Lecture 9

Advanced Dynamic Analyses

EML 5595
Mechanics of the Human Locomotor System

Outline

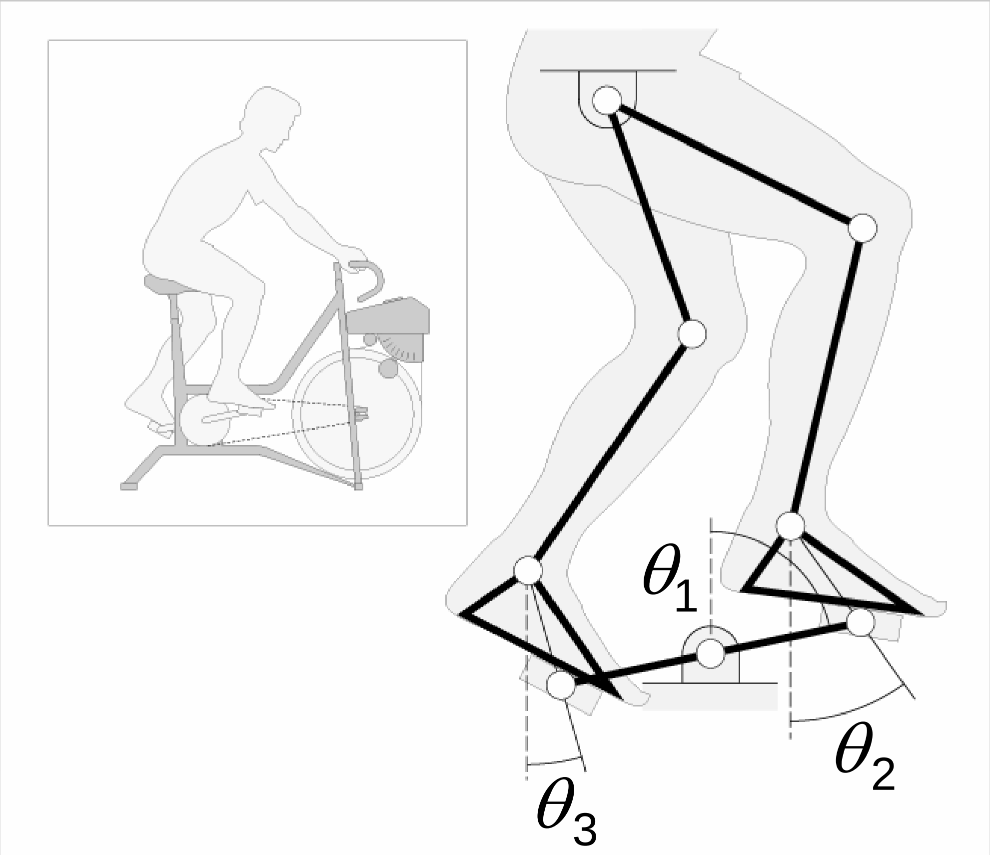
- Induced Acceleration Analysis
- Induced Power Analysis
- Journal Article Reviews

  Fregly and Zajac (1996)

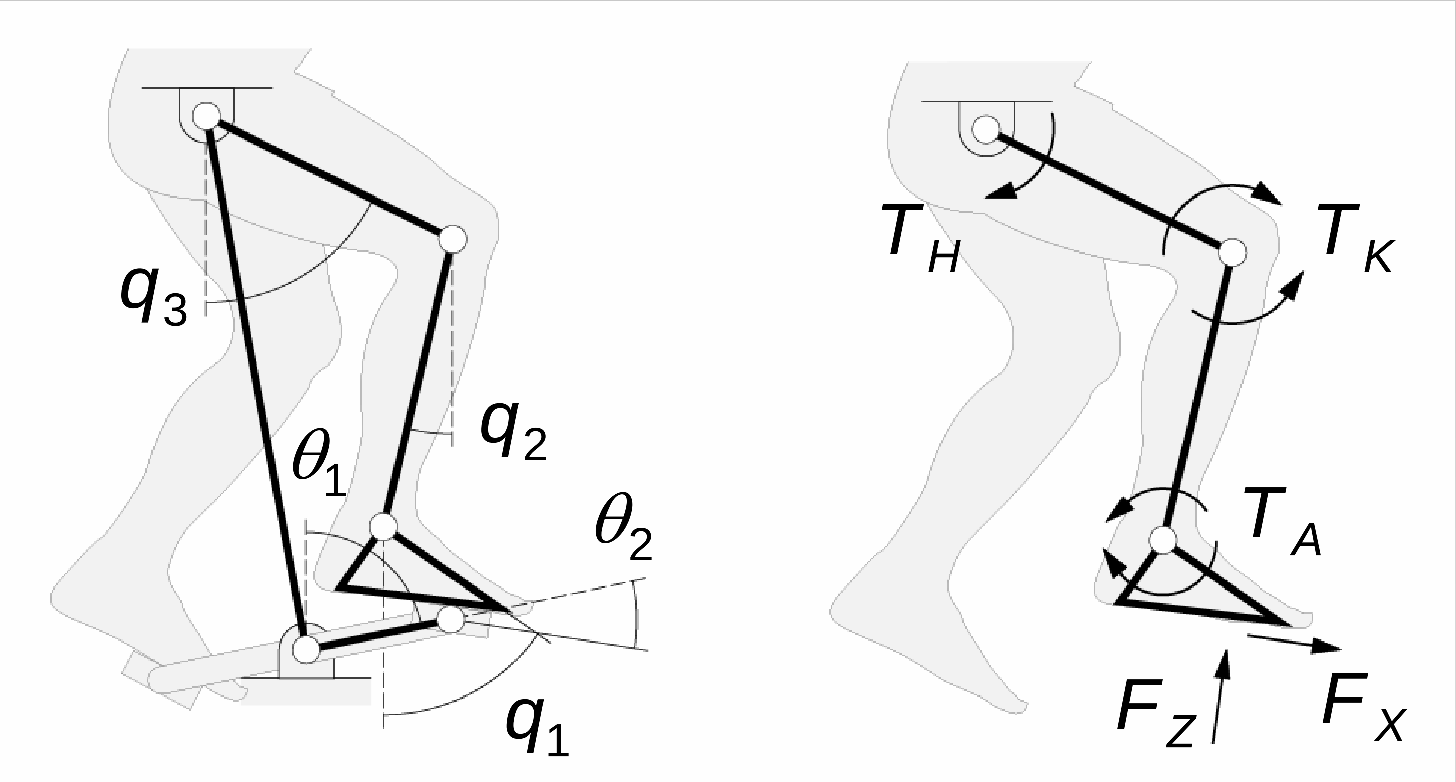
Outline

- Induced Acceleration Analysis

Pedaling Example

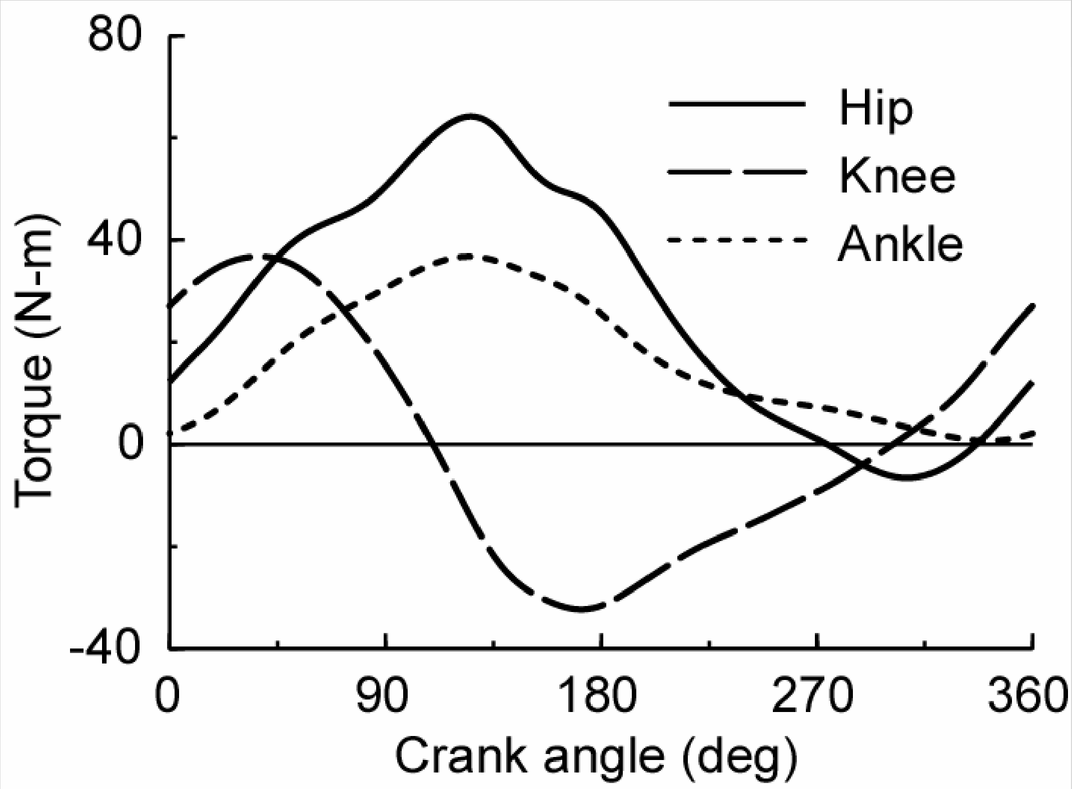


Inverse Dynamics Analysis



Kinematic model Dynamic model

Inverse Dynamics Results



Inverse Dynamics Limitations

Why not infer a muscle's function from its net torque influence?

- A muscle exerts a dynamic influence on *all* joints and segments in the system
- Some muscles cross *multiple* joints
- A muscle's dynamic influence can *vary* during the course of a movement
- A muscle's dynamic influence can *vary* from one movement to another

Equations of Motion

$$\mathbf{M}(\boldsymbol{\theta})\ddot{\boldsymbol{\theta}} = \mathbf{T}(\boldsymbol{\theta},\dot{\boldsymbol{\theta}}) + \mathbf{V}(\boldsymbol{\theta},\dot{\boldsymbol{\theta}}) + \mathbf{G}(\boldsymbol{\theta}) + \mathbf{F}(\boldsymbol{\theta},\dot{\boldsymbol{\theta}})$$

where $\boldsymbol{\theta} = [\theta_1 \quad \theta_2 \quad \theta_3]^T$

$\mathbf{M}(\boldsymbol{\theta}) = \text{mass matrix}$

$\mathbf{T}(\boldsymbol{\theta},\dot{\boldsymbol{\theta}}) = \text{muscle contribution}$

$\mathbf{V}(\boldsymbol{\theta},\dot{\boldsymbol{\theta}}) = \text{velocity contribution}$

$\mathbf{G}(\boldsymbol{\theta}) = \text{gravity contribution}$

$\mathbf{F}(\boldsymbol{\theta},\dot{\boldsymbol{\theta}}) = \text{friction contribution}$

Induced Acceleration

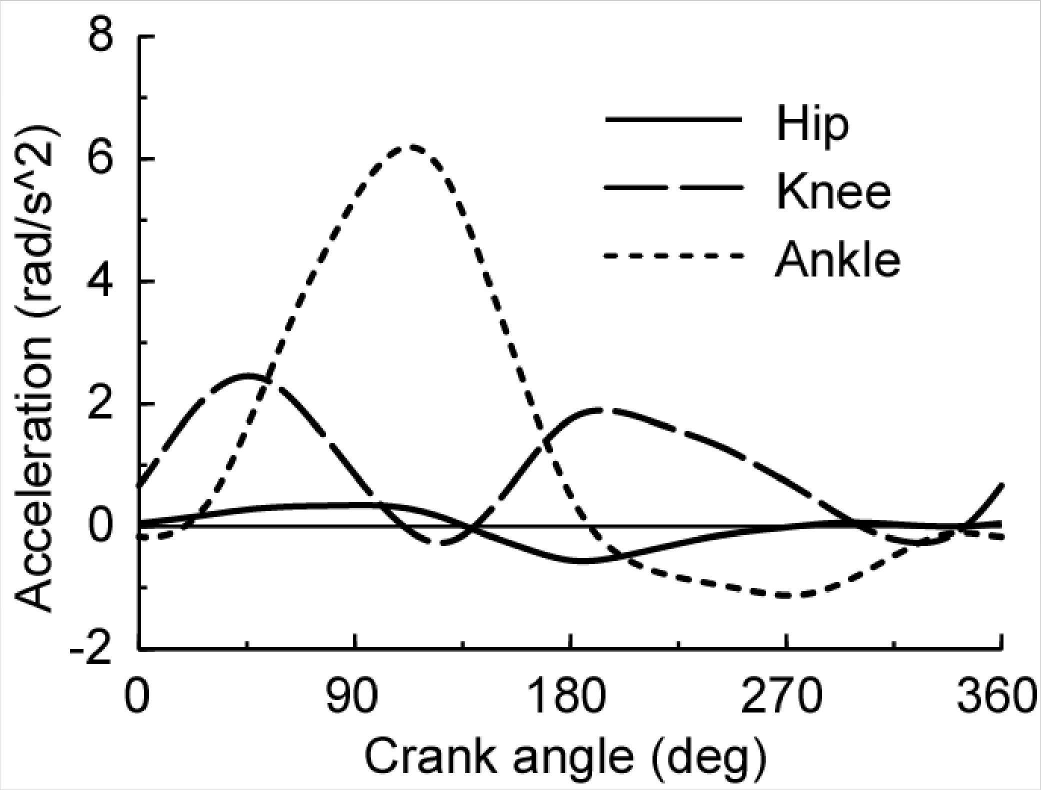
$$\ddot{\boldsymbol{\theta}} = \mathbf{M}^{-1}(\boldsymbol{\theta})[\mathbf{T}(\boldsymbol{\theta},\dot{\boldsymbol{\theta}}) + \mathbf{V}(\boldsymbol{\theta},\dot{\boldsymbol{\theta}}) + \mathbf{G}(\boldsymbol{\theta}) + \mathbf{F}(\boldsymbol{\theta},\dot{\boldsymbol{\theta}})]$$

$$= \underbrace{\mathbf{M}^{-1}(\boldsymbol{\theta})\mathbf{T}(\boldsymbol{\theta},\dot{\boldsymbol{\theta}})}_{\ddot{\boldsymbol{\theta}}^{Muscle}} + \underbrace{\mathbf{M}^{-1}(\boldsymbol{\theta})\mathbf{V}(\boldsymbol{\theta},\dot{\boldsymbol{\theta}})}_{\ddot{\boldsymbol{\theta}}^{Velocity}}$$

$$+ \underbrace{\mathbf{M}^{-1}(\boldsymbol{\theta})\mathbf{G}(\boldsymbol{\theta})}_{\ddot{\boldsymbol{\theta}}^{Gravity}} + \underbrace{\mathbf{M}^{-1}(\boldsymbol{\theta})\mathbf{F}(\boldsymbol{\theta},\dot{\boldsymbol{\theta}})}_{\ddot{\boldsymbol{\theta}}^{Friction}}$$

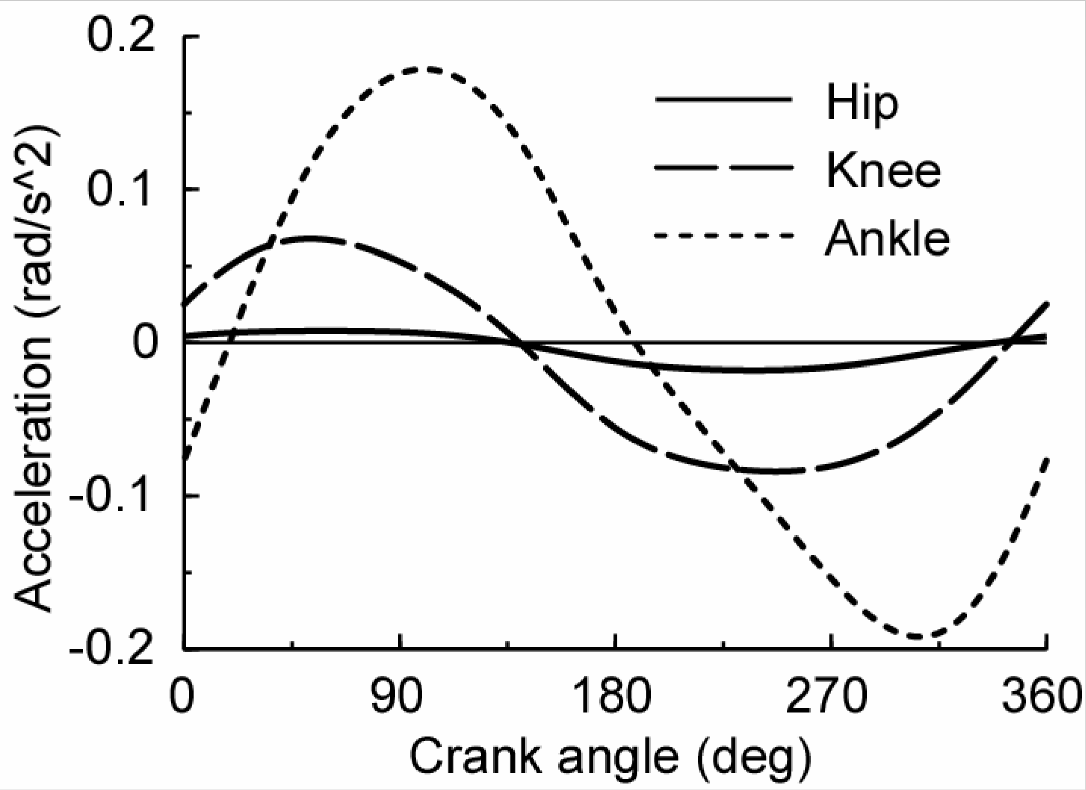
Induced Crank Accelerations

Accelerations Induced by
Net Joint Torques



Induced Crank Accelerations

Accelerations Induced by
Unit Extensor Joint Torques



Evaluation

Accounts for . . .

- influence on unspanned segments and joints
- changes in influence during a movement
- changes in influence between movements

but . . .

- can lead to paradoxical interpretations
- cannot explain synergies

Outline

- Induced Acceleration Analysis
- Induced Power Analysis

Mechanical Power

$$P = \frac{dE}{dt} = \frac{dKE}{dt} + \frac{dPE}{dt}$$

where $\frac{dKE}{dt} = [\mathbf{M}(\boldsymbol{\theta})\ddot{\boldsymbol{\theta}} - \mathbf{V}(\boldsymbol{\theta},\dot{\boldsymbol{\theta}})]^T \dot{\boldsymbol{\theta}}$

$$\frac{dPE}{dt} = -\mathbf{G}(\boldsymbol{\theta})^T \dot{\boldsymbol{\theta}}$$

so that $P = [\mathbf{M}(\boldsymbol{\theta})\ddot{\boldsymbol{\theta}} - \mathbf{V}(\boldsymbol{\theta},\dot{\boldsymbol{\theta}}) - \mathbf{G}(\boldsymbol{\theta})]^T \dot{\boldsymbol{\theta}}$

Induced Mechanical Power

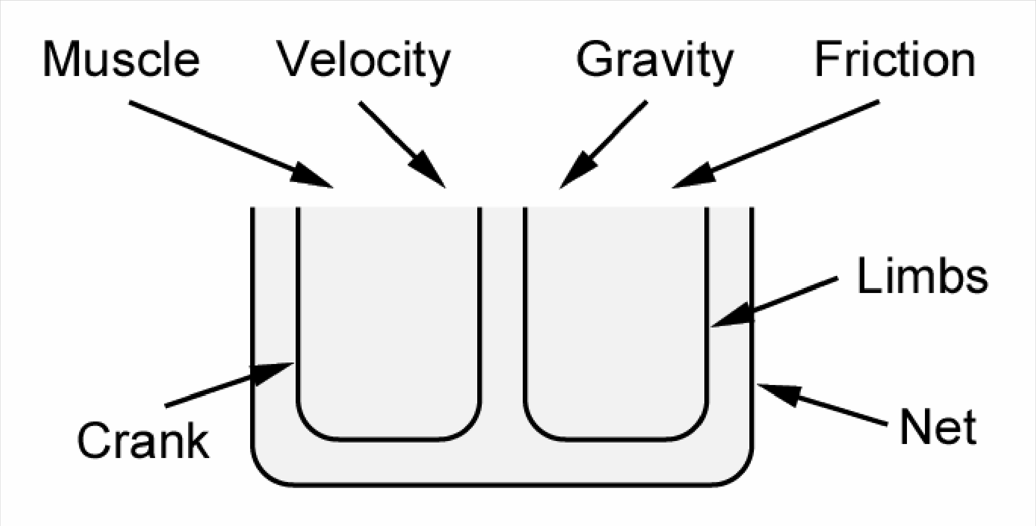
$$P_i = [\mathbf{M}_i(\boldsymbol{\theta})\ddot{\boldsymbol{\theta}} - \mathbf{V}_i(\boldsymbol{\theta},\dot{\boldsymbol{\theta}}) - \mathbf{G}_i(\boldsymbol{\theta})]^T \dot{\boldsymbol{\theta}}$$

$$= \underbrace{[\mathbf{M}_i(\boldsymbol{\theta})\ddot{\boldsymbol{\theta}}^{Muscle}]^T \dot{\boldsymbol{\theta}}}_{P_i^{Muscle}} + \underbrace{[\mathbf{M}_i(\boldsymbol{\theta})\ddot{\boldsymbol{\theta}}^{Velocity} - \mathbf{V}_i(\boldsymbol{\theta},\dot{\boldsymbol{\theta}})]^T \dot{\boldsymbol{\theta}}}_{P_i^{Velocity}}$$

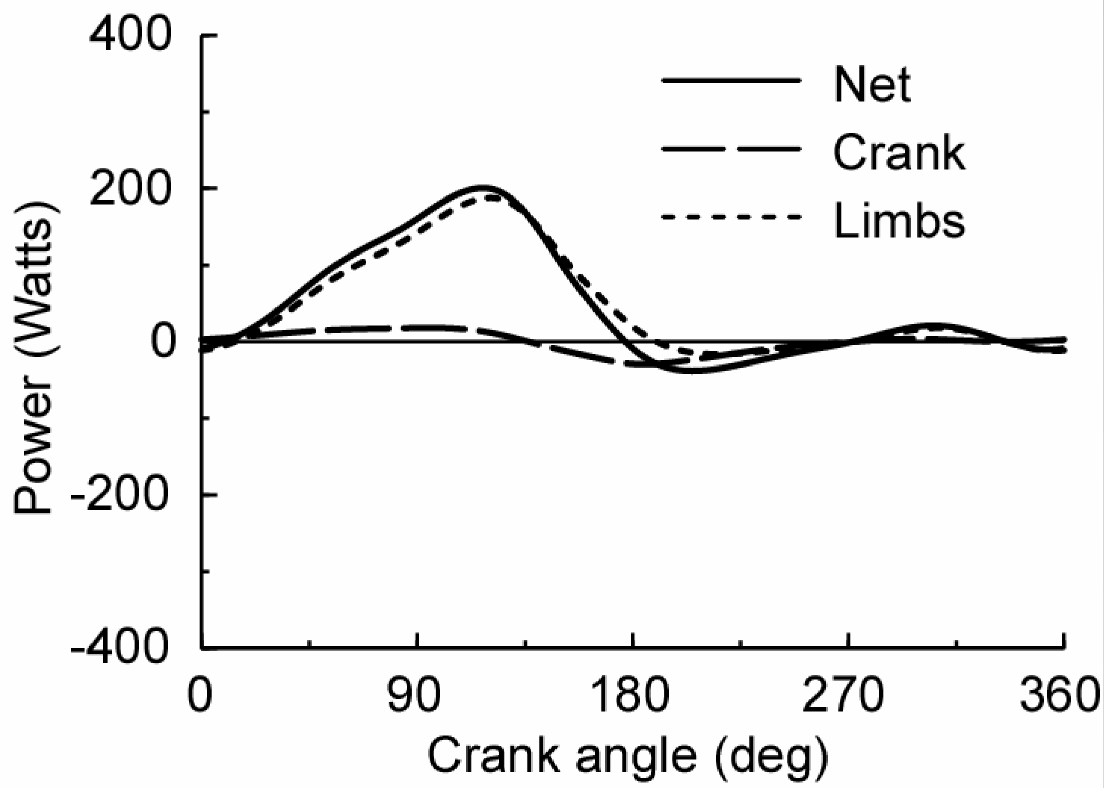
$$+ \underbrace{[\mathbf{M}_i(\boldsymbol{\theta})\ddot{\boldsymbol{\theta}}^{Gravity} - \mathbf{G}_i(\boldsymbol{\theta},\dot{\boldsymbol{\theta}})]^T \dot{\boldsymbol{\theta}}}_{P_i^{Gravity}} + \underbrace{[\mathbf{M}_i(\boldsymbol{\theta})\ddot{\boldsymbol{\theta}}^{Friction}]^T \dot{\boldsymbol{\theta}}}_{P_i^{Friction}}$$

Power Partitioning

$$\underbrace{\sum_{i=1}^{n} P_i}_{P_{Net}} = \underbrace{\sum_{i=1}^{m} P_i}_{P_{Crank}} + \underbrace{\sum_{i=m+1}^{n} P_i}_{P_{Limbs}}$$

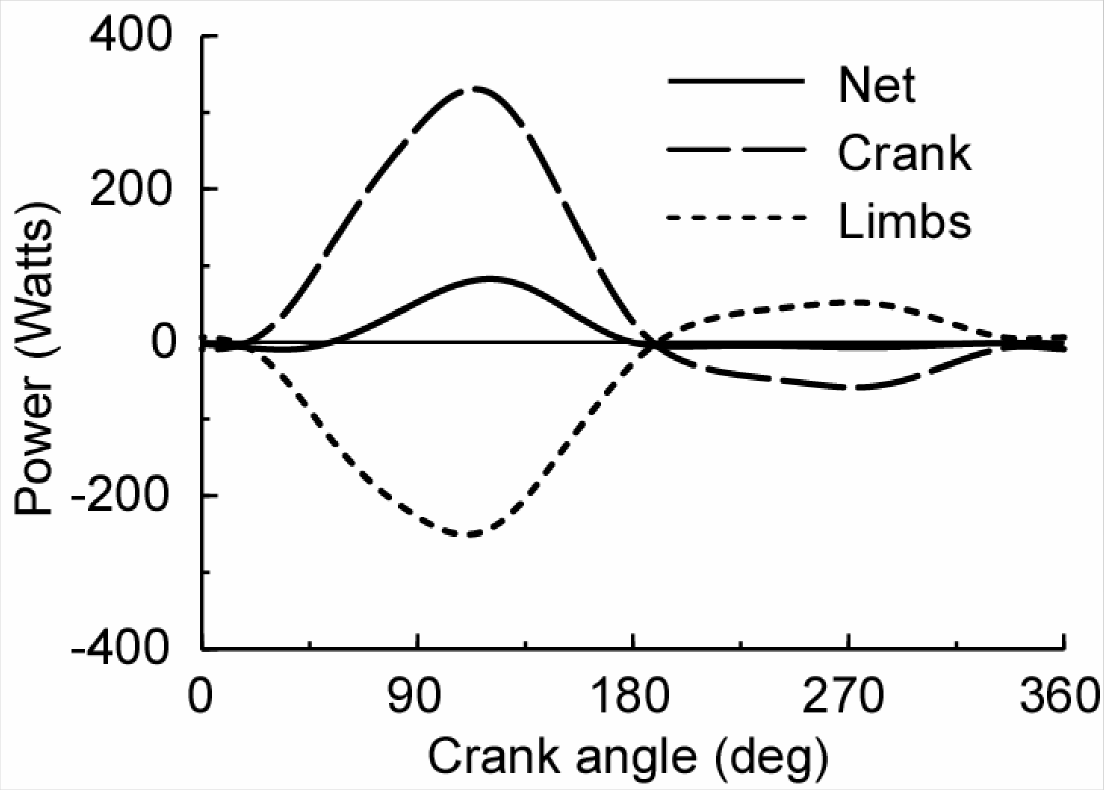


Hip Power



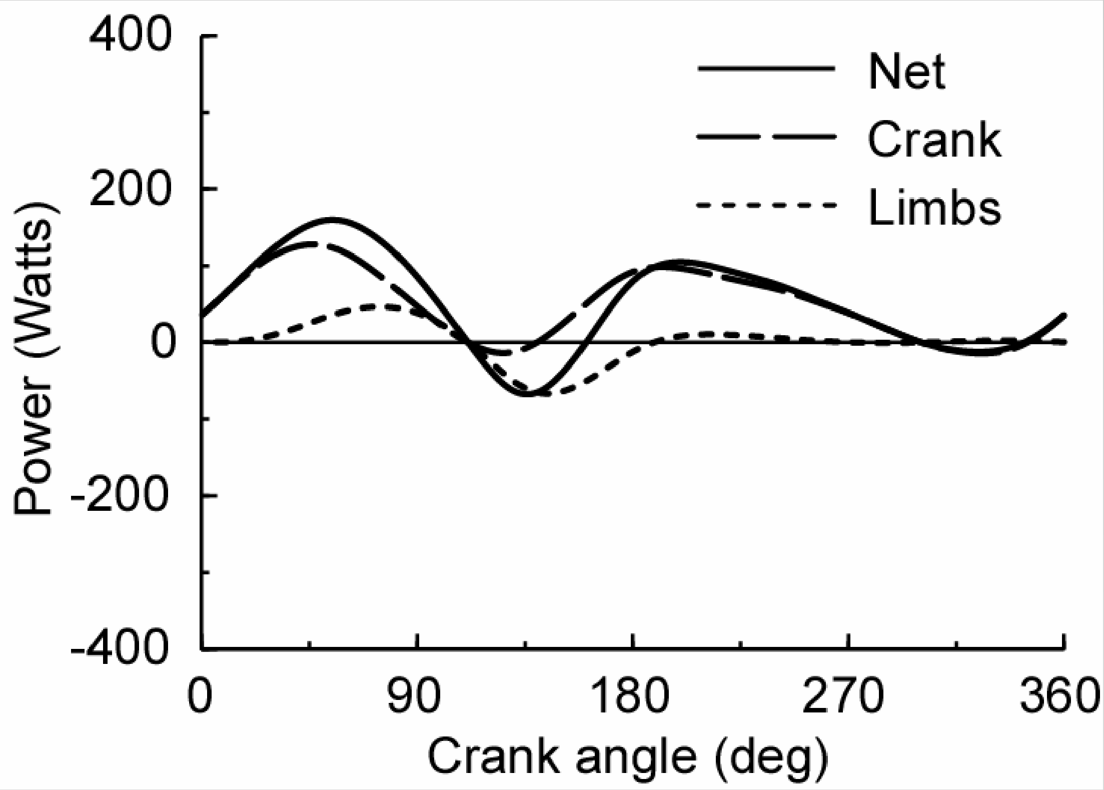
400
200
0
-200
-400
Power (Watts)
0
90
180
270
360
Crank angle (deg)
Net
Crank
Limbs

Ankle Power



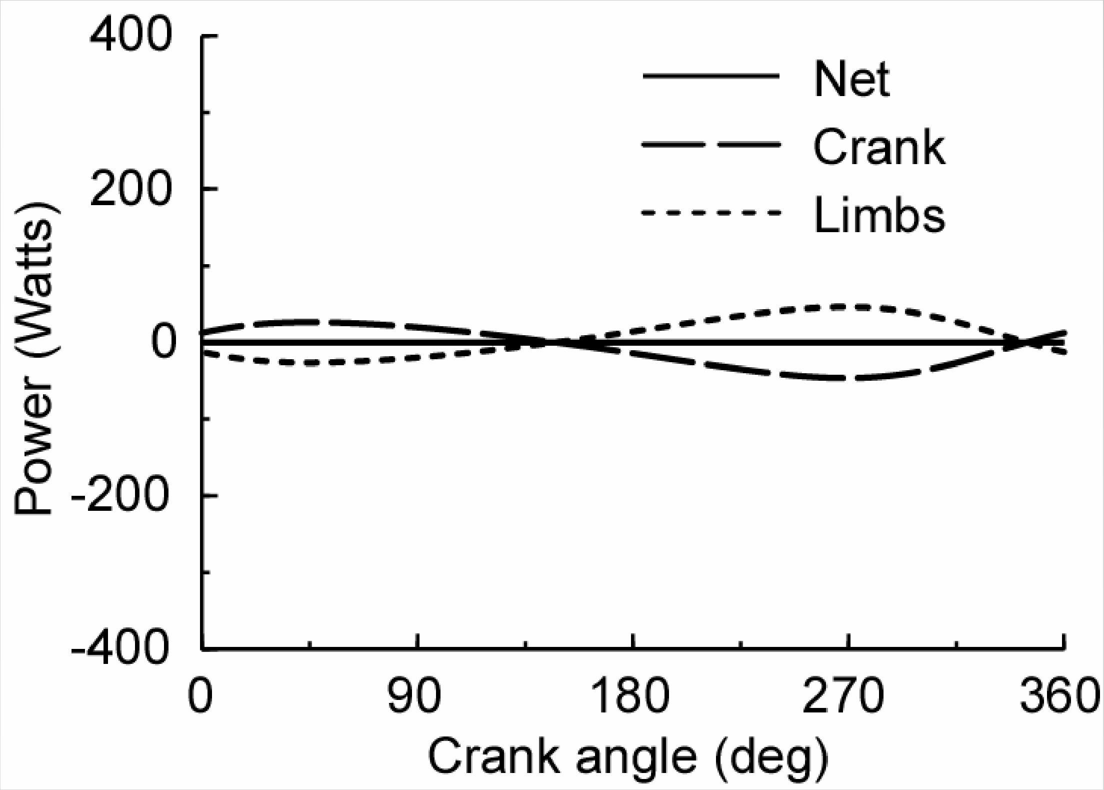
400
200
0
-200
-400
Power (Watts)
0
90
180
270
360
Crank angle (deg)
Net
Crank
Limbs

Knee Power

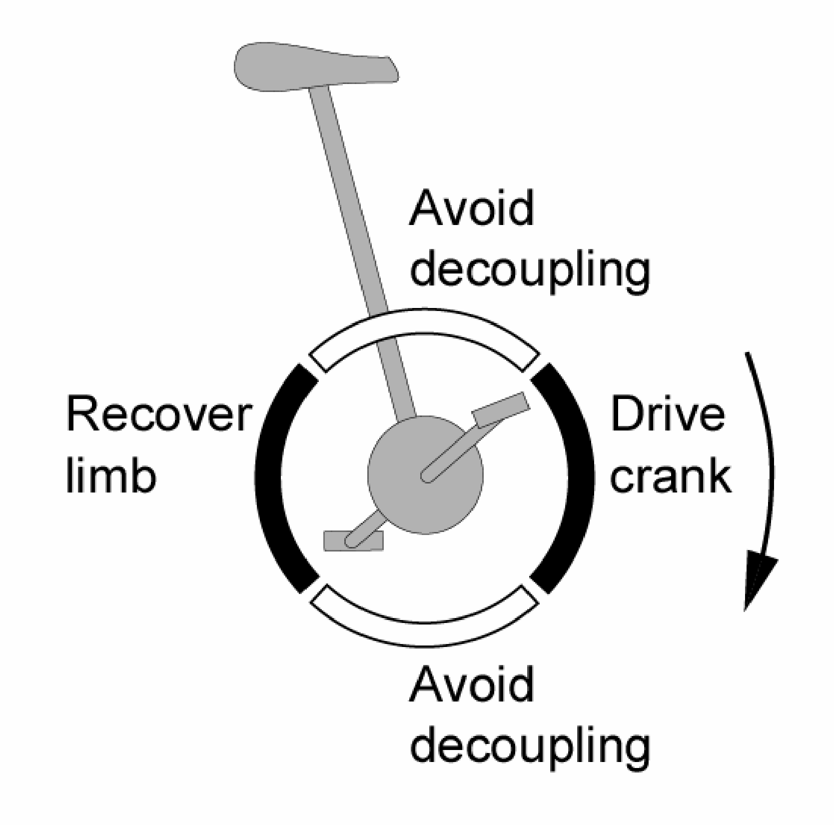


400
200
0
-200
-400
Power (Watts)
0
90
180
270
360
Crank angle (deg)
Net
Crank
Limbs

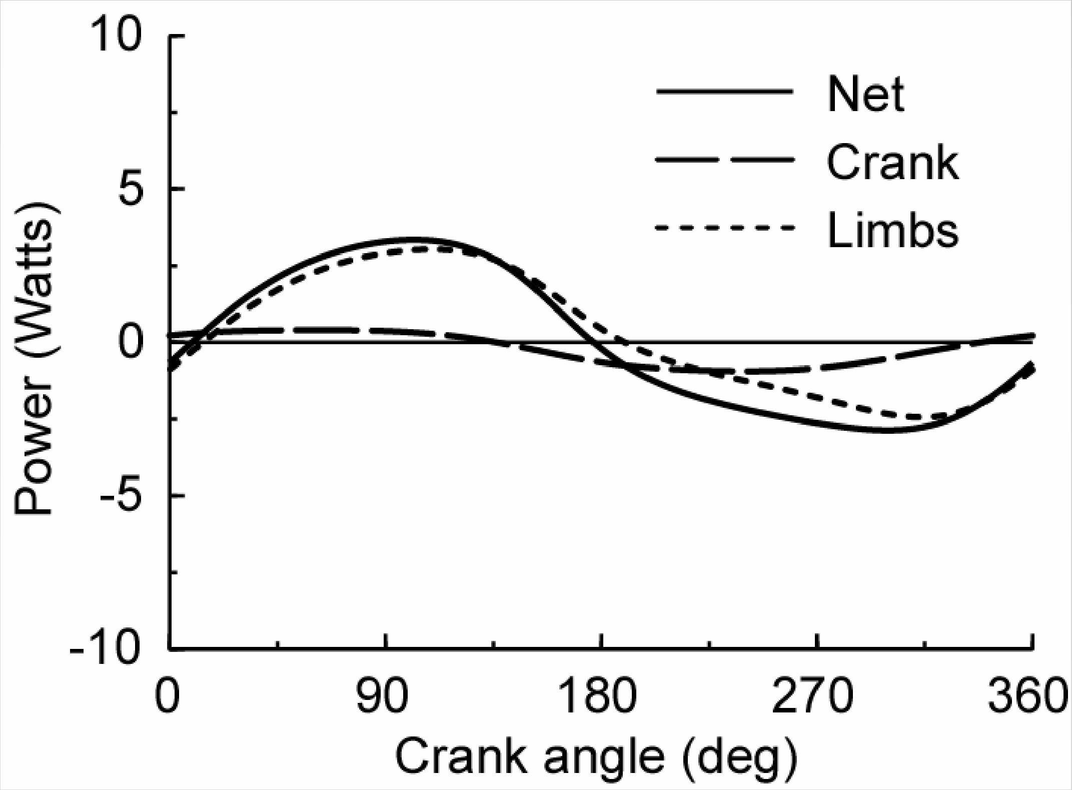
Gravity Power



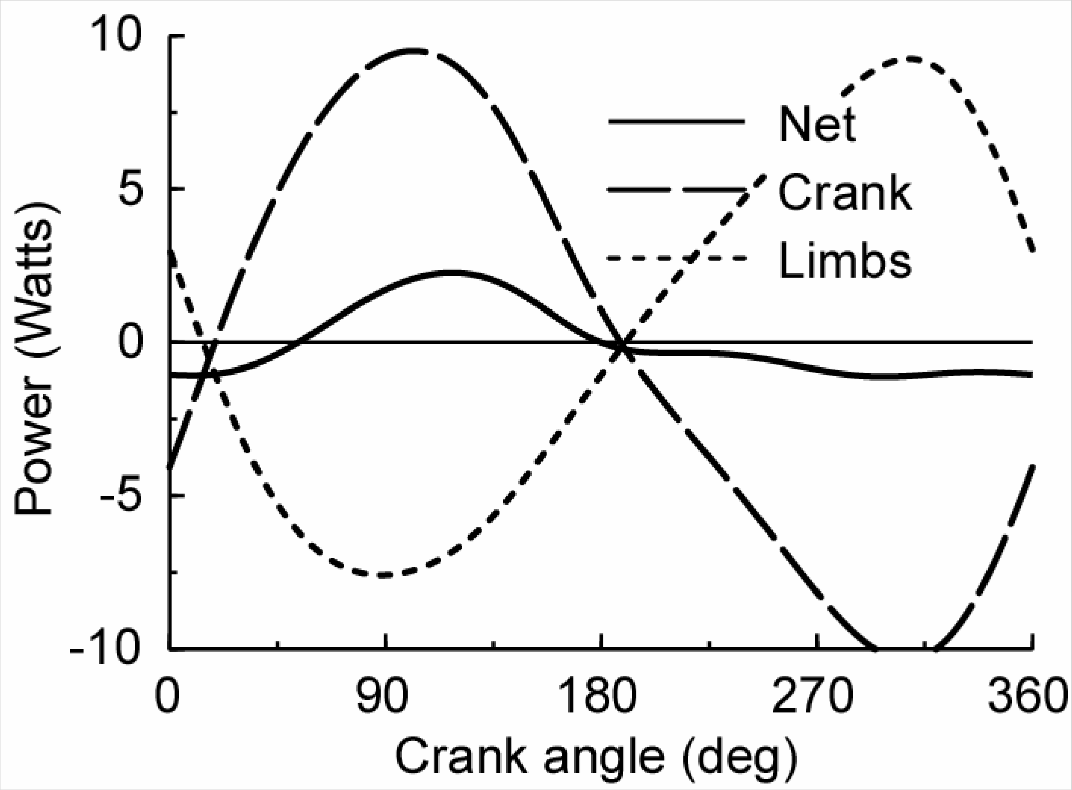
Control Hypothesis



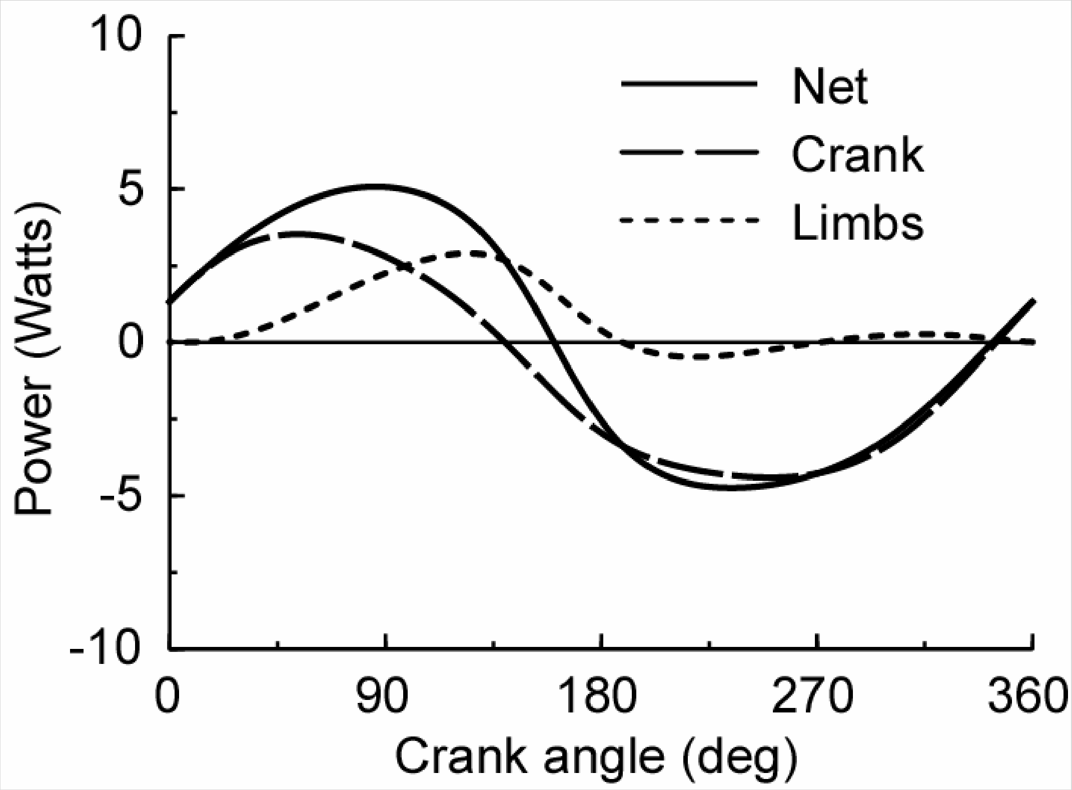
Unit Hip Power



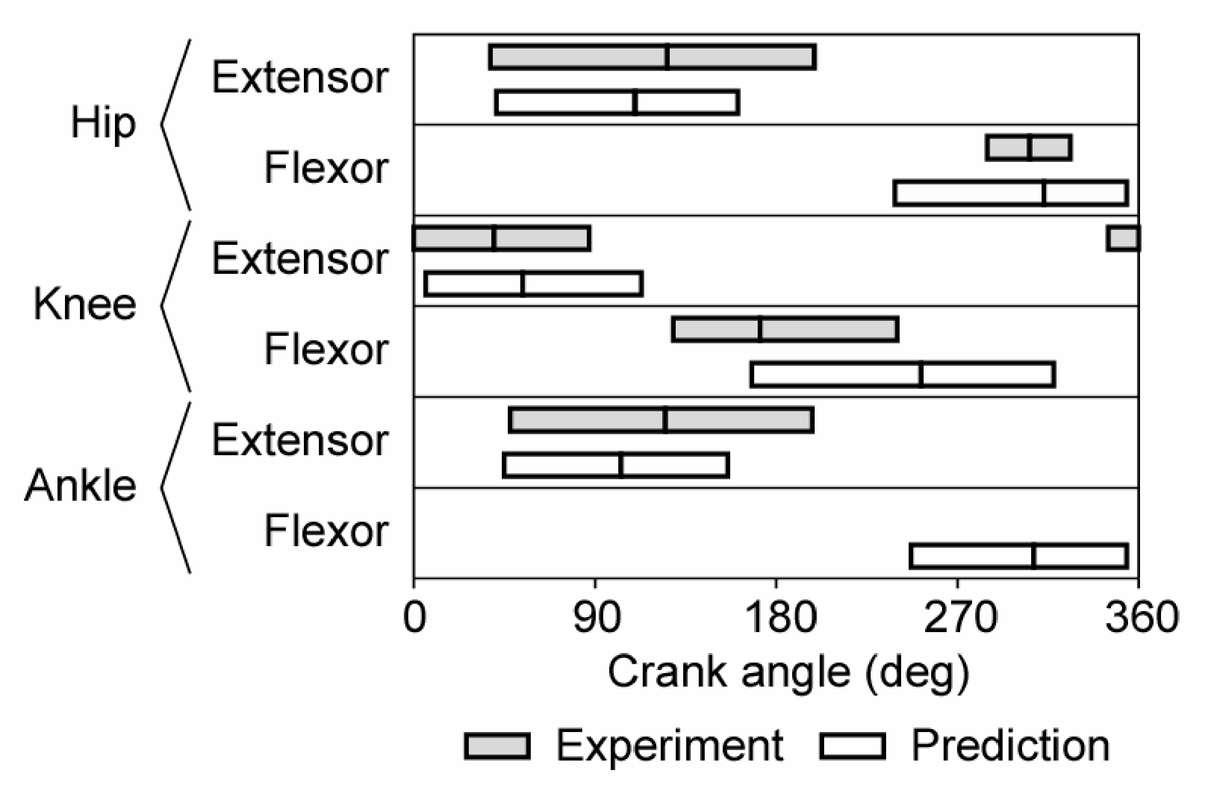
Unit Ankle Power



Unit Knee Power



Control Predictions



Advantages

- Can study muscular *and* nonmuscular contributions
- Can study influence on *any* segment or *group* of segments in model
- Can *decompose* sources of energy transfer
- Can study muscular *synergies*
- Can use even when individual muscle forces *unknown*

Disadvantages

- Requires a complex task-specific dynamical model
- Not useful for static tasks
- Less useful for tasks without a clear mechanical energy objective
- Path of energy flow not always unique

Outline

- Induced Acceleration Analysis
- Induced Power Analysis
- Journal Article Review
  Fregly and Zajac (1996)

Advanced Dynamics Analyses

- What was the goal of the Fregly and Zajac paper?
- What were some of the strengths of the proposed approach for interpreting muscle function?
- What were some of the weaknesses of the proposed approach for interpreting muscle function?
- What would happen if you tried to apply the induced power analysis to a simulation of walking?