The cost of comfort:
what's it worth to avoid pain?

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Net positive work must be done by muscles

	Net Positive Work
Active Muscles	

Negative work can be done by muscles

	Net Positive Work	Net Negative Work
Active Muscles		

Negative work can also be done passively

People can choose how to distribute neg. work[1]

	Net Positive Work	Net Negative Work
Active Muscles		
Passive Soft Tissues		

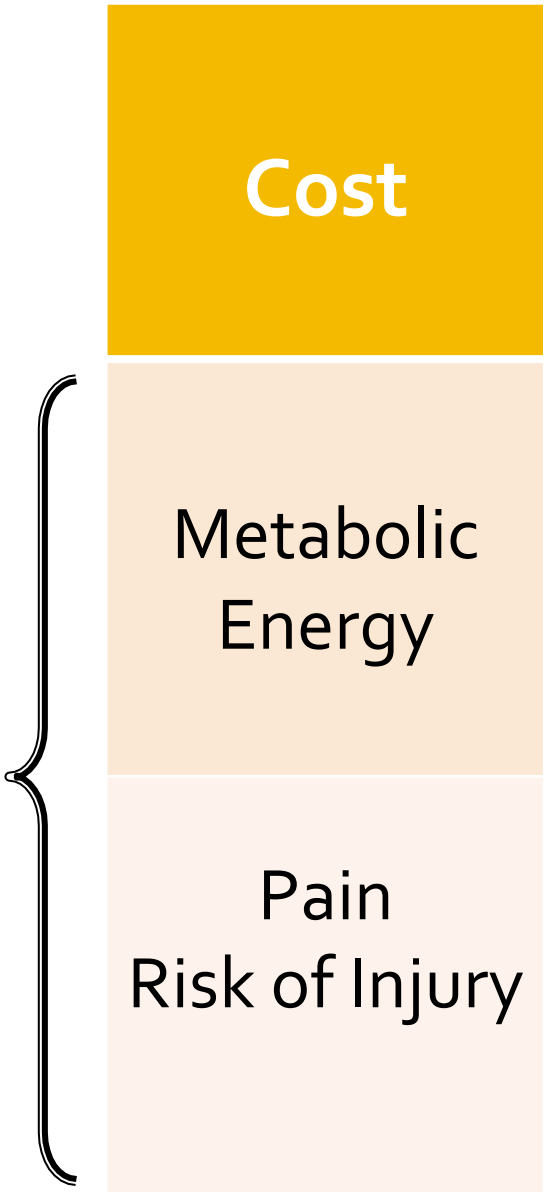
[1]Zatsiorsky & Prilutsky 1982

There are costs to both active and passive work

	Net Positive Work	Net Negative Work	Cost
Active Muscles			Metabolic Energy
Passive Soft Tissues			Pain Risk of Injury

Jump-landing

Preferred landing strategy is a compromise between these costs



How can we compare costs quantitatively?

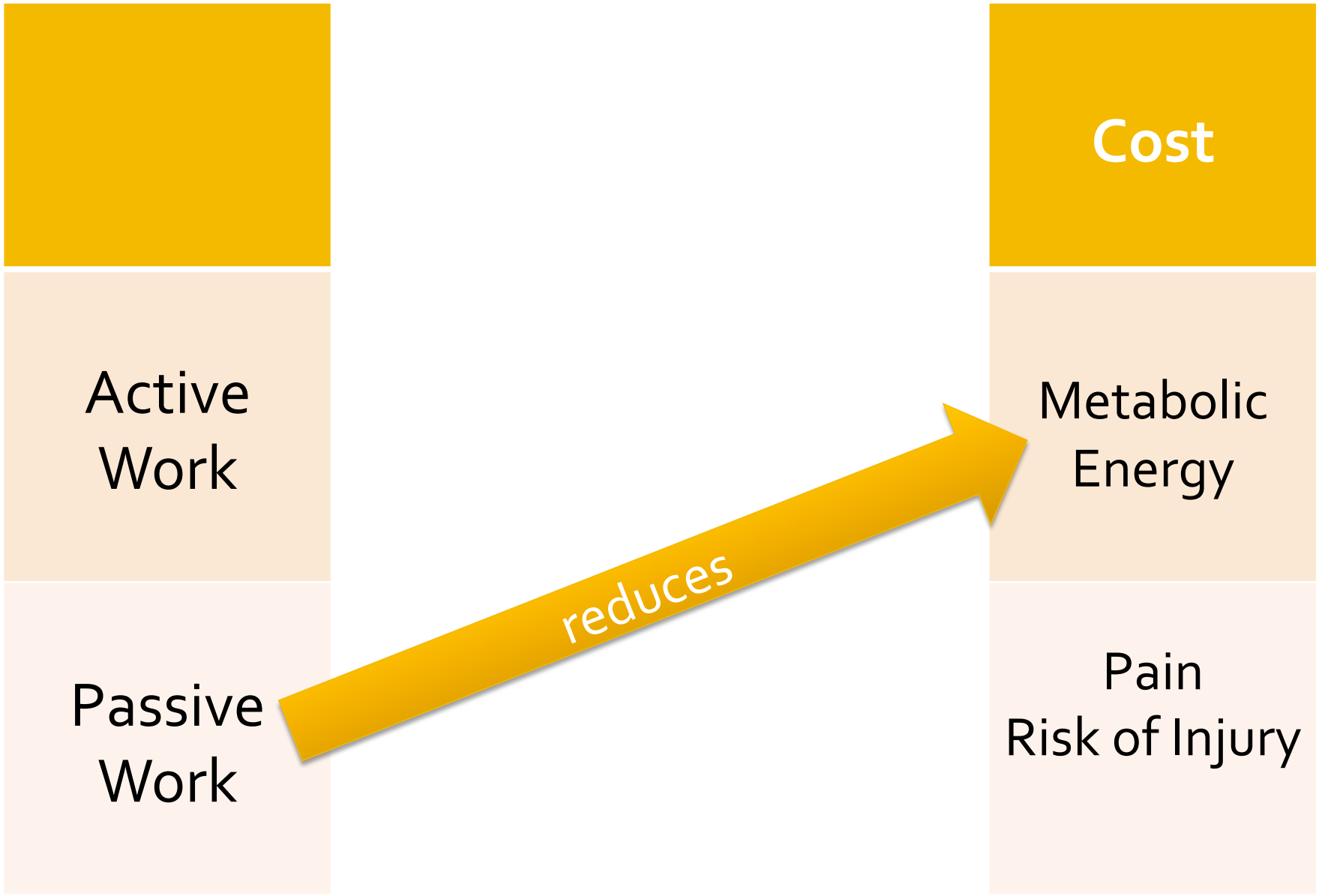
Preferred landing strategy is a compromise between these costs

Cost

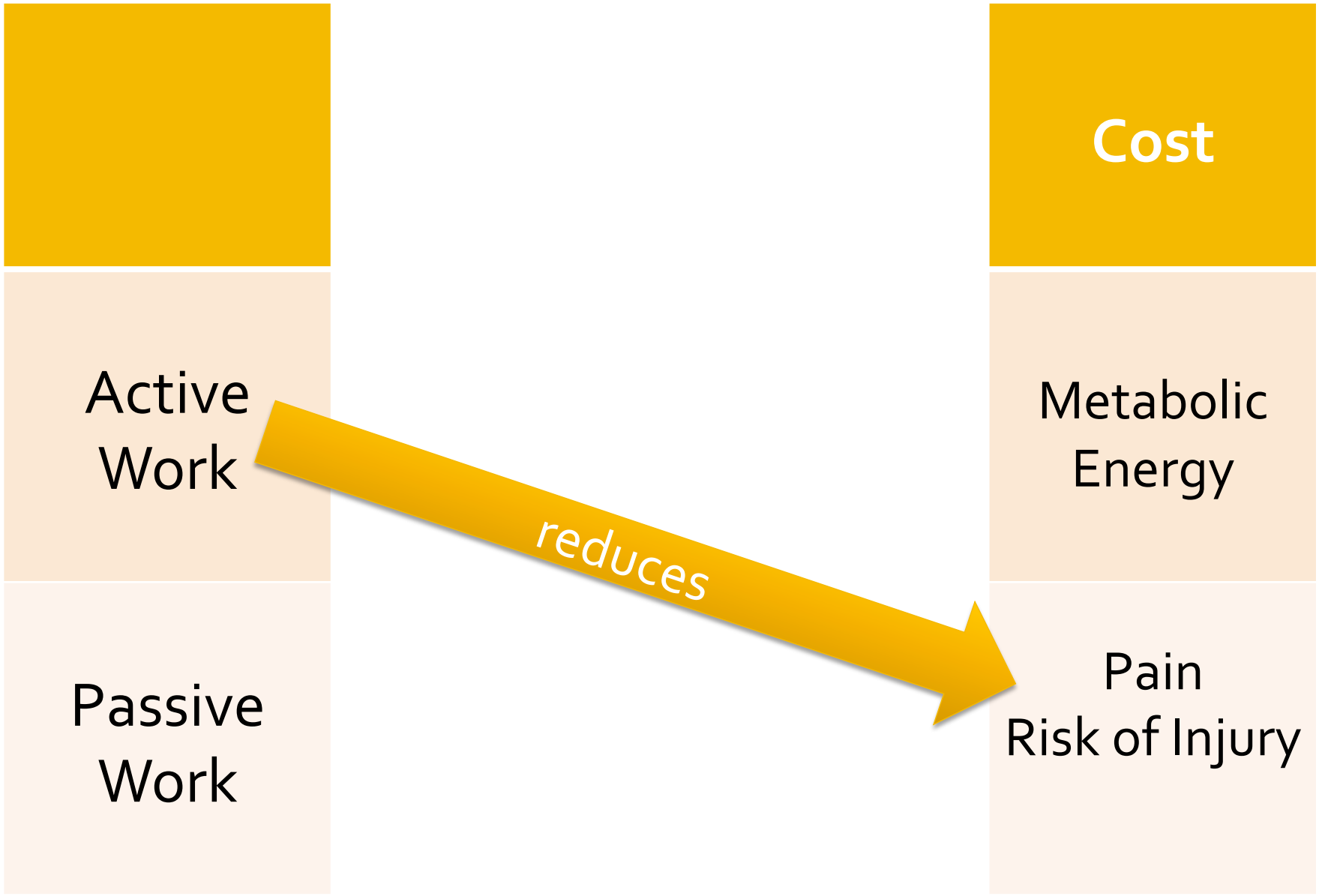
Metabolic Energy

Pain
Risk of Injury

Distribution of work → how people value costs



Distribution of work → how people value costs



How do people choose to distribute work?

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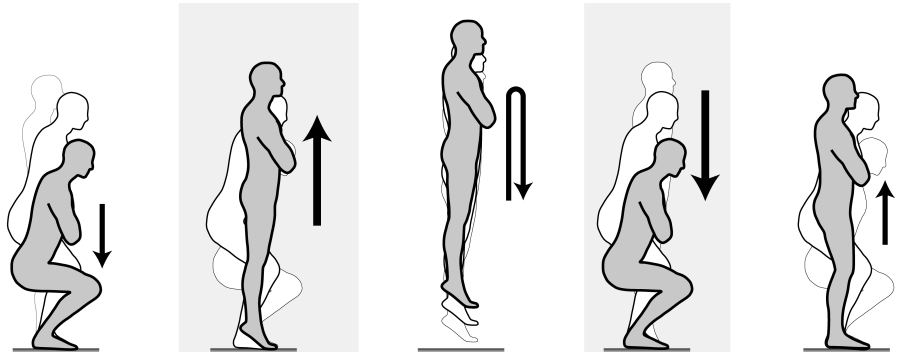
Jump-Landing Experiment



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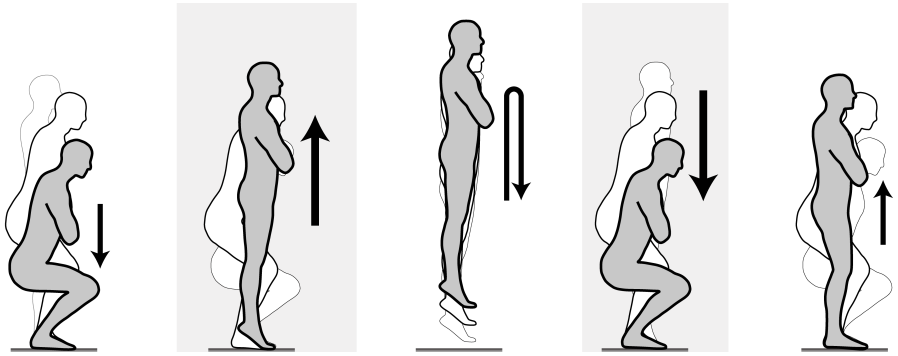
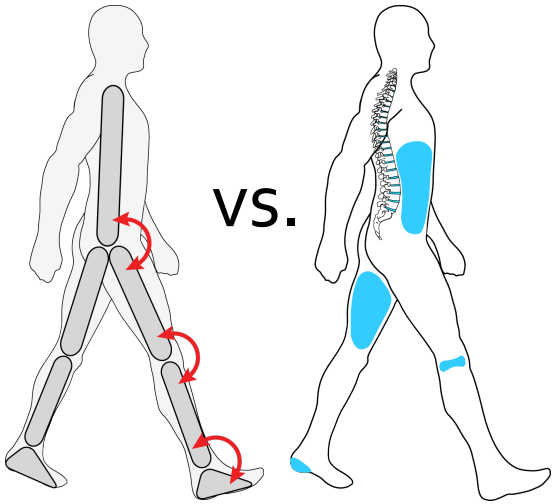
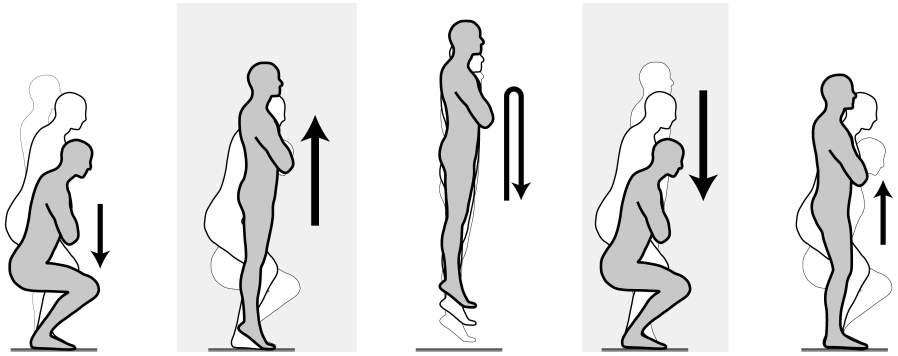
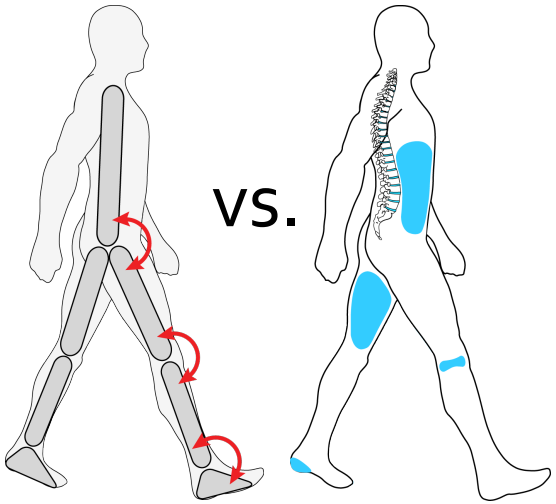


Estimating
Active vs. Passive
Contributions



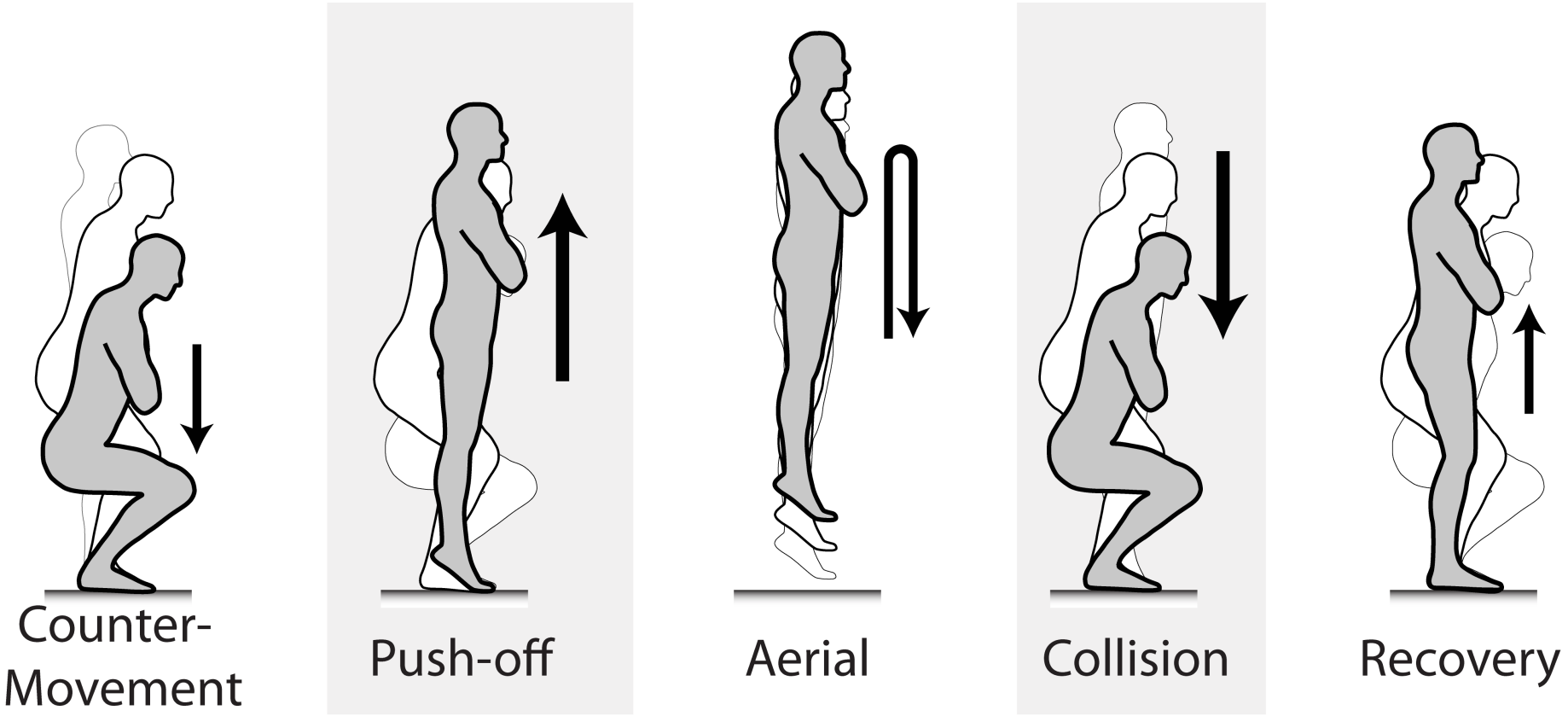
How do people choose to distribute work?





People prefer to do more active work than necessary

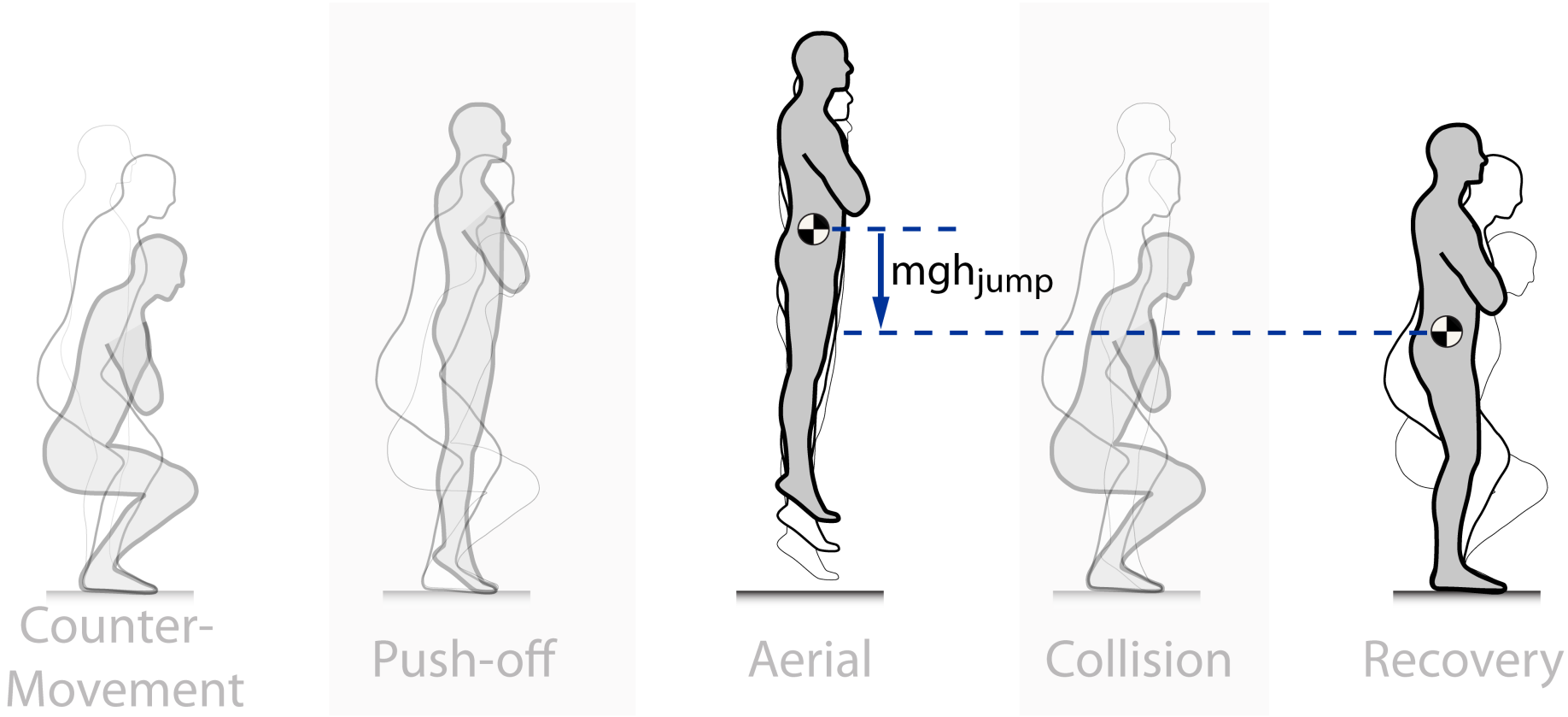
Jump-landing experiment



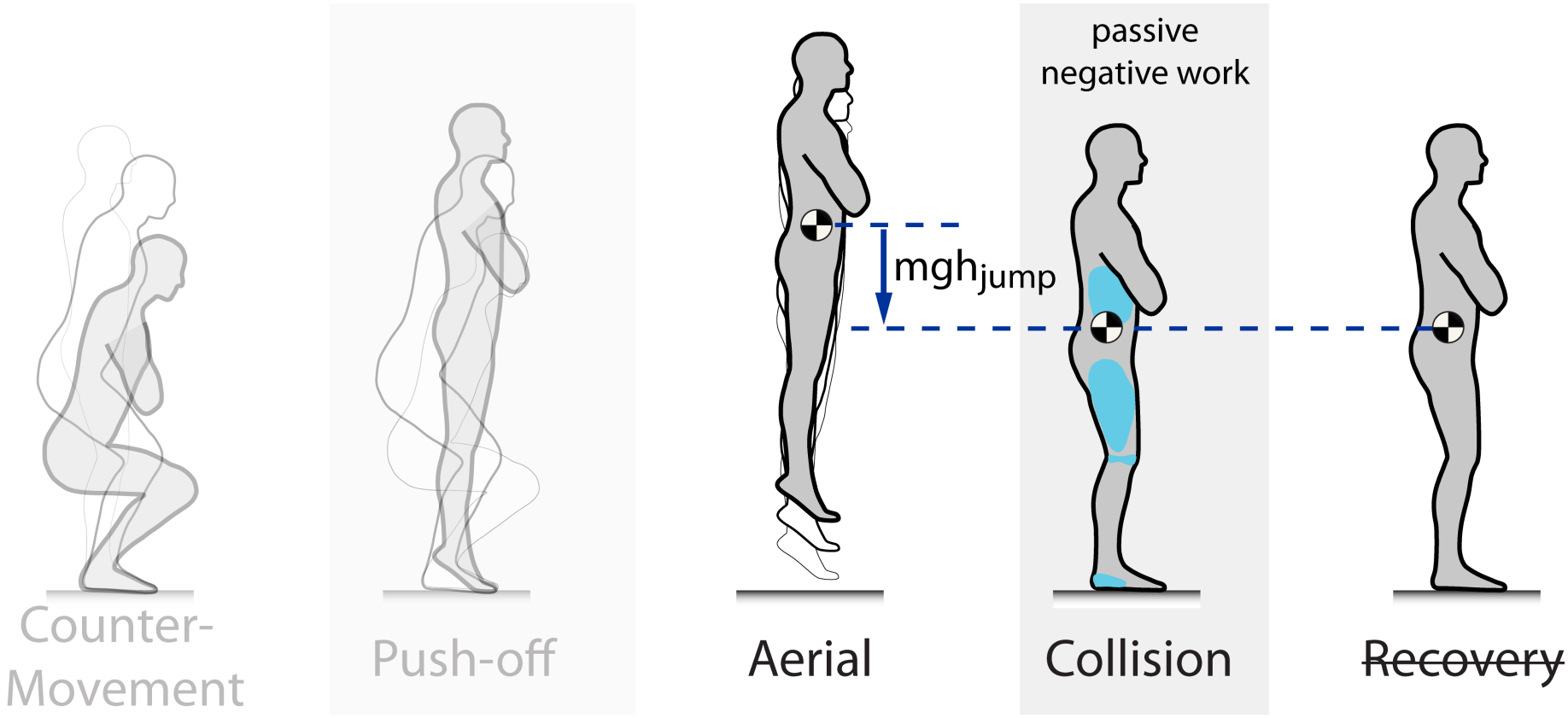
N=8

Collected ground reaction forces and full-body kinematics

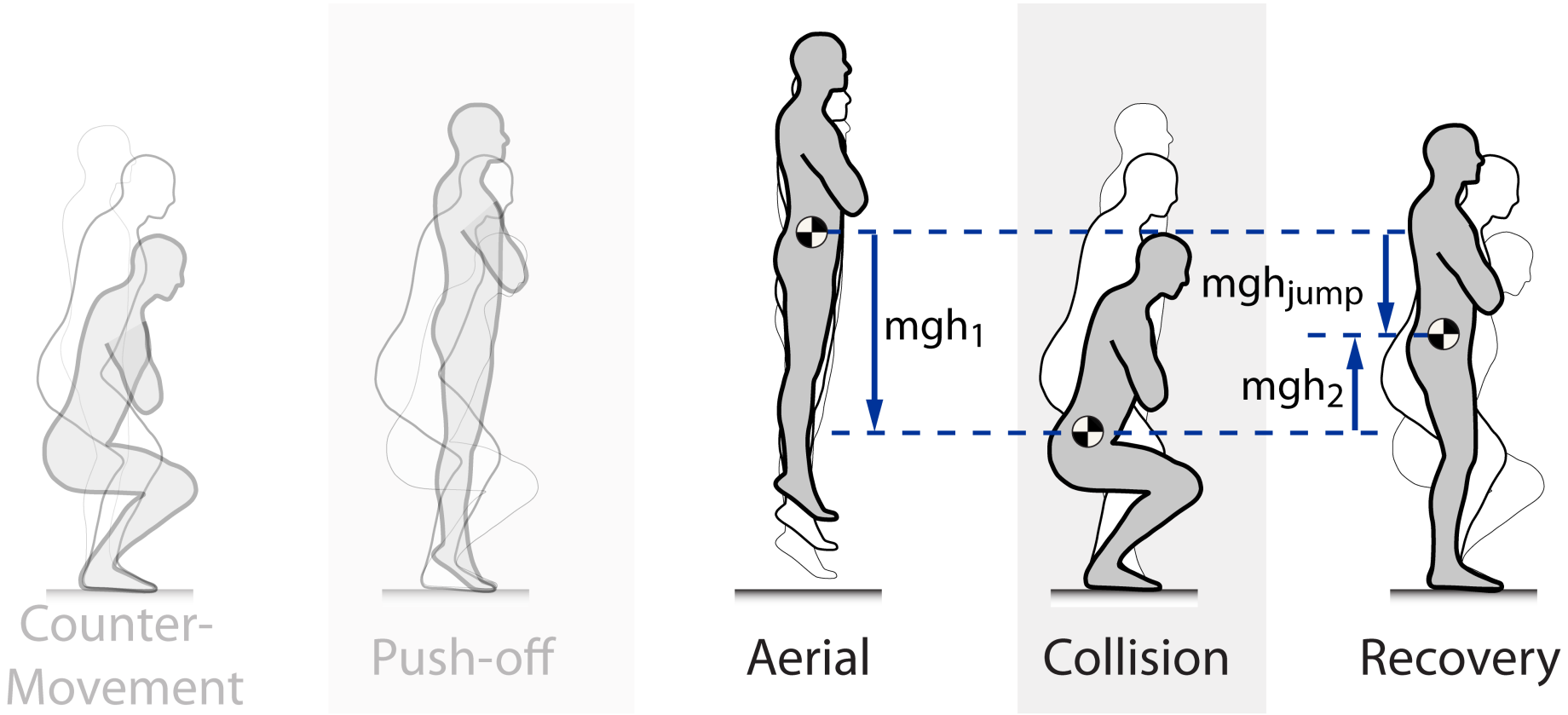
Range of jump heights



Stiff-legged landing minimizes negative work



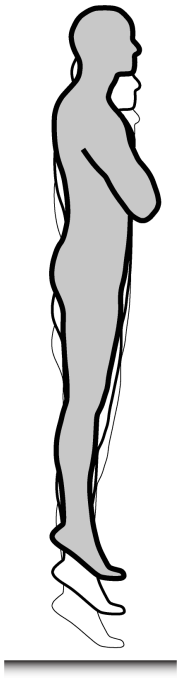
Doing work actively increases total work done



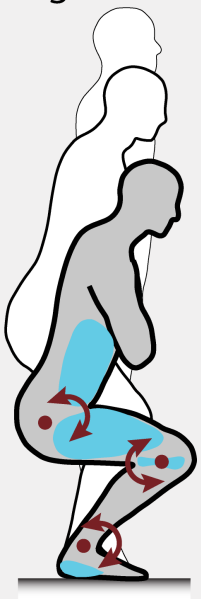
Hypothesis: people prefer to perform extra work

Counter-Movement

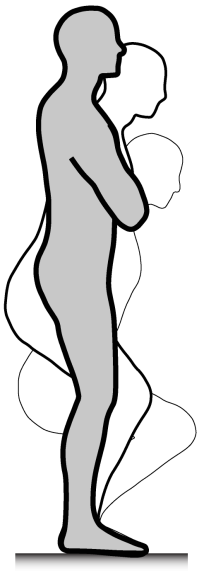
Push-off



Aerial

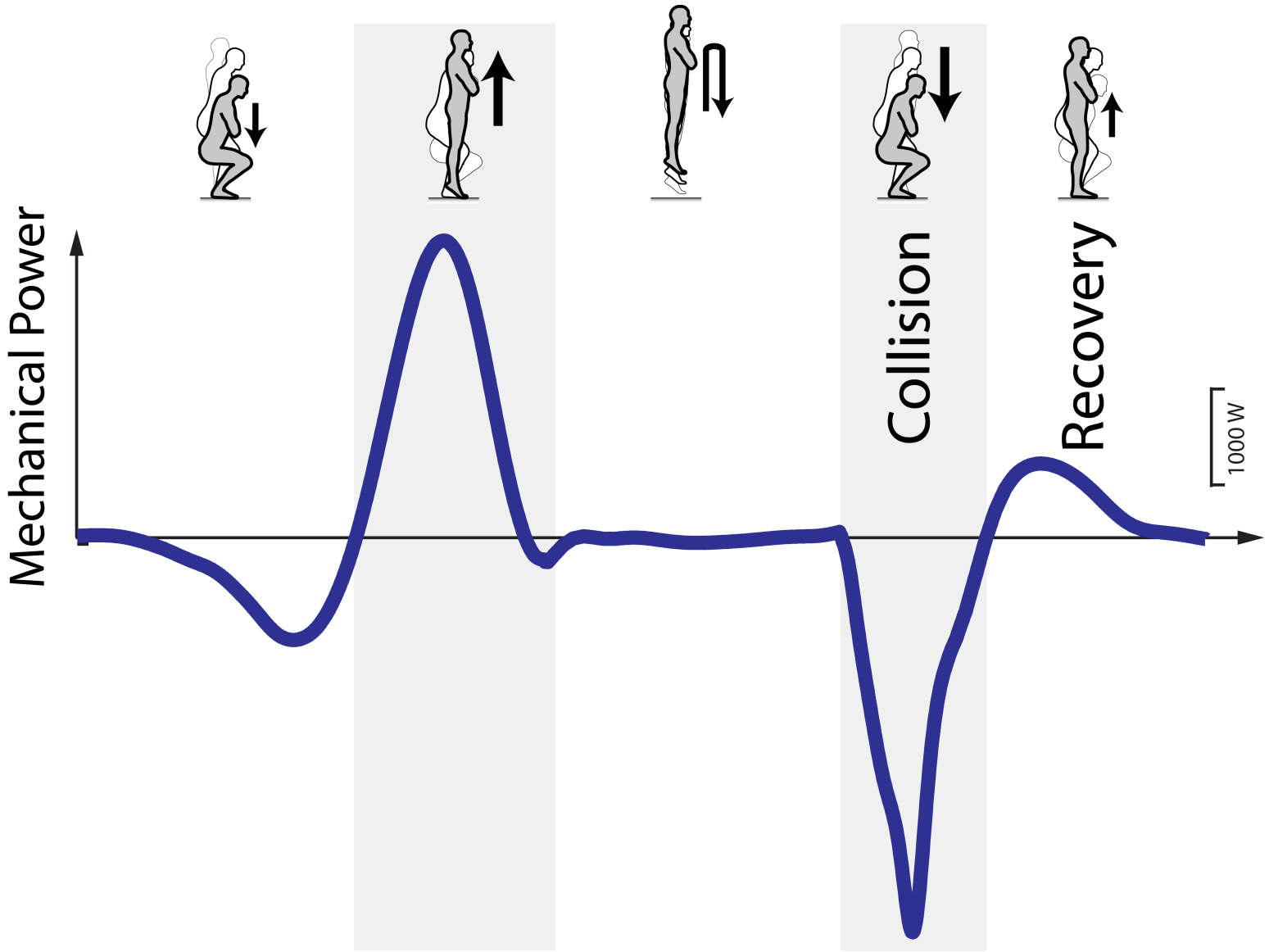


Collision

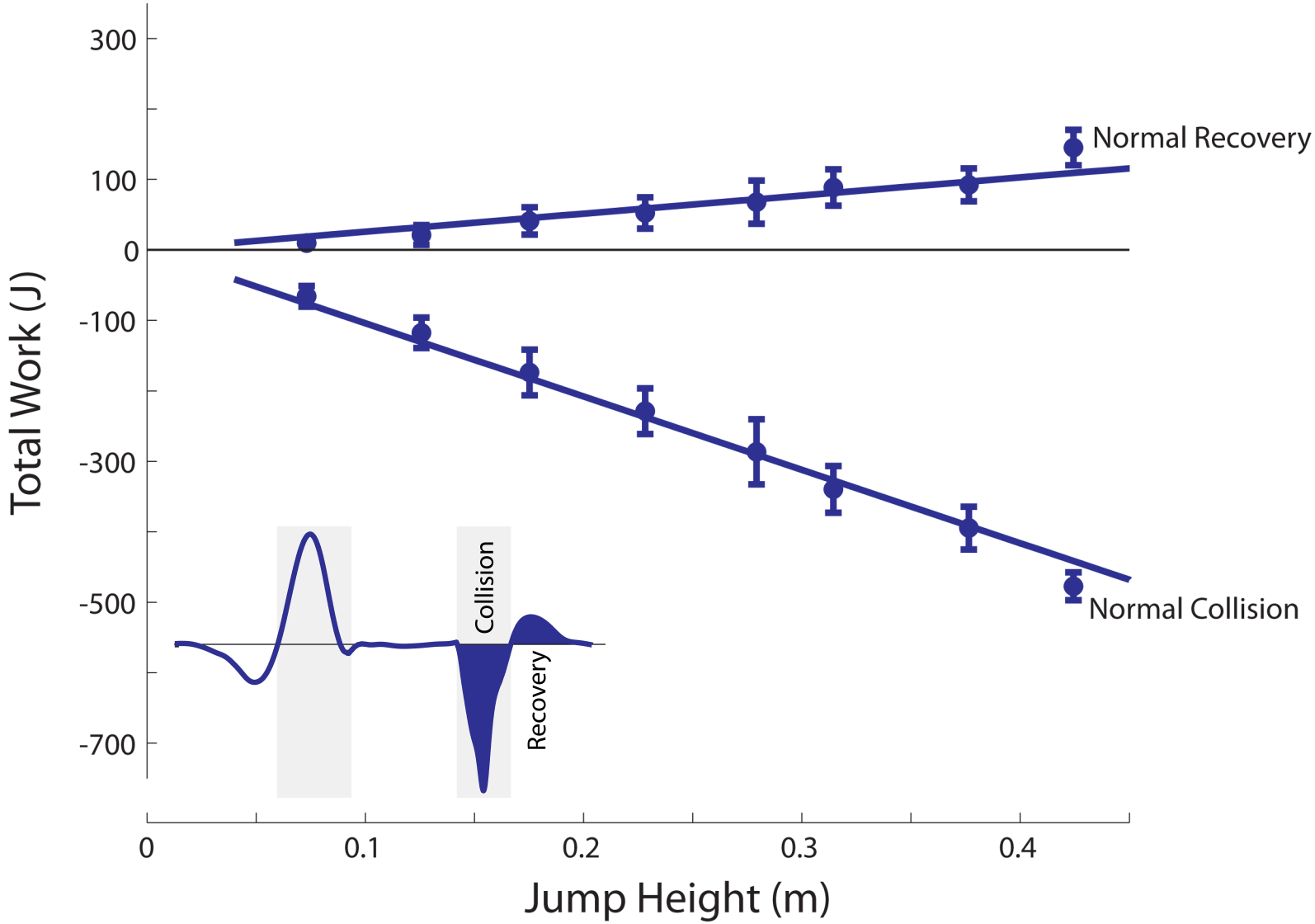


Recovery

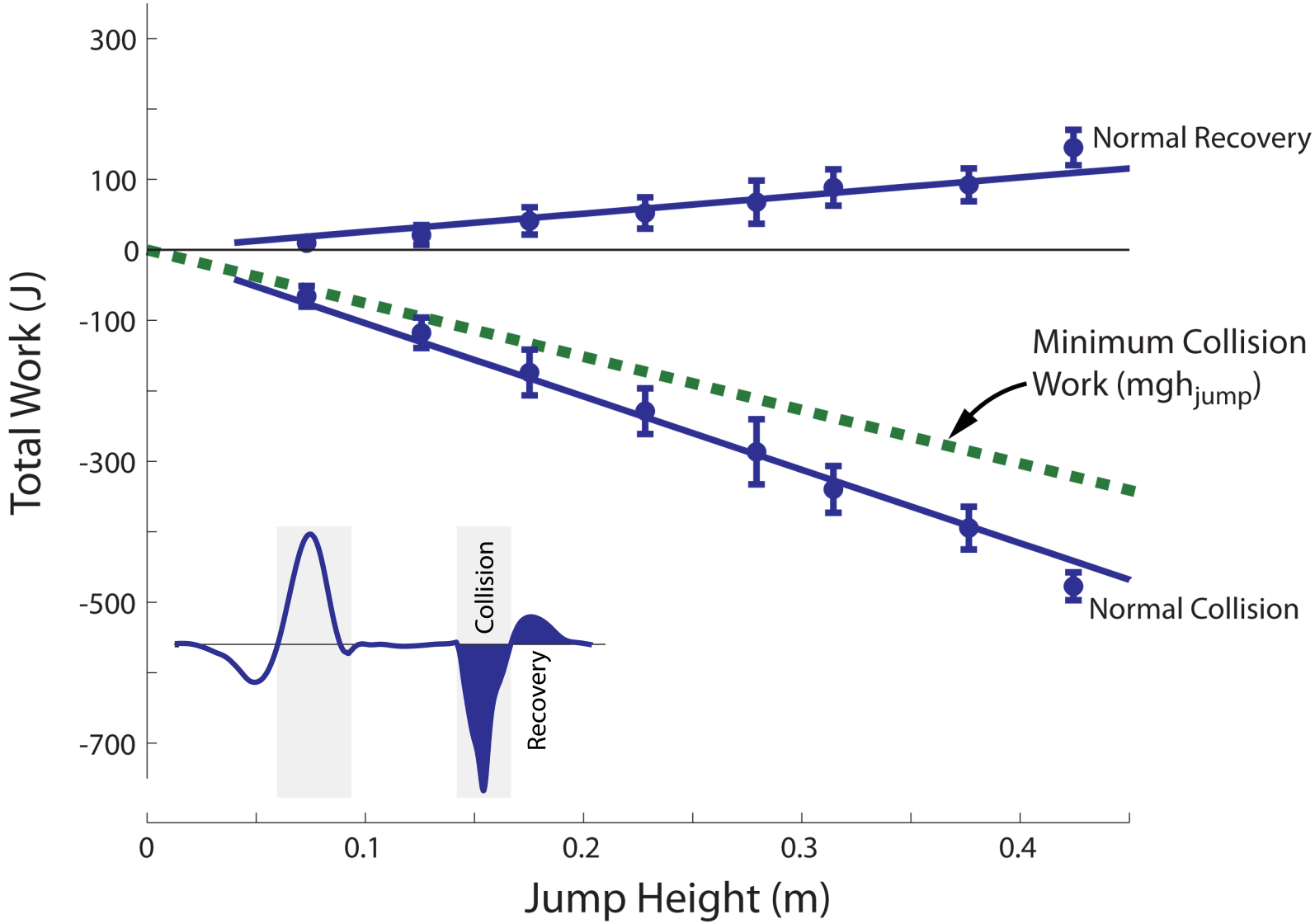
Representative mechanical power



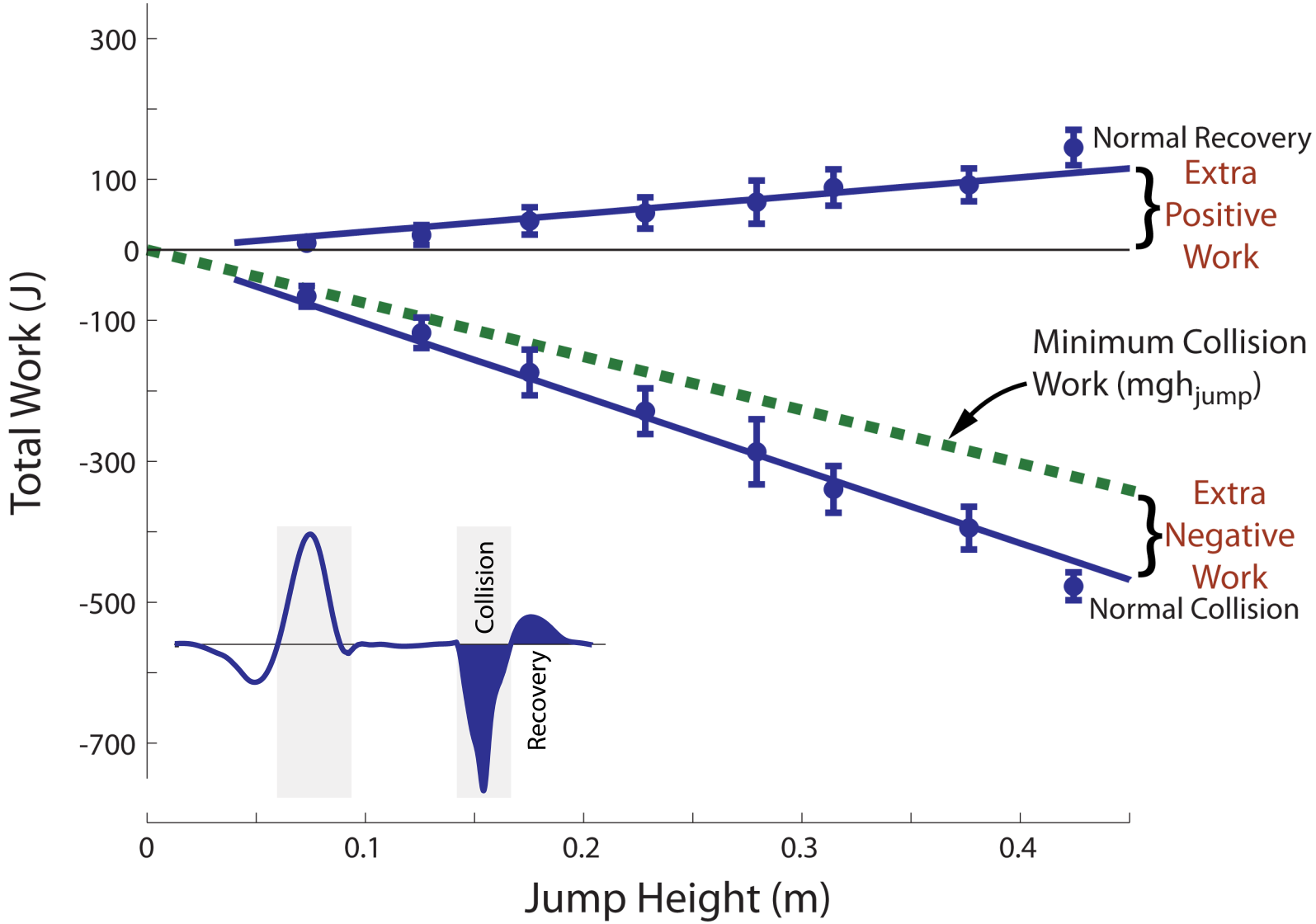
Preferred landing style



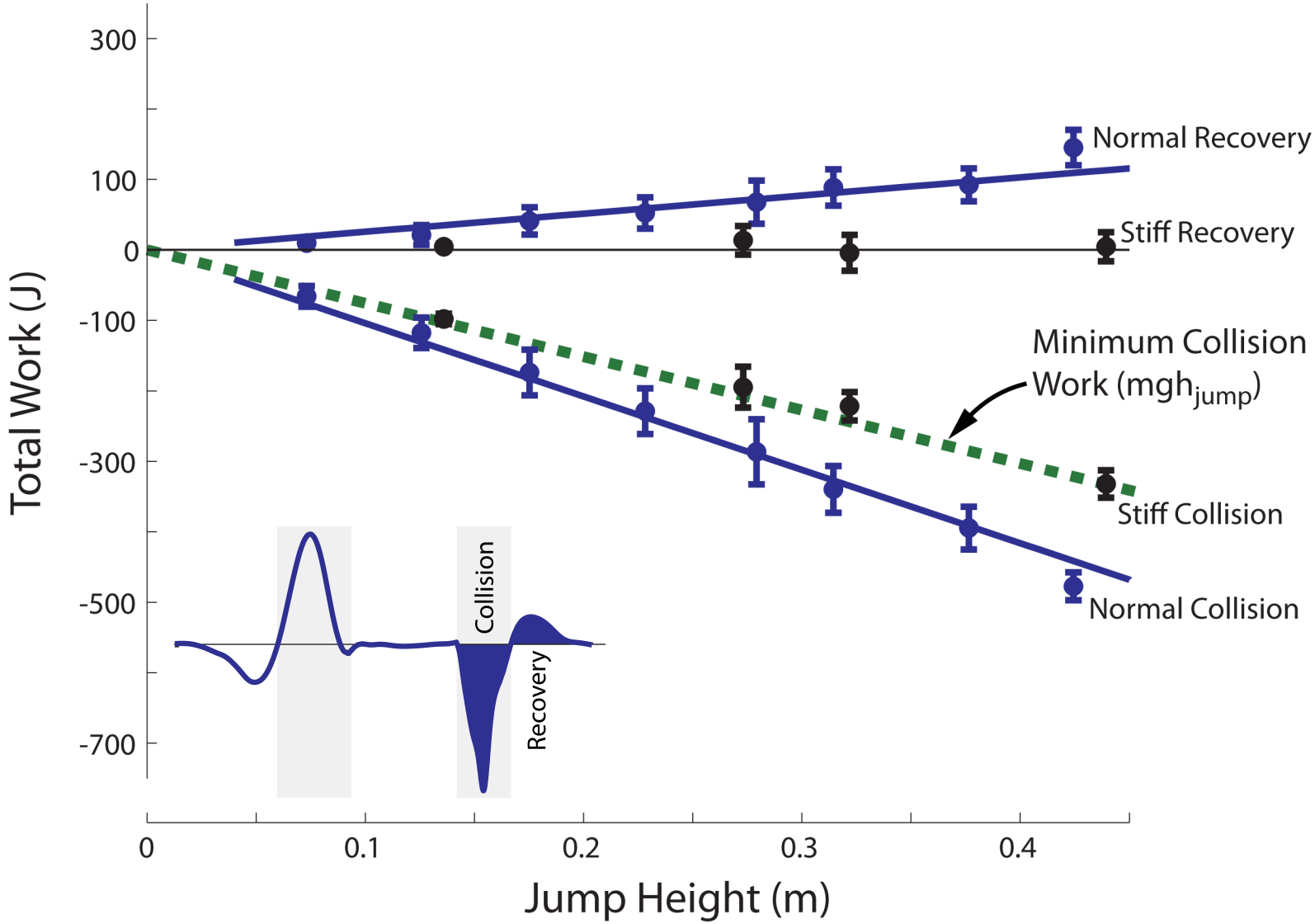
Theoretical minimum: only negative work



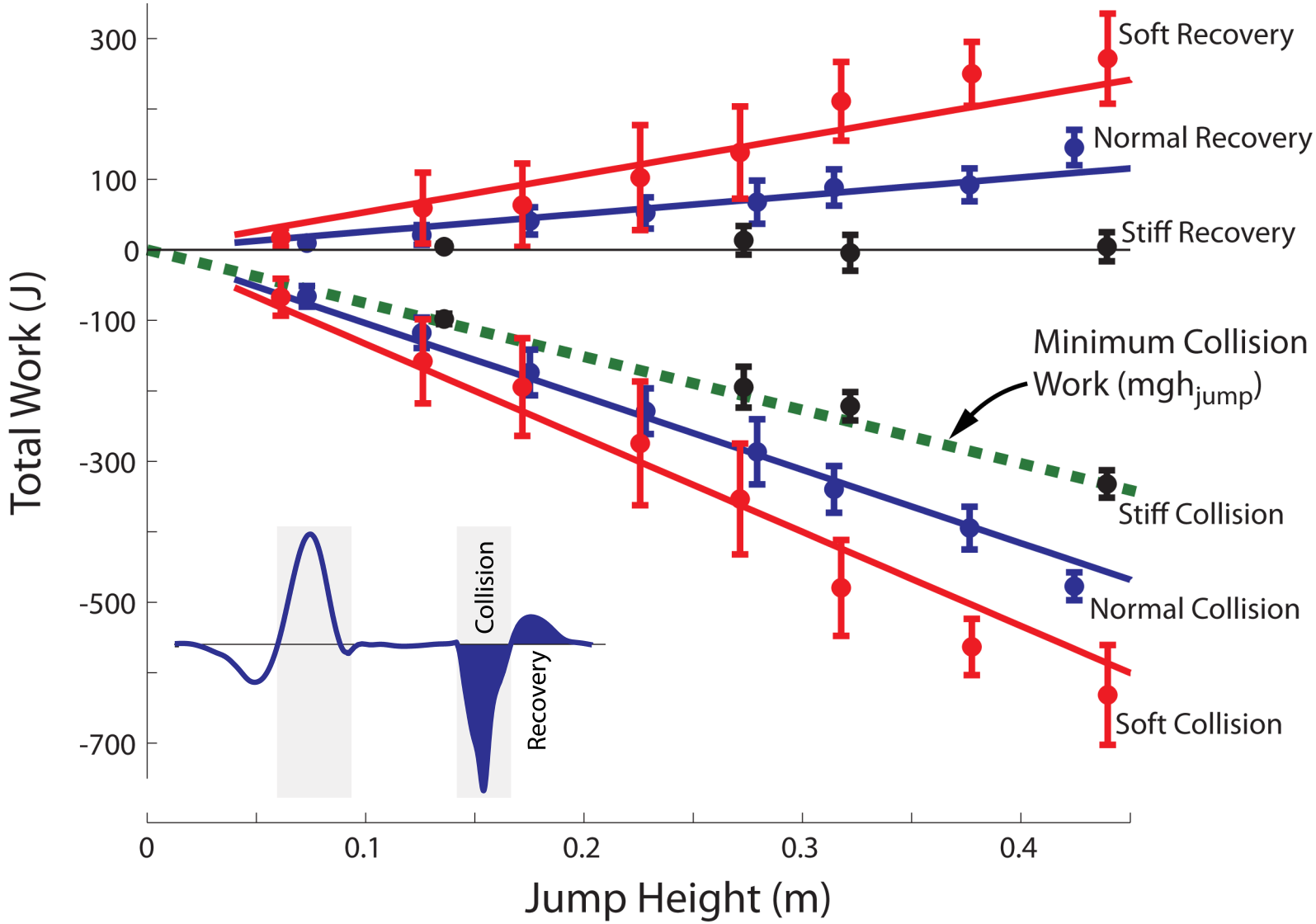
People choose to do more work than necessary



Landing stiff-legged minimizes work



Landing softly increases neg. & pos. work



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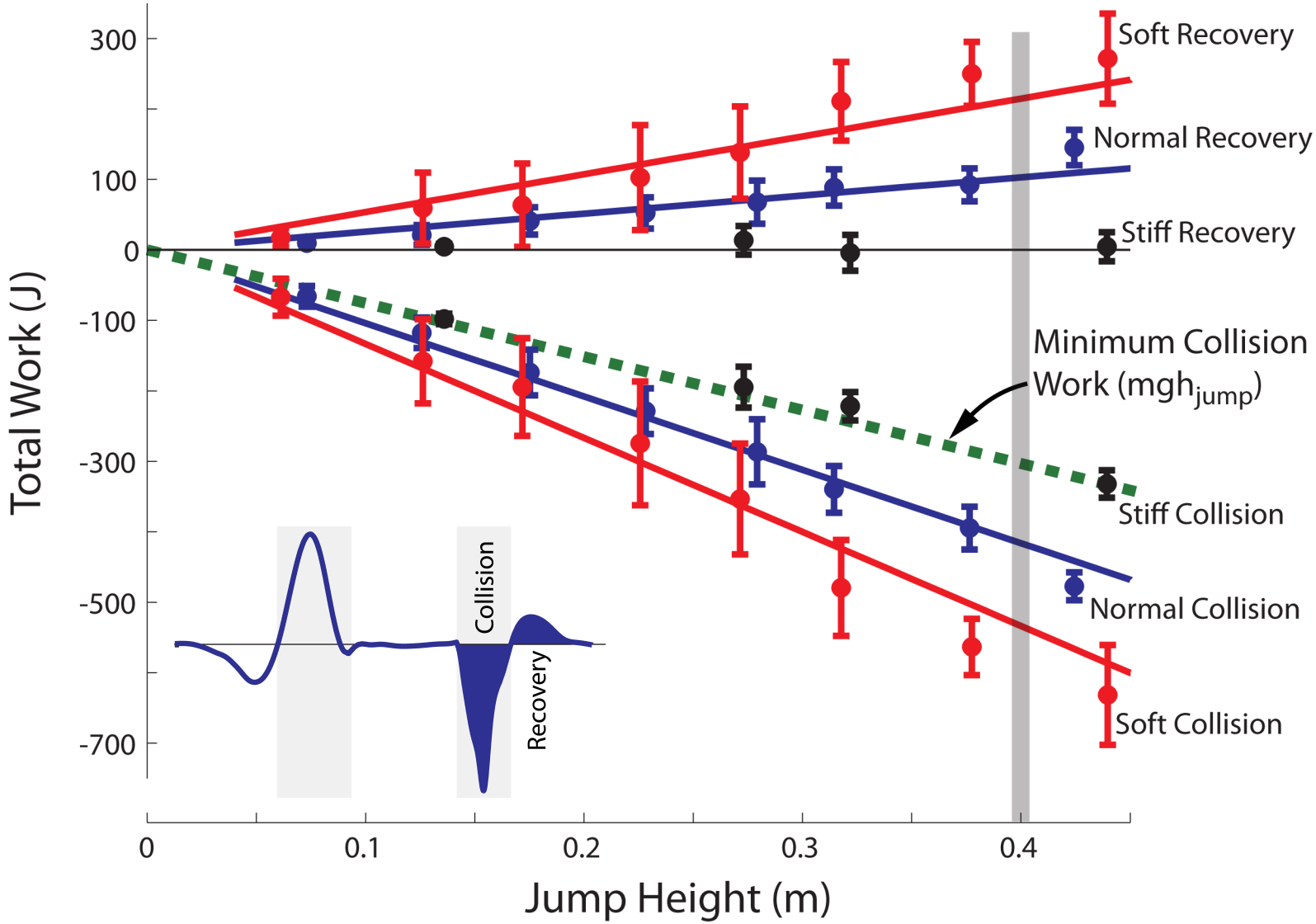
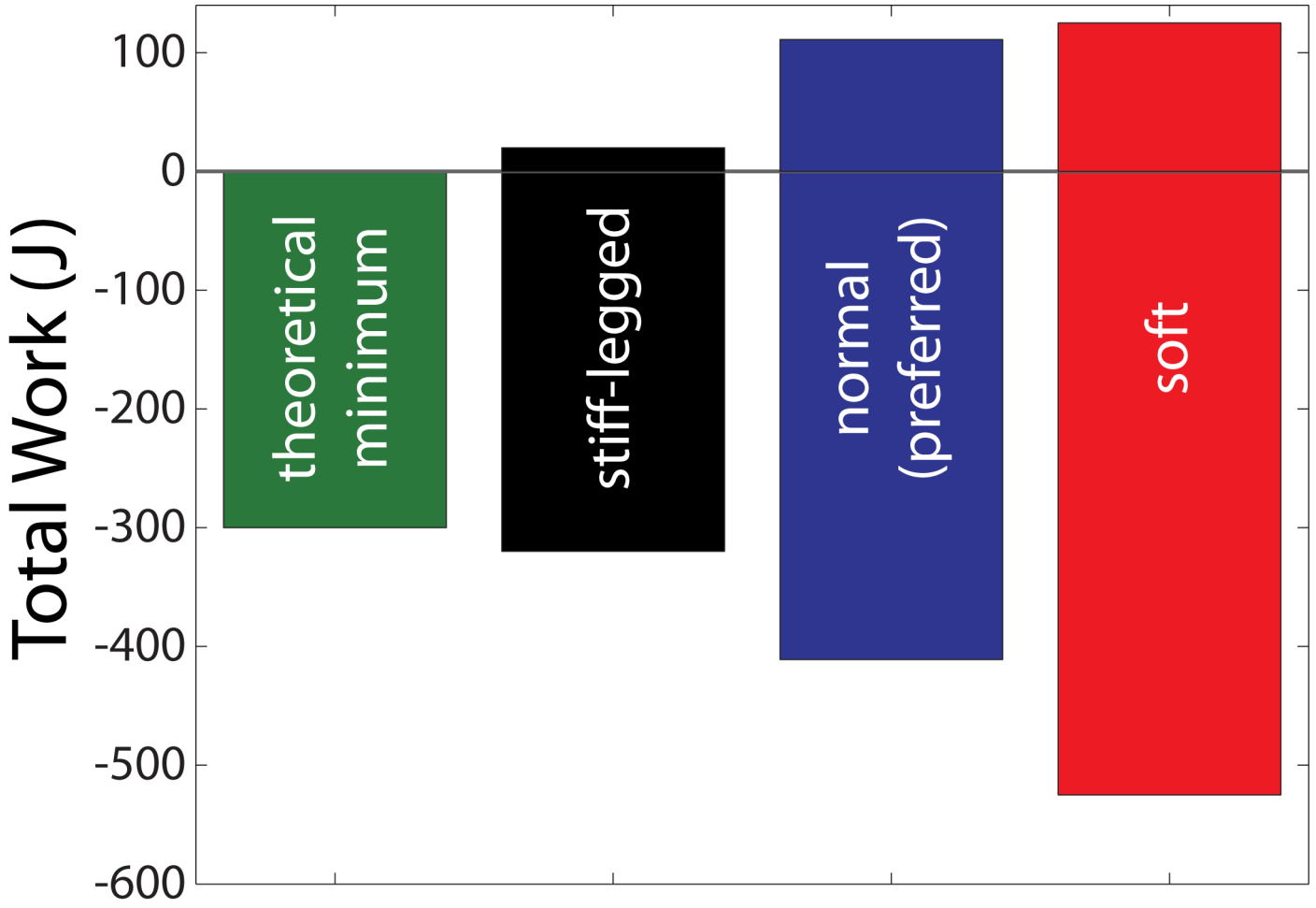
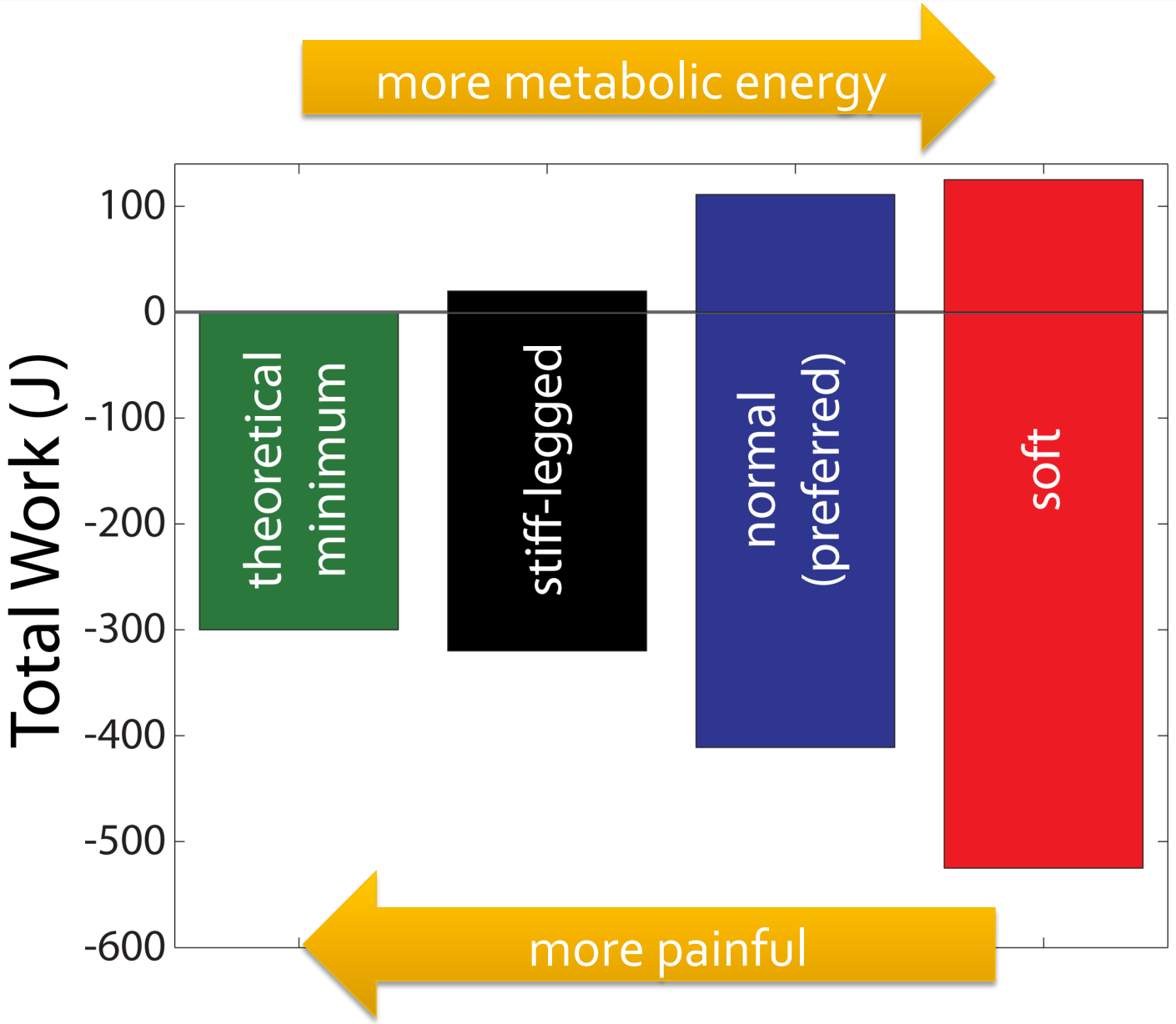


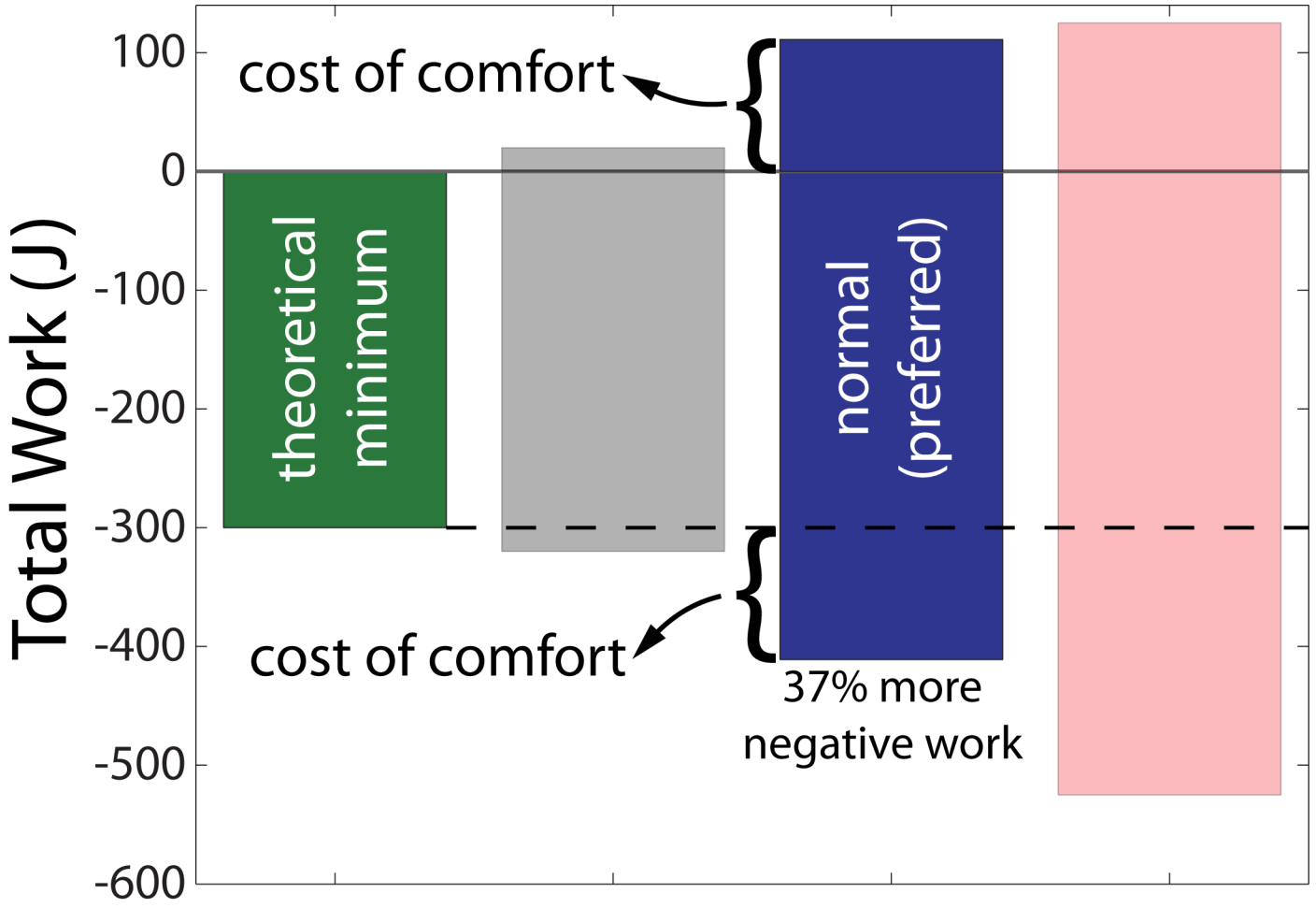
Mechanical work performed landing from 40cm

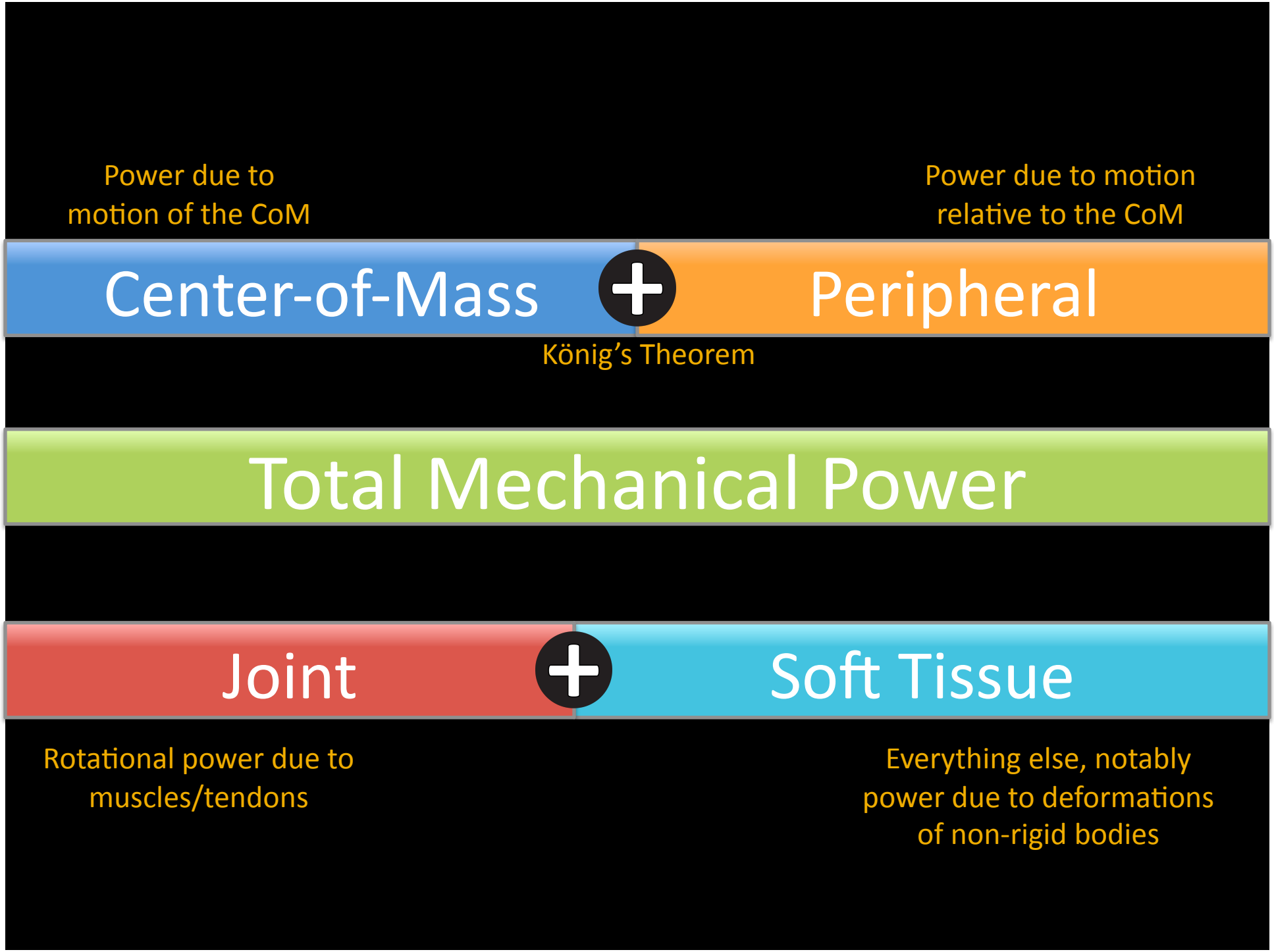


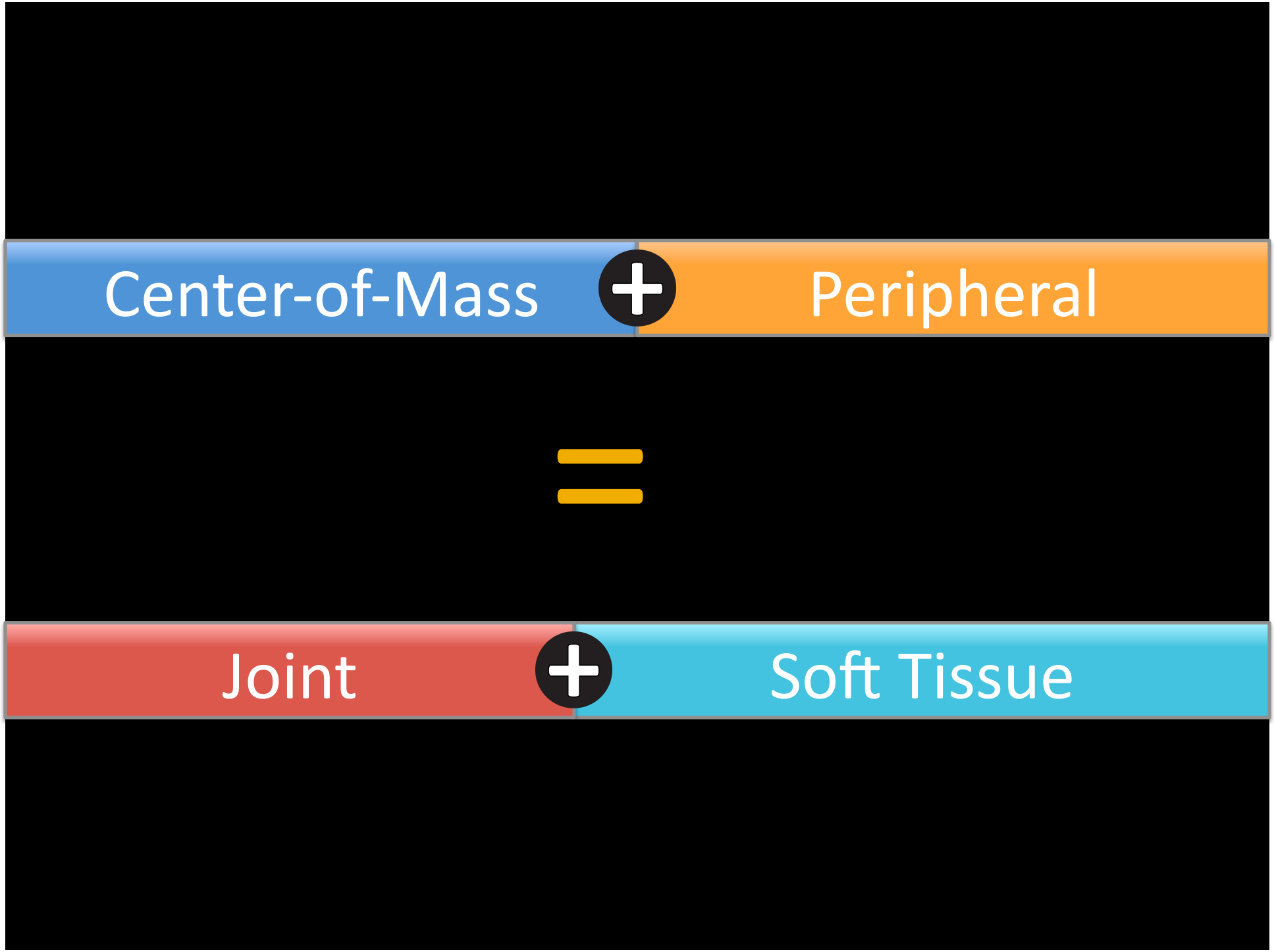
Trade-off between energy and pain



People prefer to do 37% more negative work




Power due to motion of the CoM
Power due to motion relative to the CoM
Center-of-Mass
Peripheral
König's Theorem
Total Mechanical Power
Joint
Soft Tissue
Rotational power due to muscles/tendons
Everything else, notably power due to deformations of non-rigid bodies


Center-of-Mass
Peripheral
Joint
Soft Tissue

$$\sum_{legs} F_i \cdot v_{COM}$$

$$\frac{d}{dt} \sum_{segments} \frac{1}{2} m_s (v_s - v_{COM})^2 + \frac{1}{2} I_s \cdot \omega_s^2$$

Center-of-Mass + Peripheral*

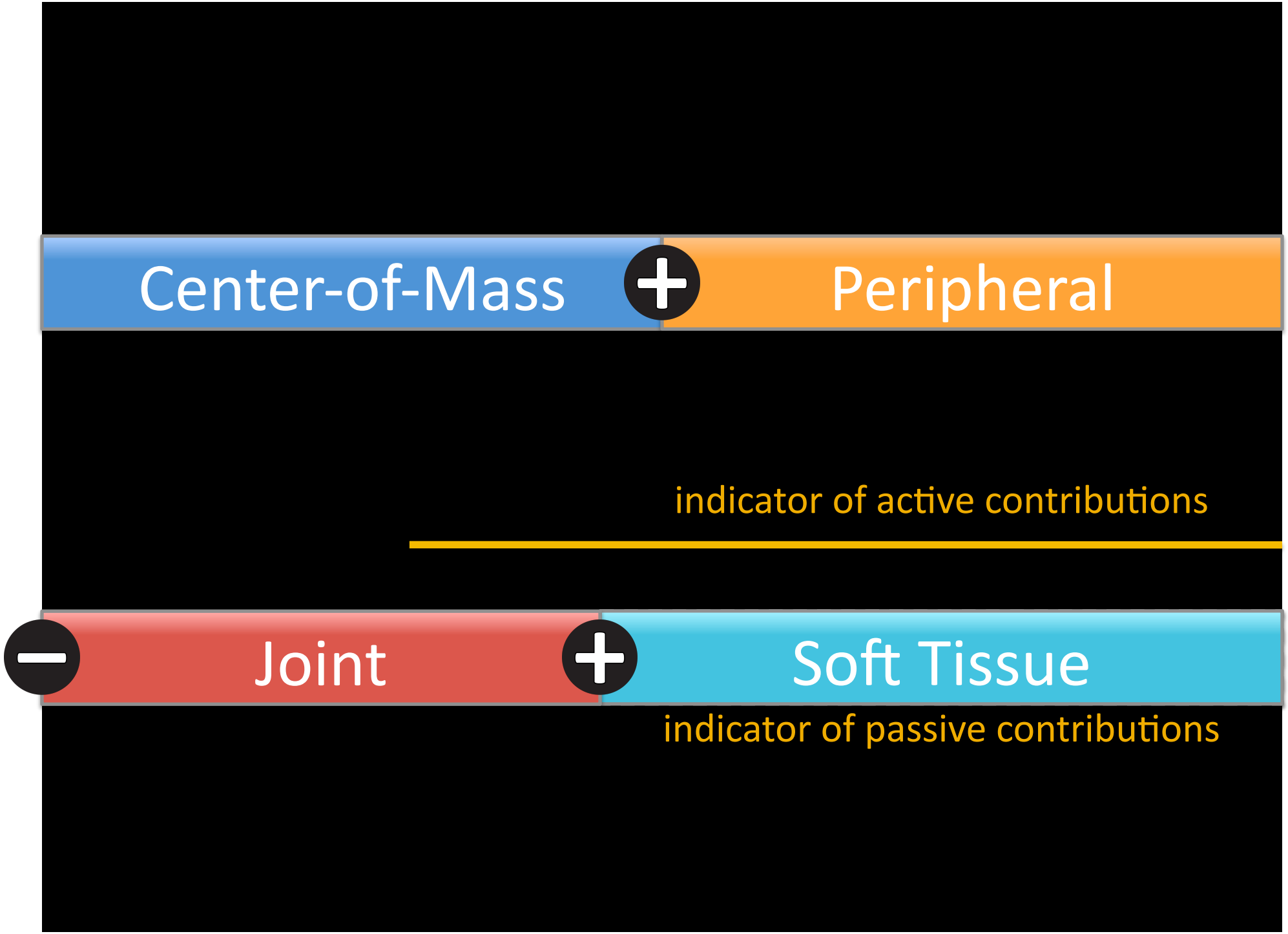
≈

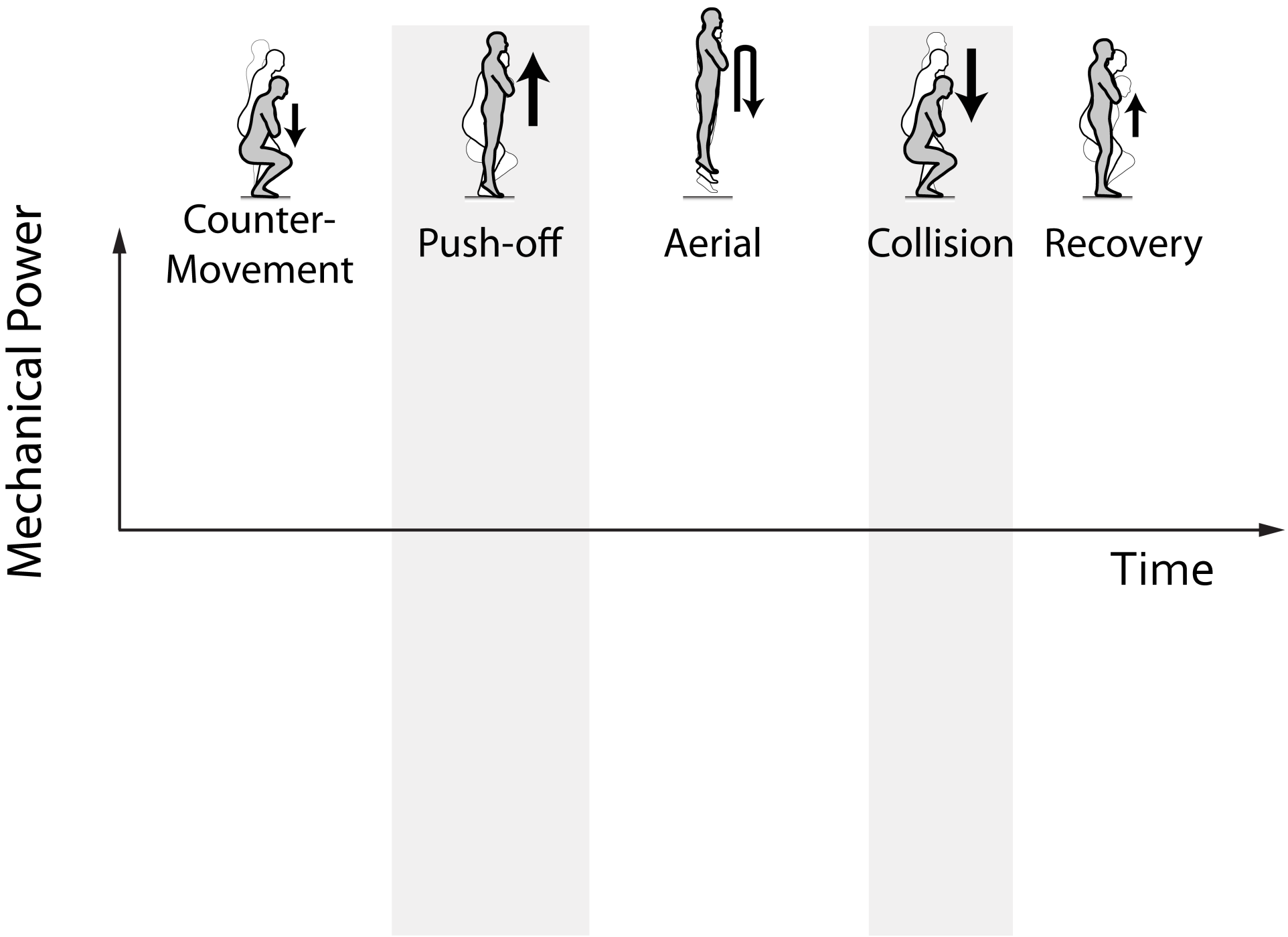
(inverse dynamics)

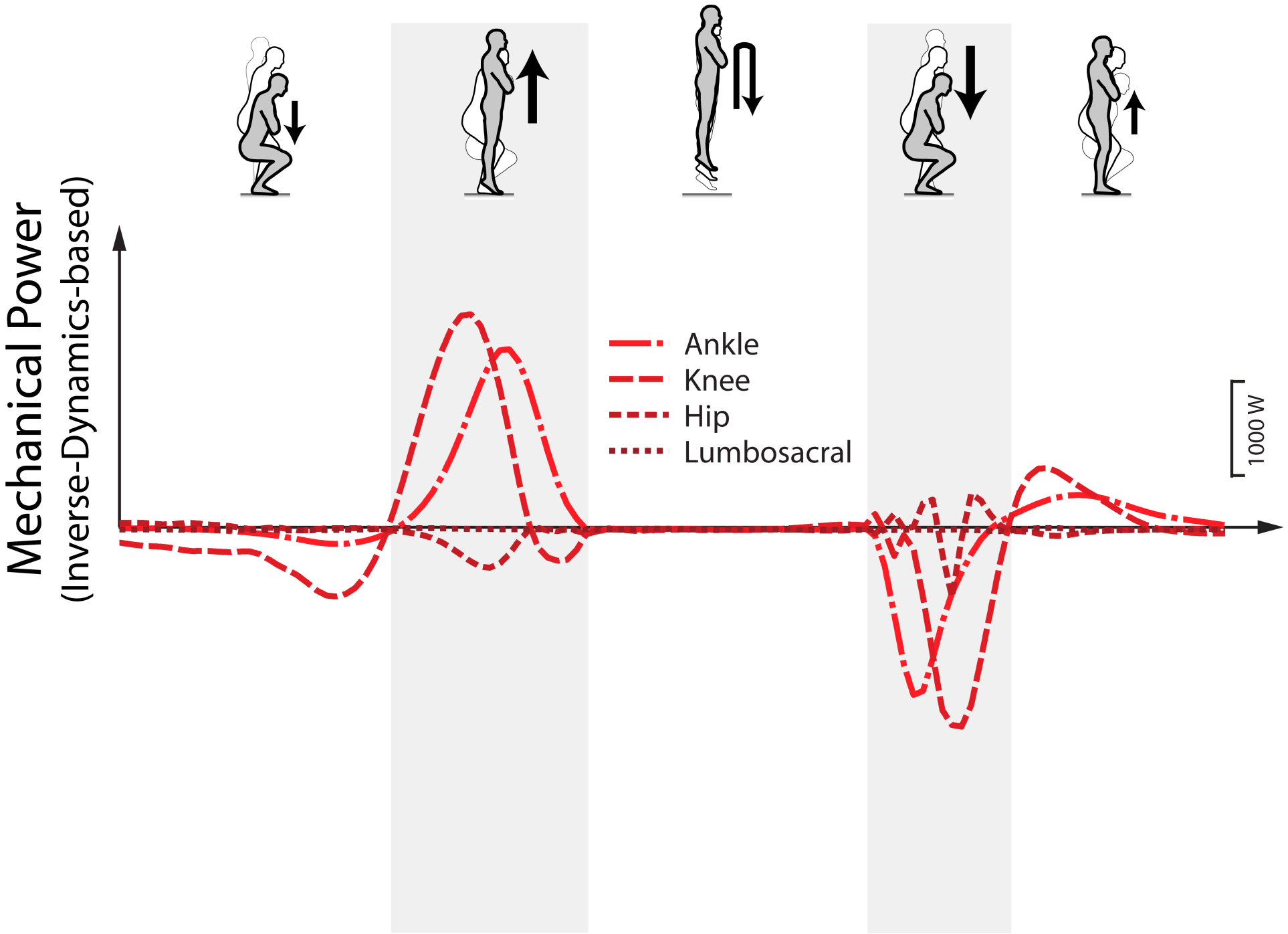
Joint* + Soft Tissue

$$\sum_{joints} M_j \cdot \omega_j$$

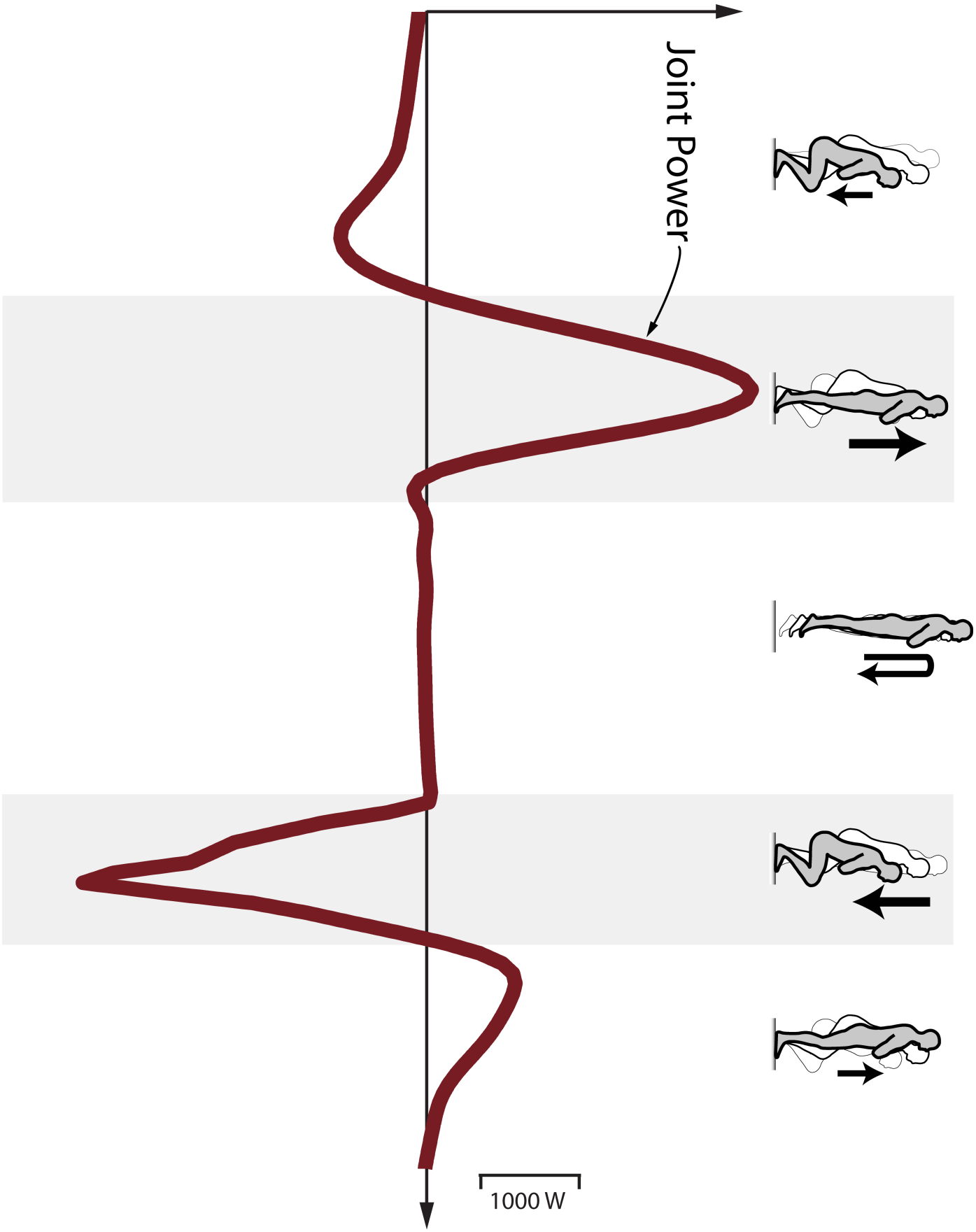
*rigid-body assumptions

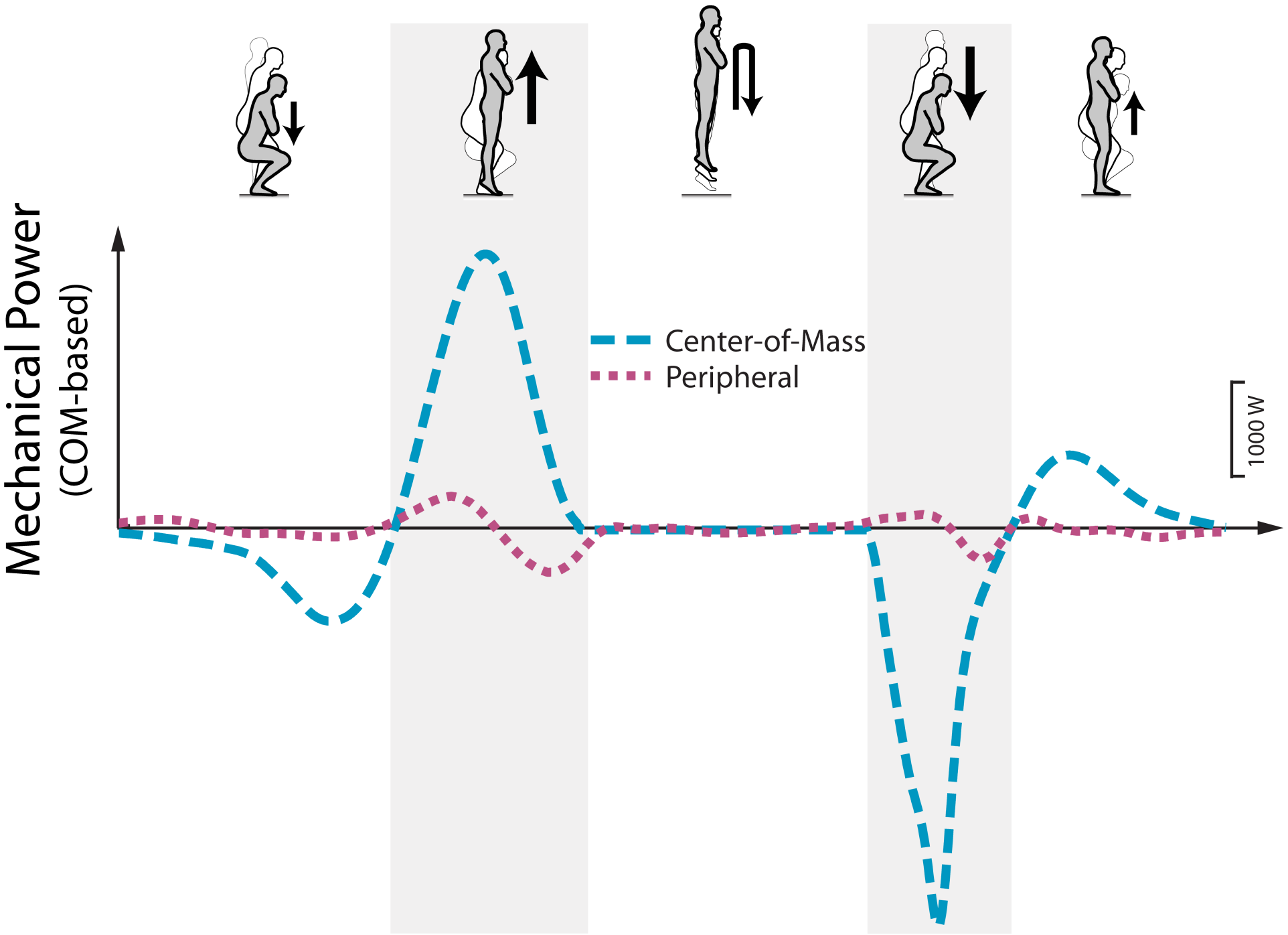

Center-of-Mass
Peripheral
indicator of active contributions
Joint
Soft Tissue
indicator of passive contributions

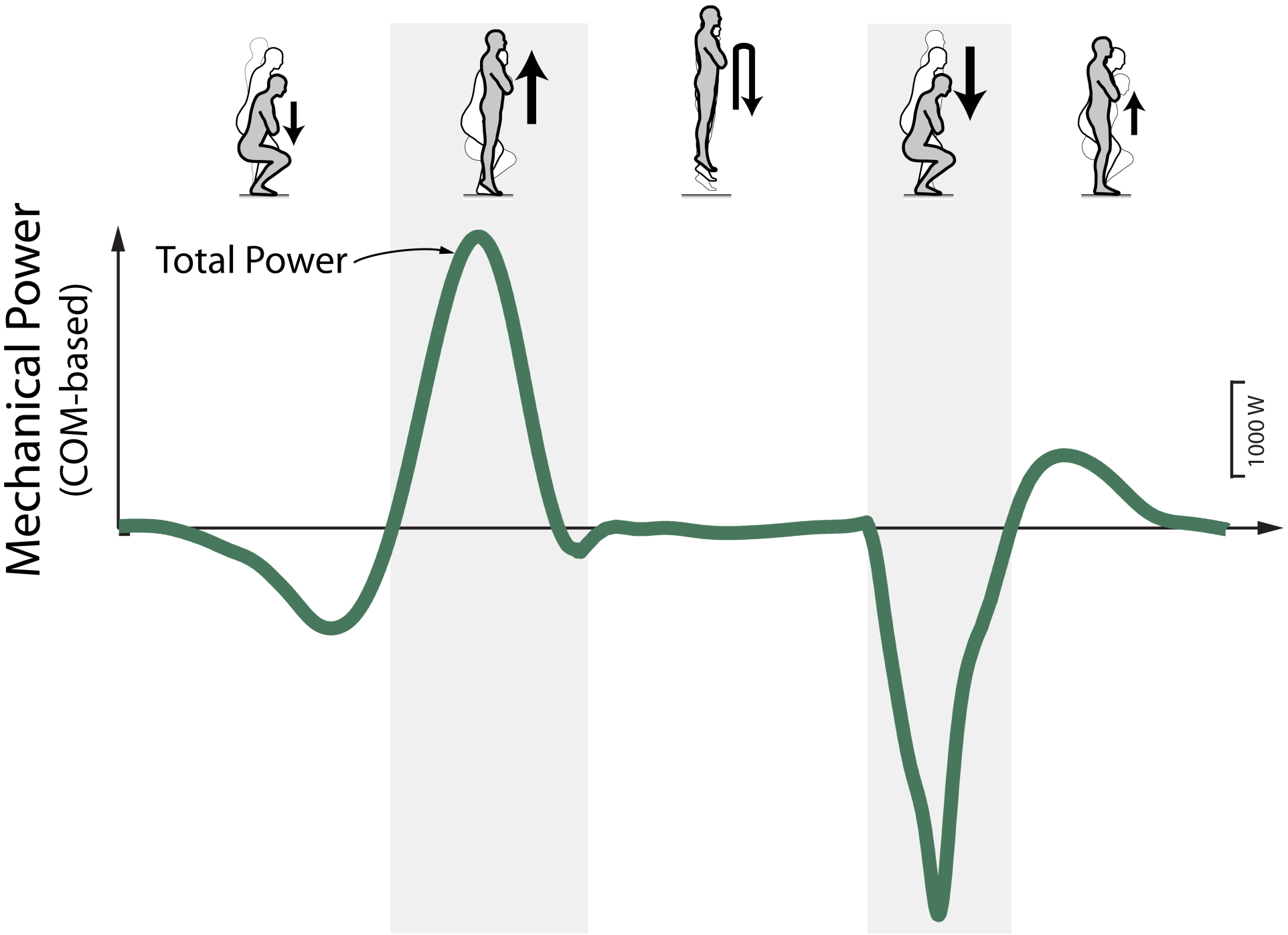

Mechanical Power
Counter-
Movement
Push-off
Aerial
Collision
Recovery
Time


Mechanical Power
(Inverse-Dynamics-based)
Ankle
Knee
Hip
Lumbosacral
1000 W

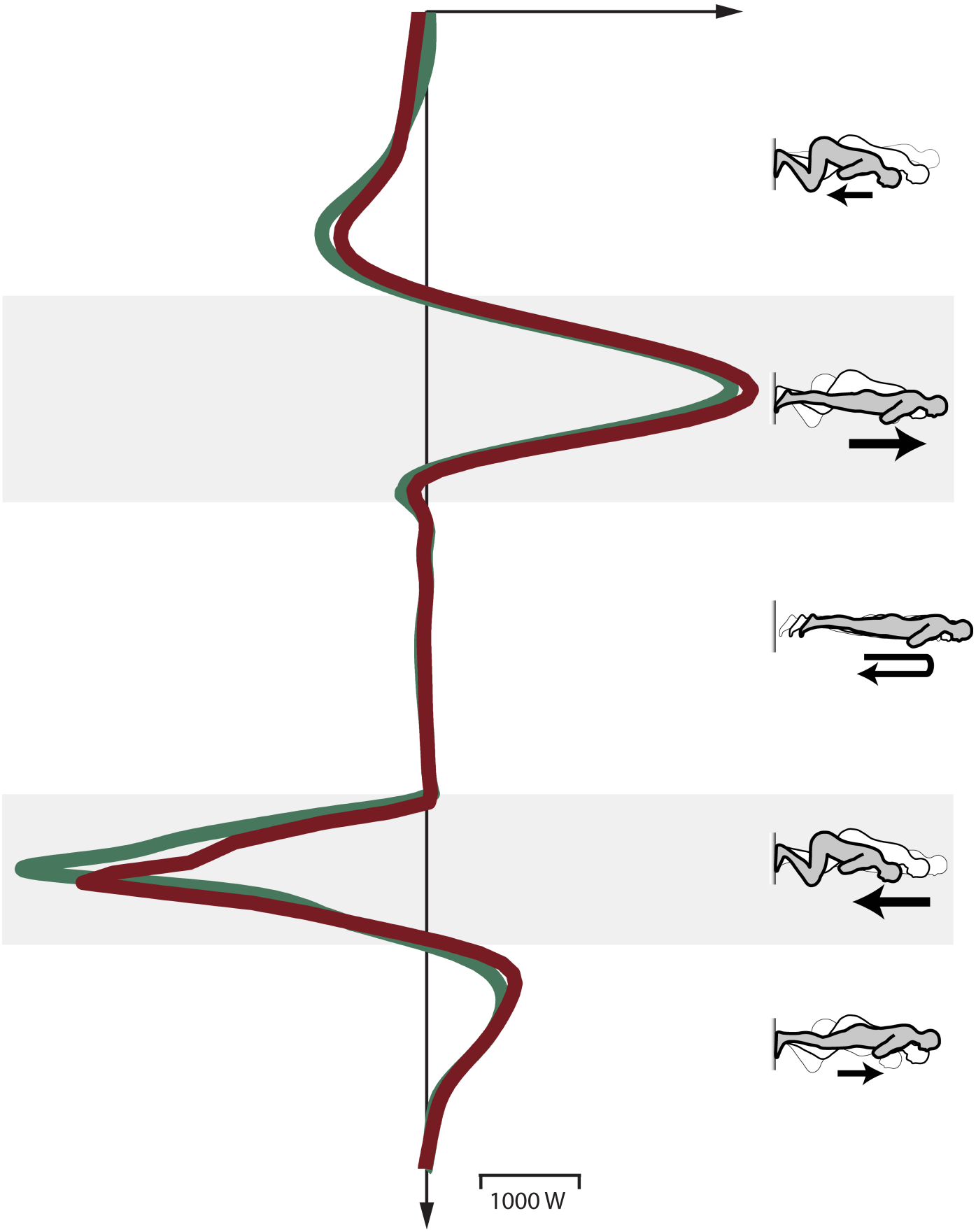
Mechanical Power
(Inverse-Dynamics-based)

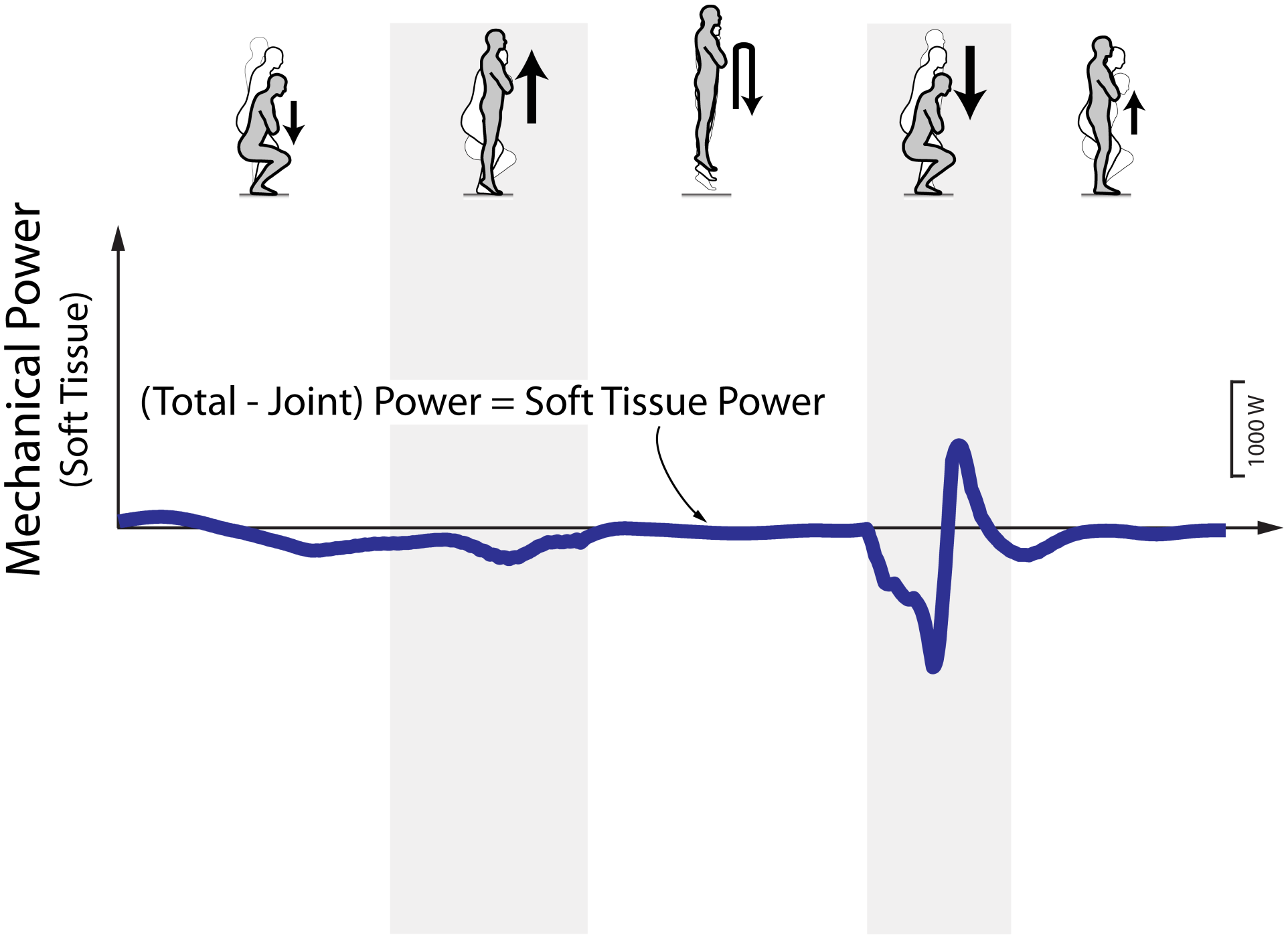


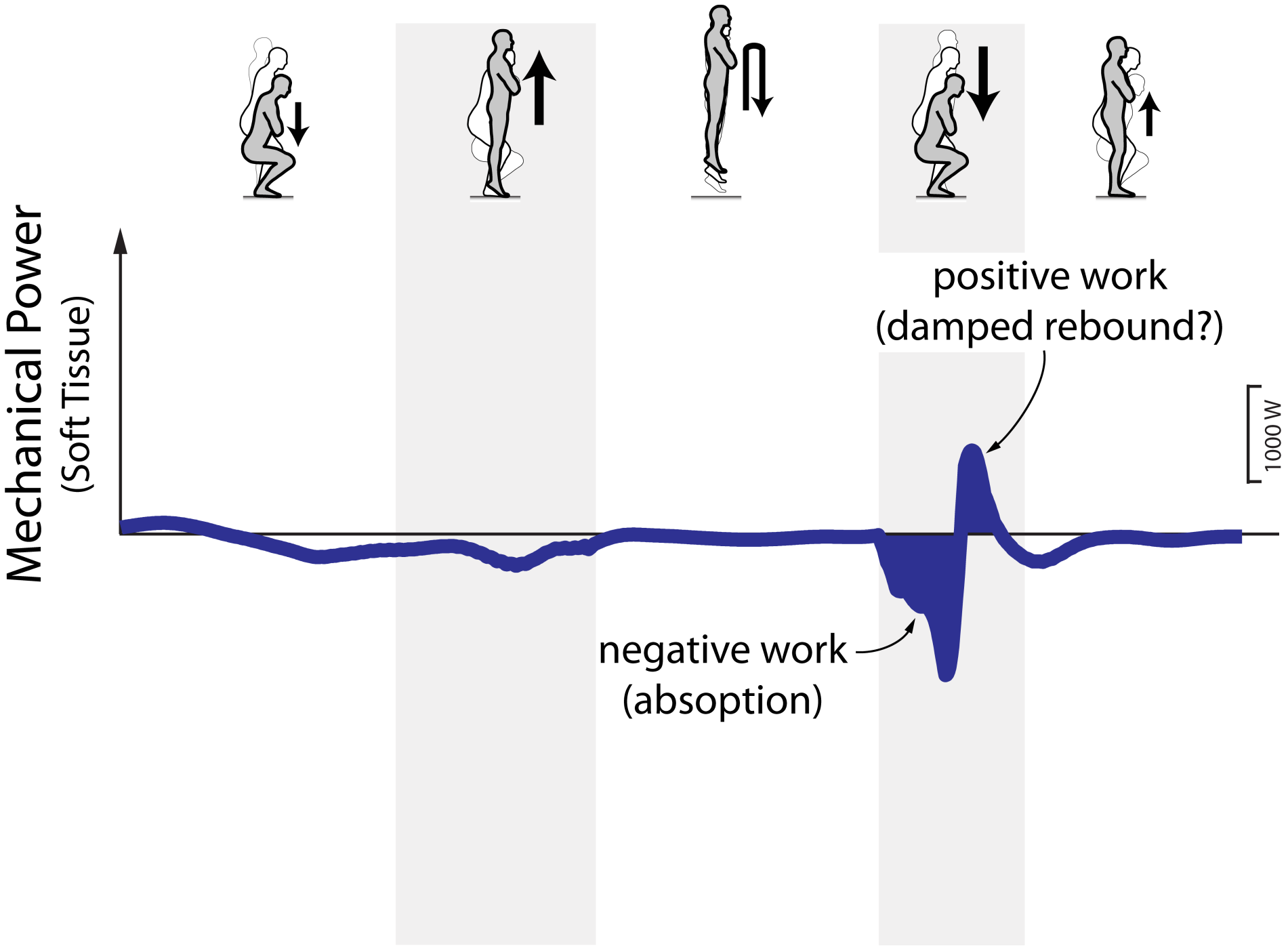

Mechanical Power
(COM-based)
Center-of-Mass
Peripheral
1000 W

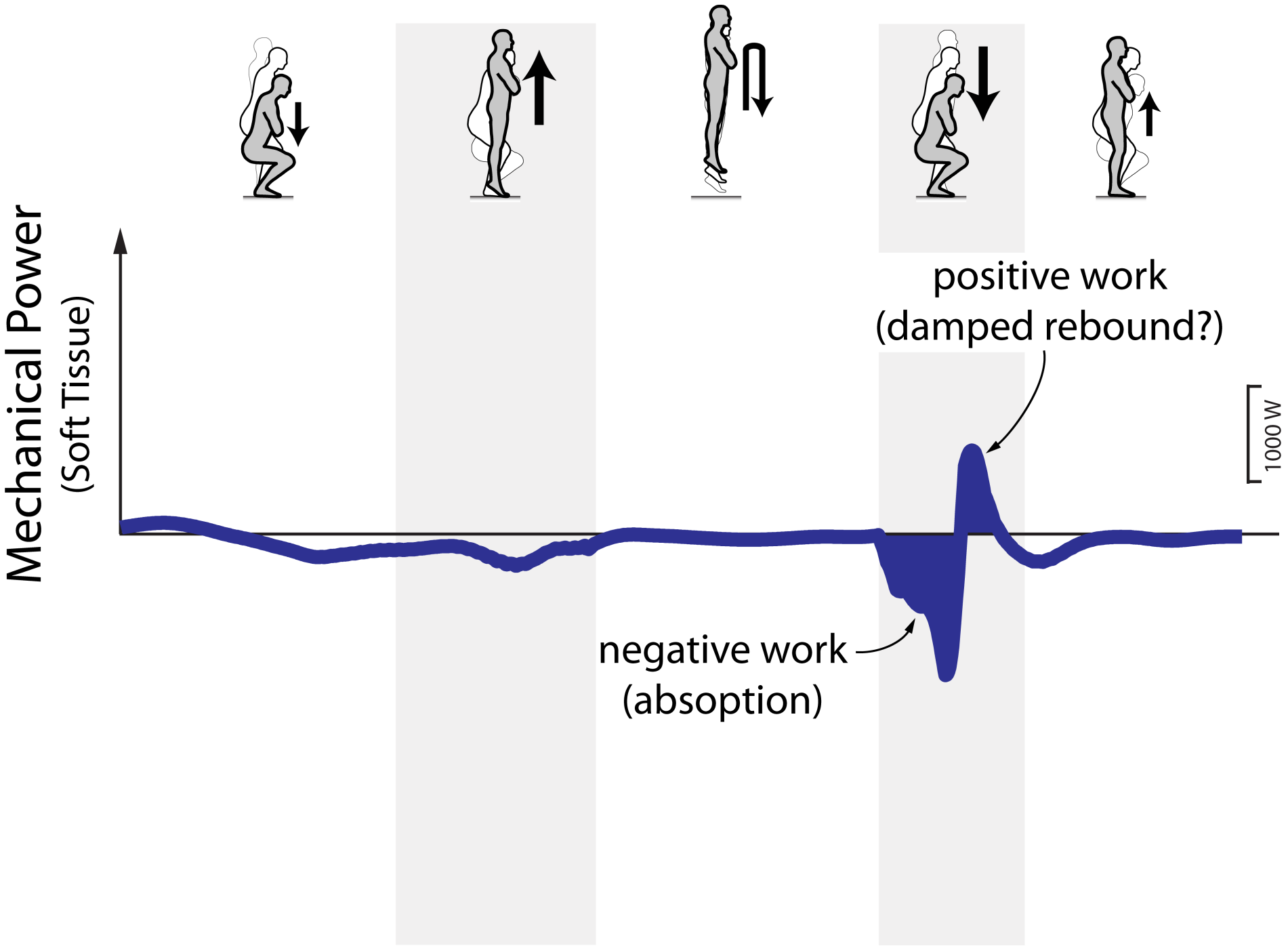

Mechanical Power
(COM-based)
Total Power
1000 W

Mechanical Power

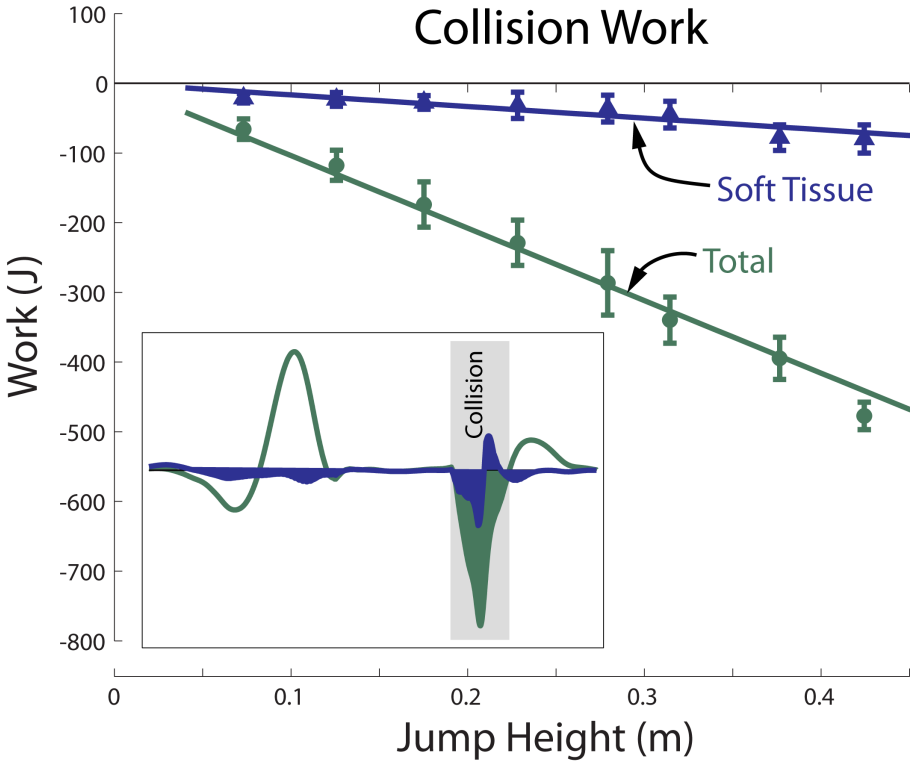



Mechanical Power
(Soft Tissue)
(Total - Joint) Power = Soft Tissue Power
1000 W

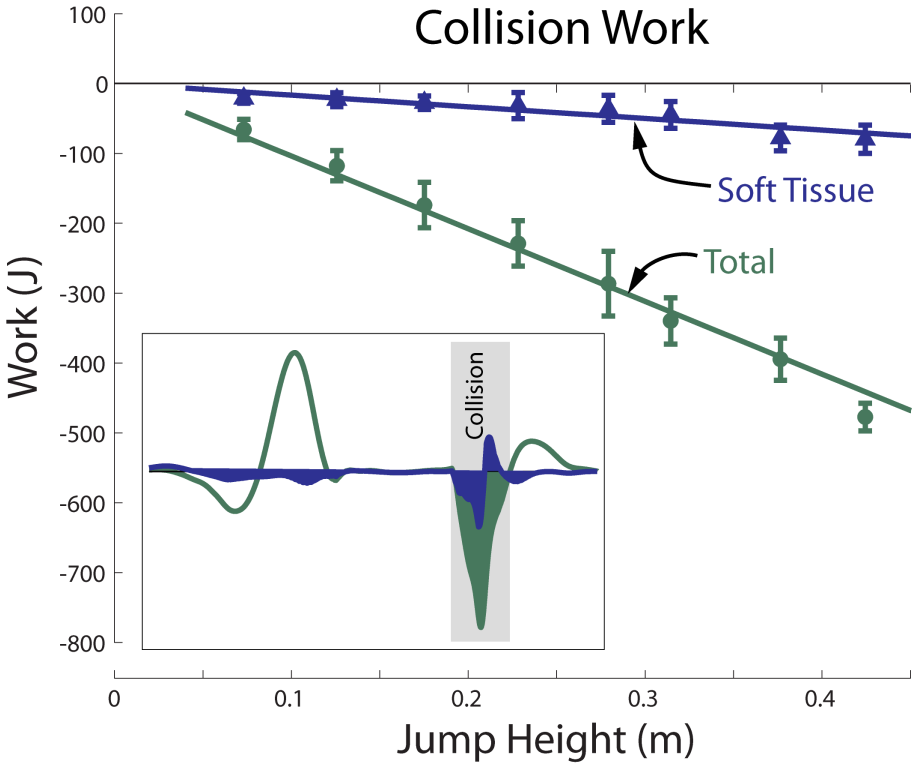

Mechanical Power
(Soft Tissue)
positive work
(damped rebound?)
1000 W
negative work
(absoption)

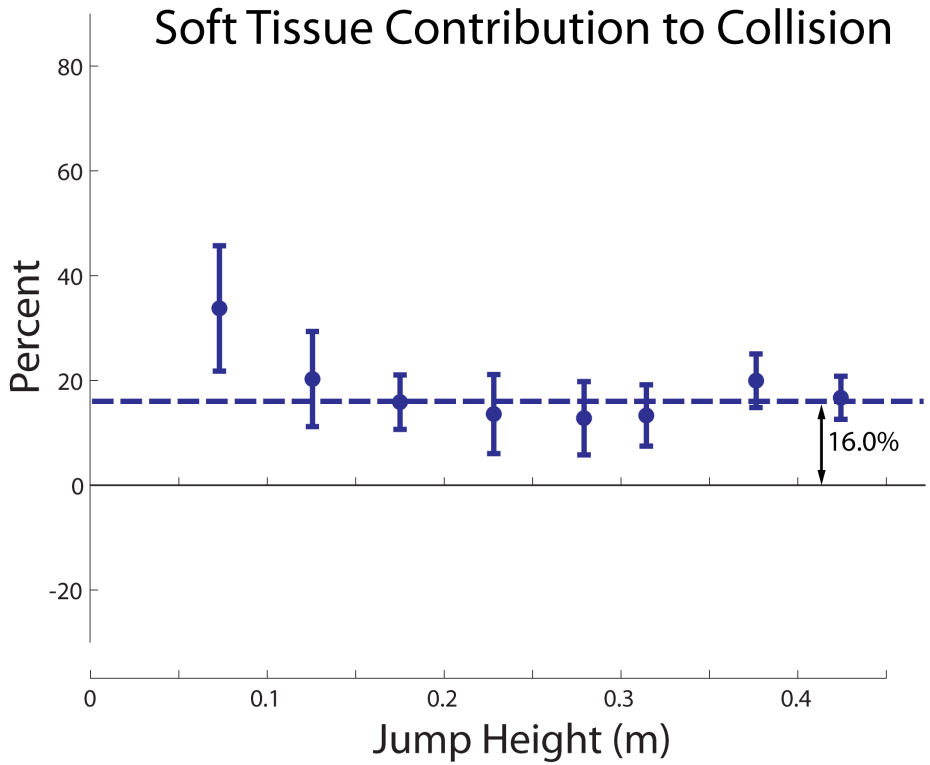

Mechanical Power
(Soft Tissue)
positive work
(damped rebound?)
1000 W
negative work
(absoption)

Soft Tissue Collision work increases with Total

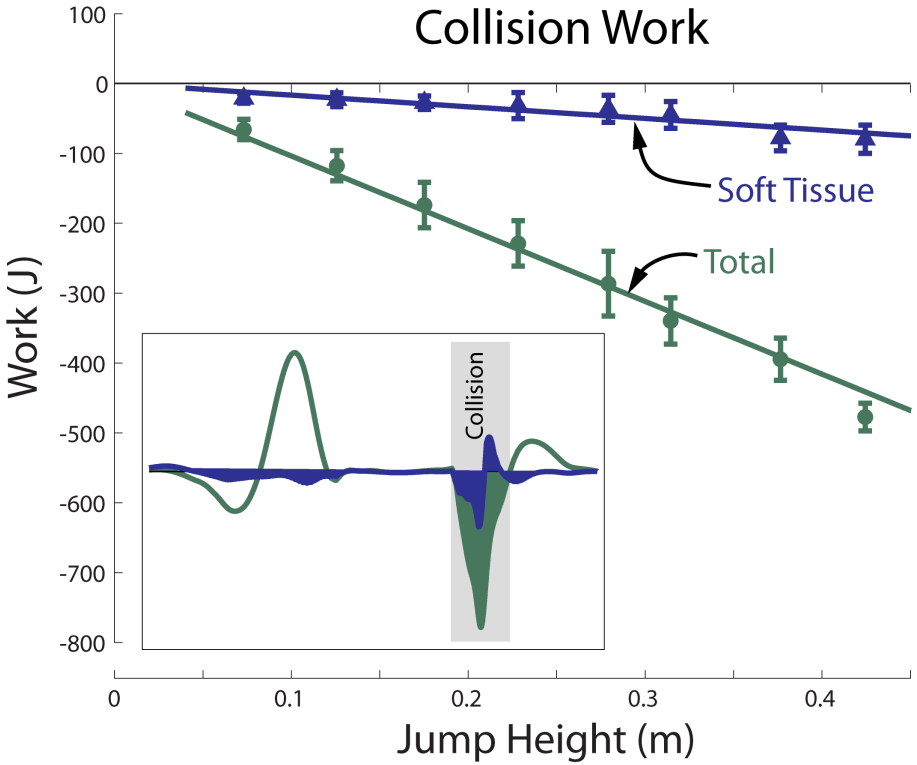


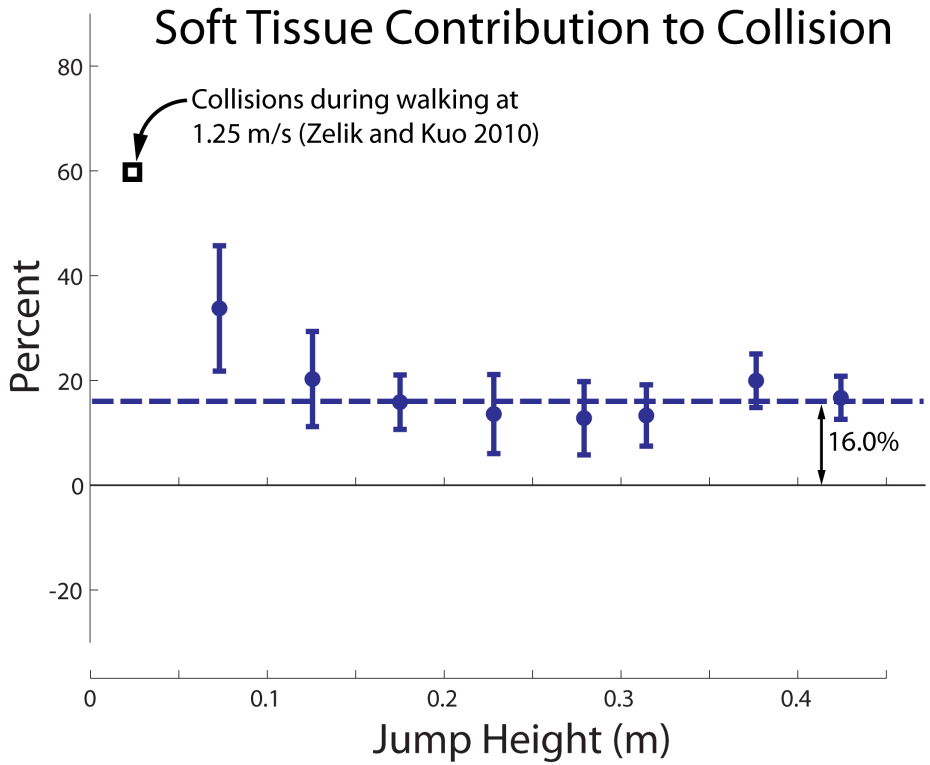
Soft Tissues perform 16% of Collision work





Passive contribution highest for small Collisions





People prefer to distribute work between active & passive tissues, doing 37% more than needed

Collisions could be done for free,
but it hurts to land passively,
So people will choose
Mostly muscles to use.
Comfort is worth energy.

Acknowledgements
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