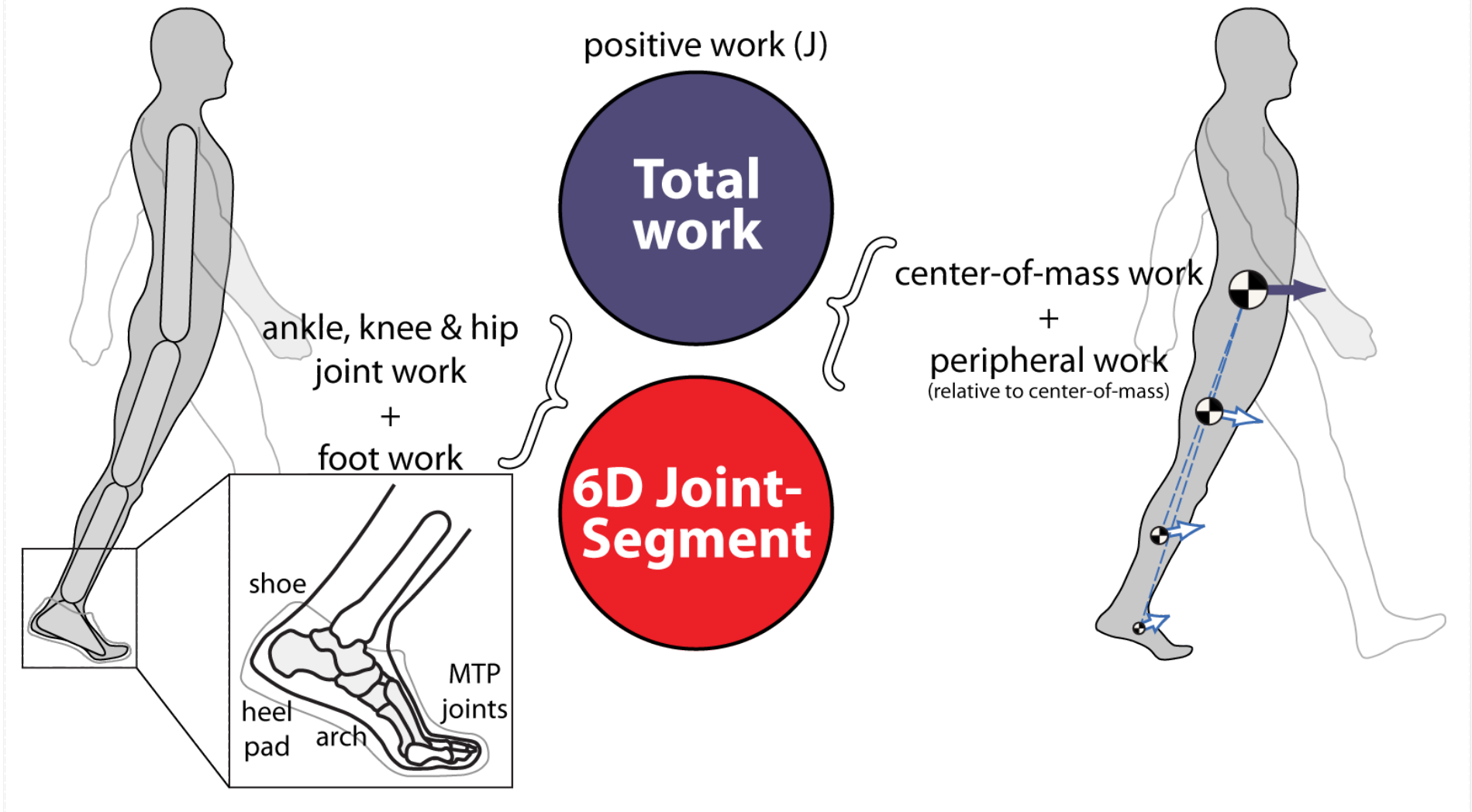
when estimating joint work from conventional 3D inverse dynamics



SUMMARY

1. We all make bad pie charts (in biomechanics)

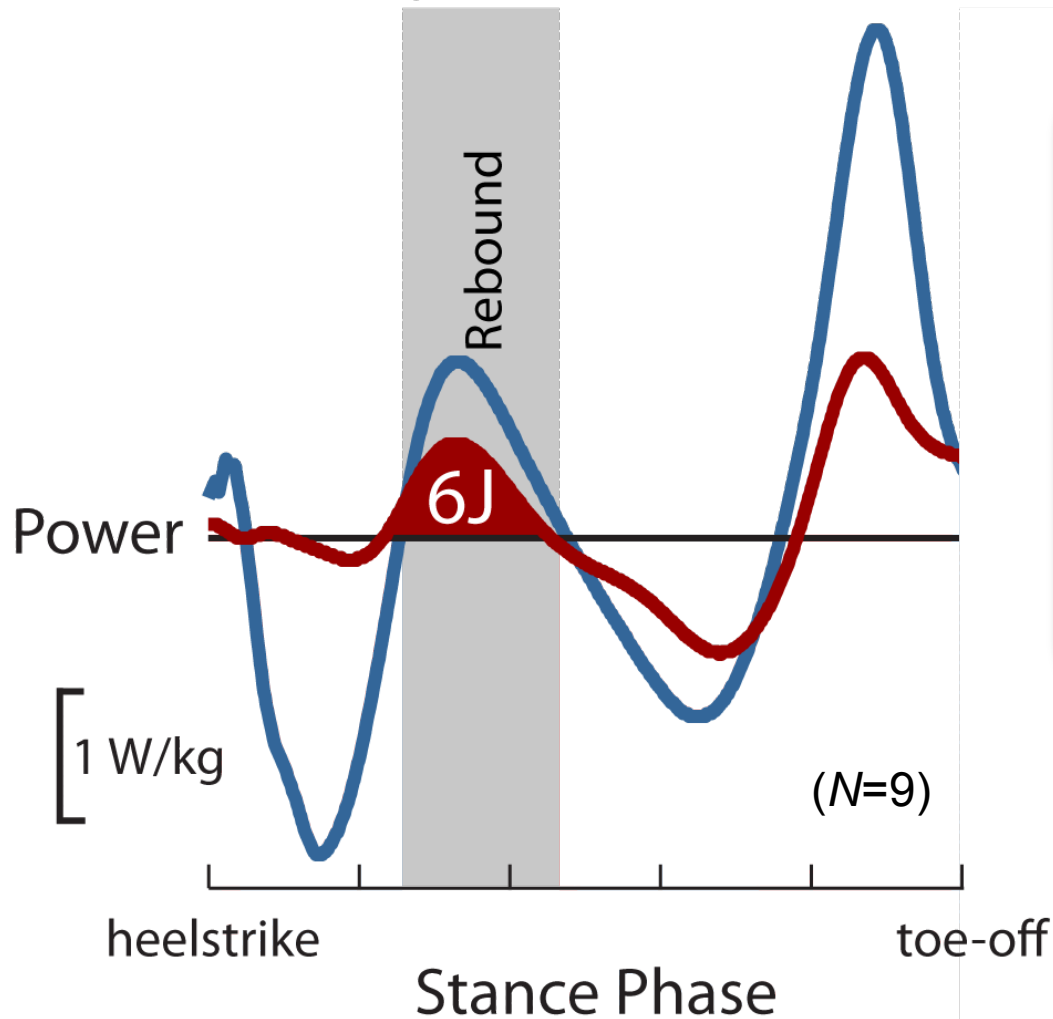
... but we don't have to if we do 6D analysis of joints & feet



SUMMARY

2. Why Rebound?

Not all work is done
by Push-off



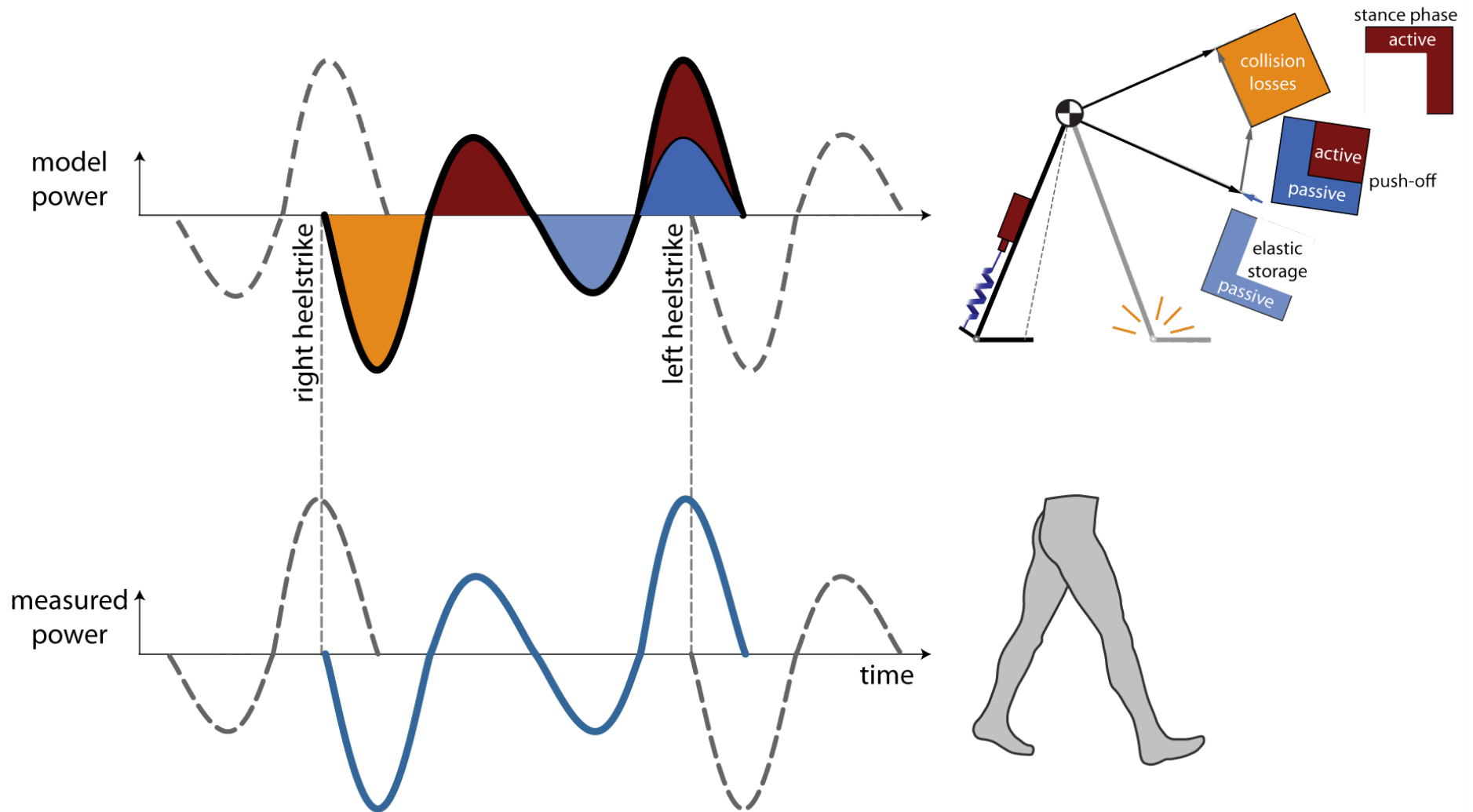
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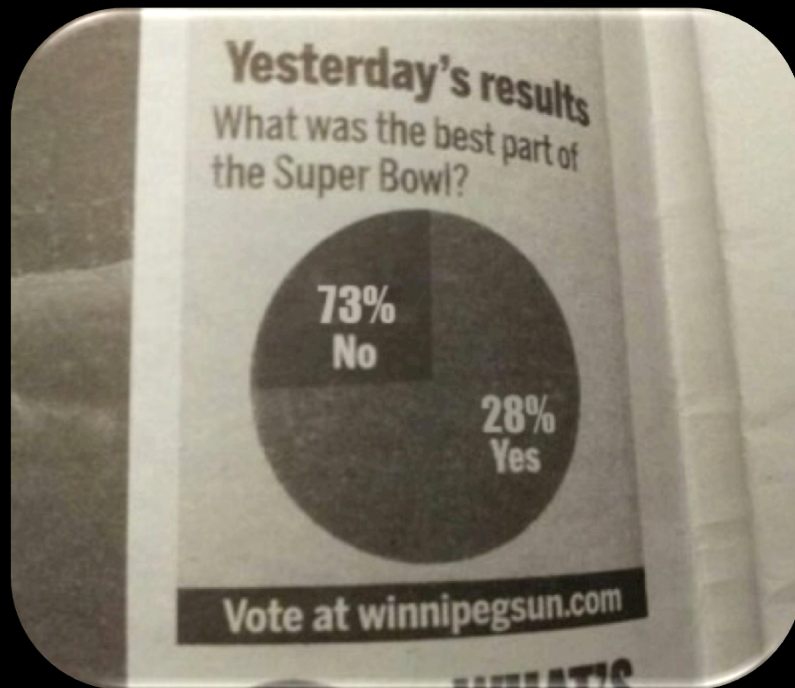


SUMMARY

2. Why Rebound?

passive Push-off model explains need for active Rebound work





Thanks for your attention.

Collaborators: Greg Sawicki & Kota Takahashi (North Carolina State)
Funding: Whitaker International Program