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Separating muscular and non-muscular forces at the pedal

Science & Cycling 2015 Utrecht

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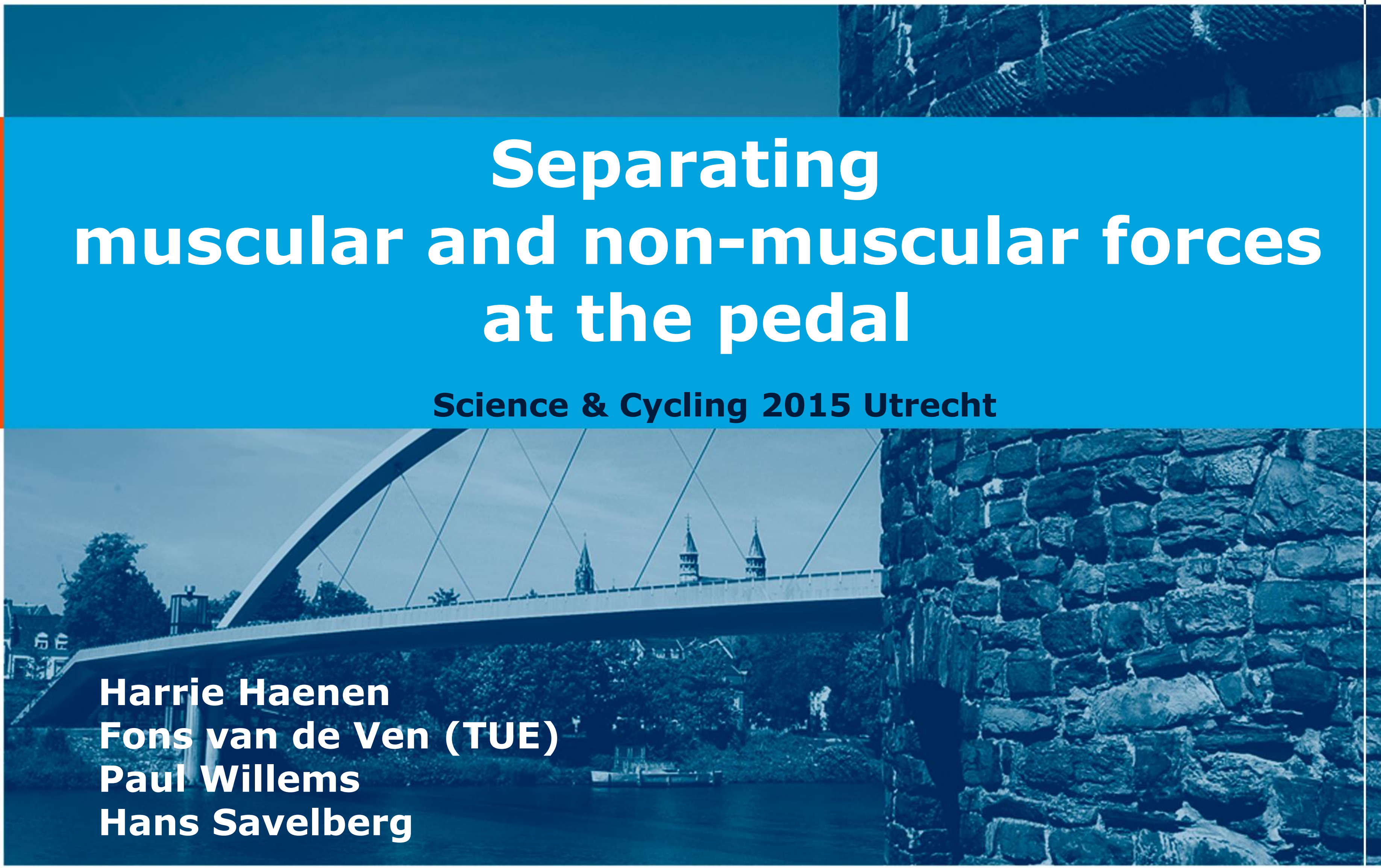


Overview

- Problem statement
- Ways to a solution
- The power based approach
- Applications

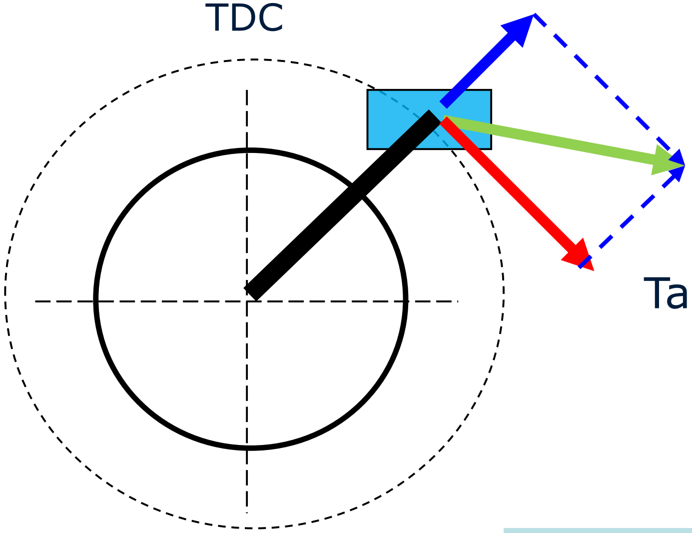
Problem statement

?

measured pedal force = muscular pedal force

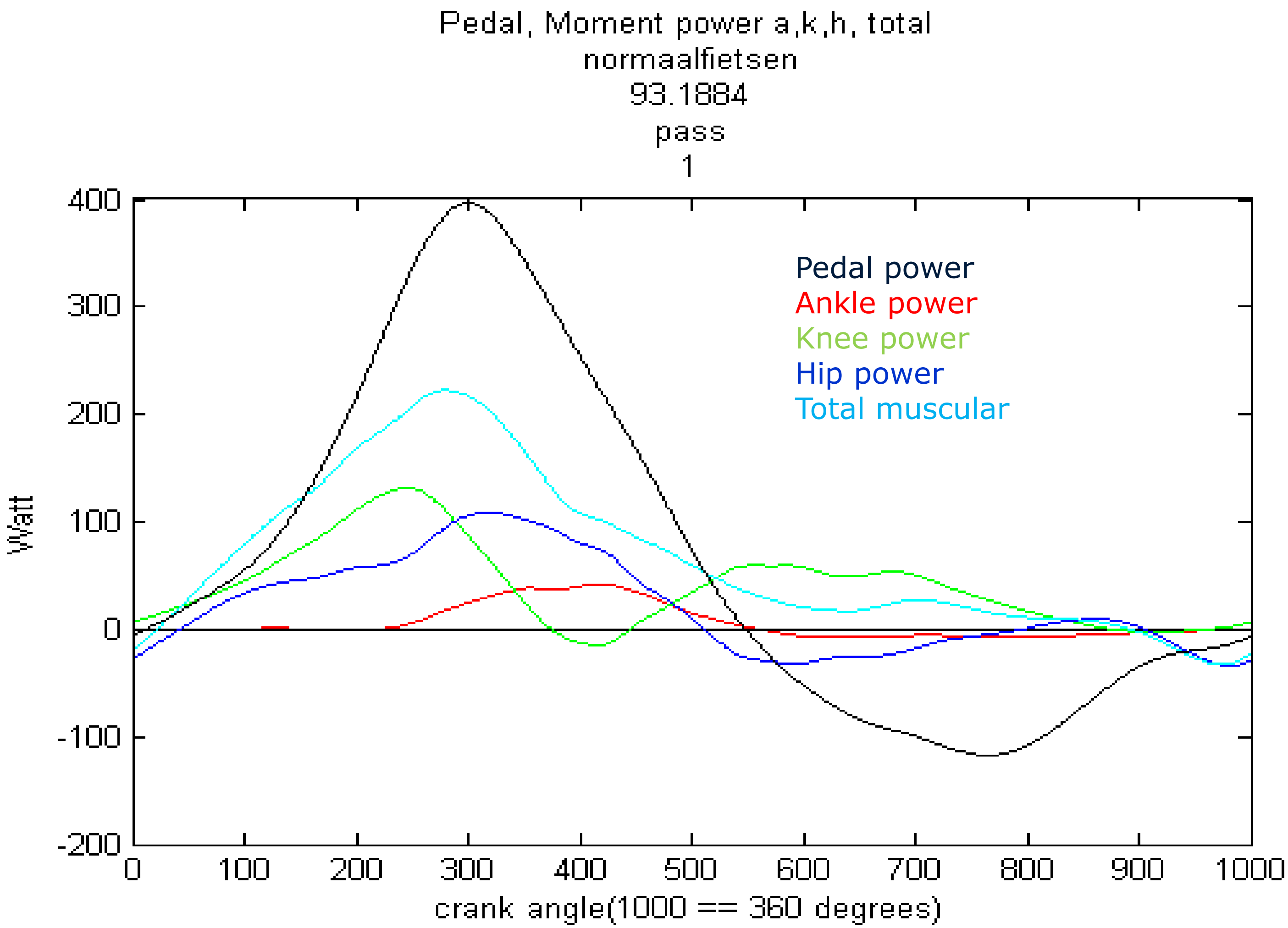
Forces at the pedal

IE = size tangential/total force



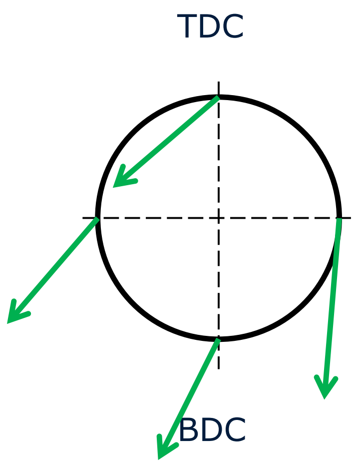
to be complete: + crank angle + pedal angle

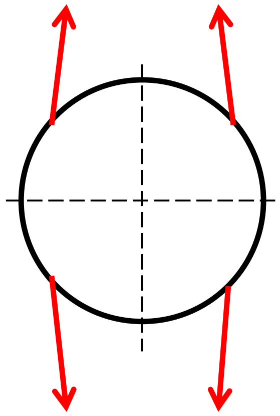
Problem statement



Problem statement

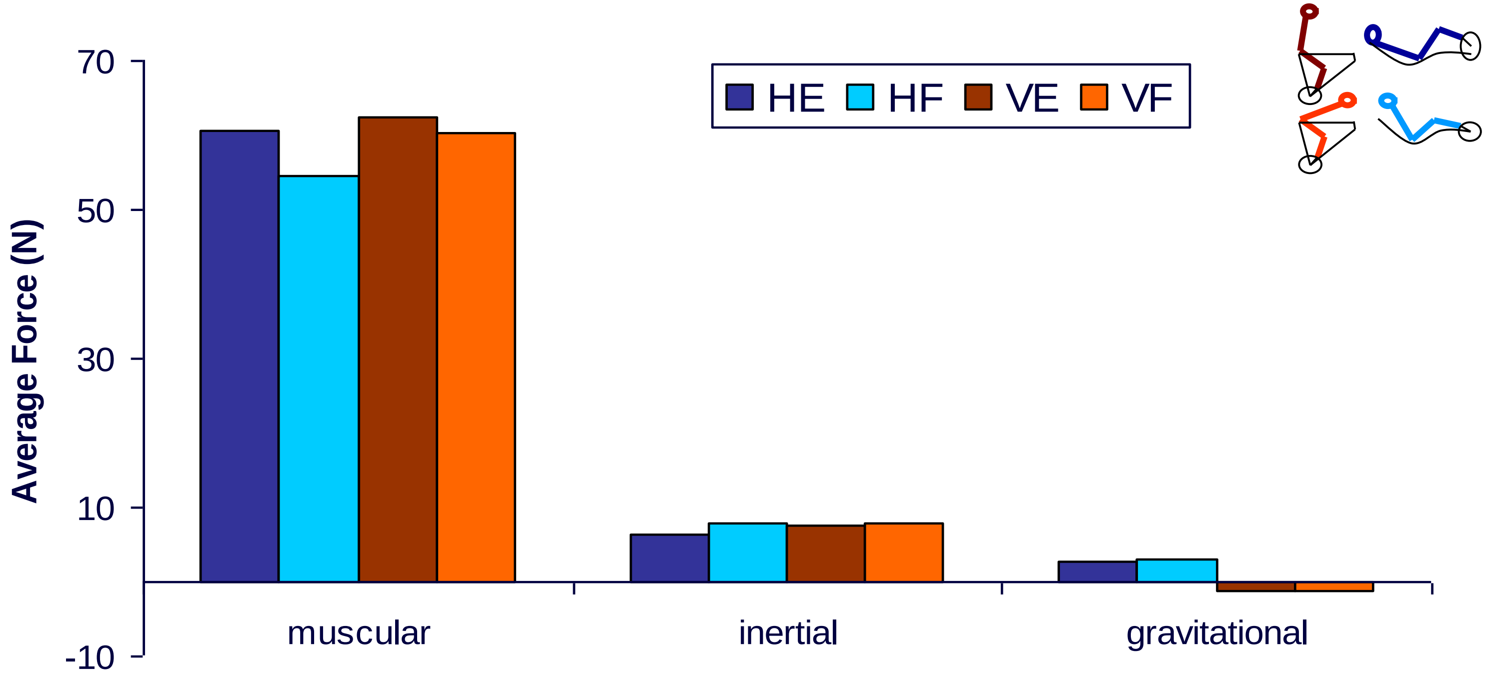
Pedal force = muscular force
+ gravity force (position)
+ inertial force (position, cadence)





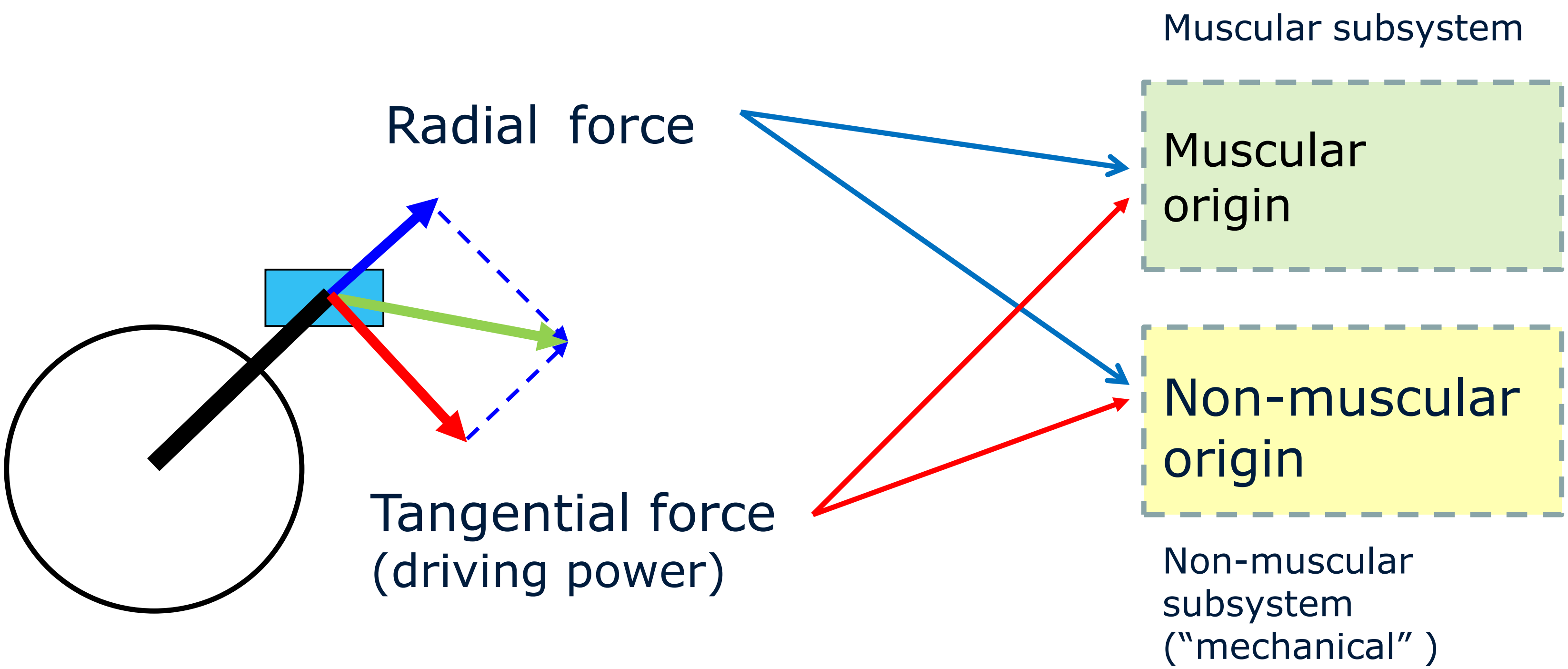
Problem statement

Contribution of Muscular, Inertial and Gravitational component to Tangetial Force



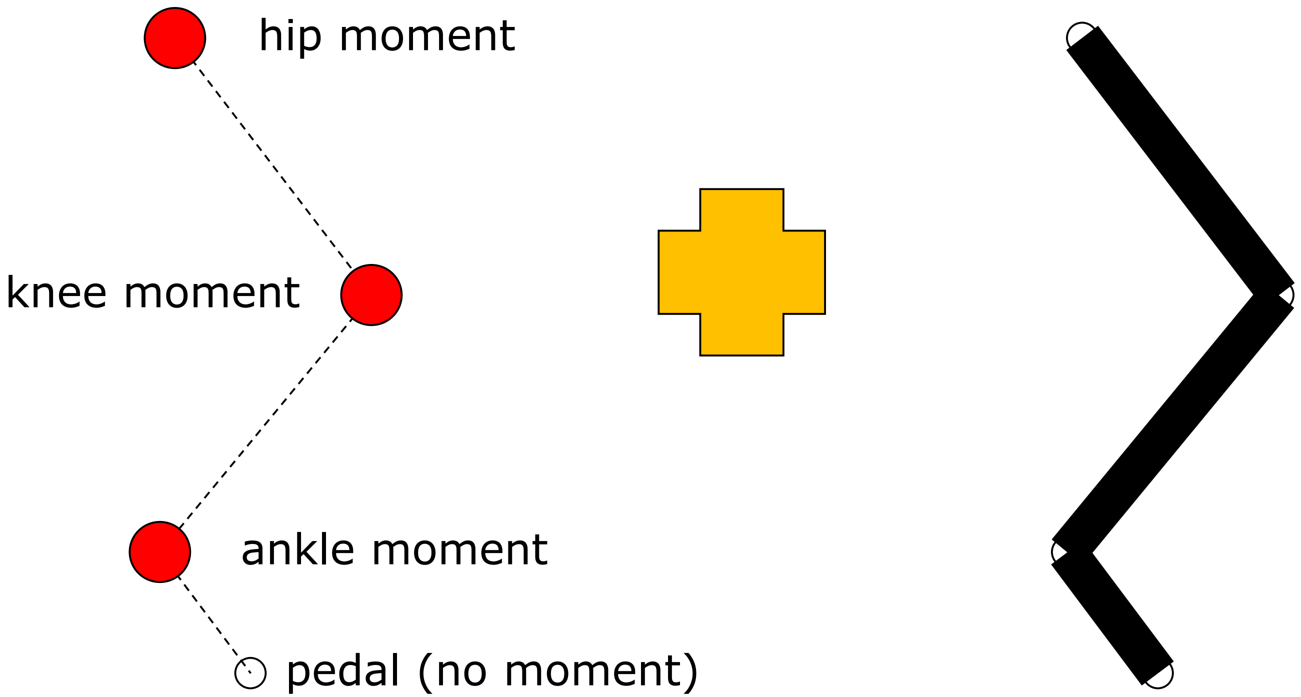
Ref. decomposition: Kautz 1993

Ways to a solution



subsystems

Muscular leg **Non-muscular leg**



massless !

mass = sum(hinged legsegments)

Cycling leg math

Pedal forces (Fpx,Fpy or Tp, Rp)

Unknown:

$$a_{11}F_{Py} + a_{12}F_{Px} = C_1 + M_H - M_K,$$

$$a_{21}F_{Py} + a_{22}F_{Px} = C_2 + M_K - M_A,$$

$$a_{31}F_{Py} + a_{32}F_{Px} = C_3 + M_A,$$

Joint moments a,k,h

Mechanical (inertia, gravity)

Ways to a solution

Muscular leg

Unknown:

$$a_{11}F_{PyE} + a_{12}F_{PxE} = M_H - M_K,$$
$$a_{21}F_{PyE} + a_{22}F_{PxE} = M_K - M_A,$$
$$a_{31}F_{PyE} + a_{32}F_{PxE} = M_A$$

EP: External Power

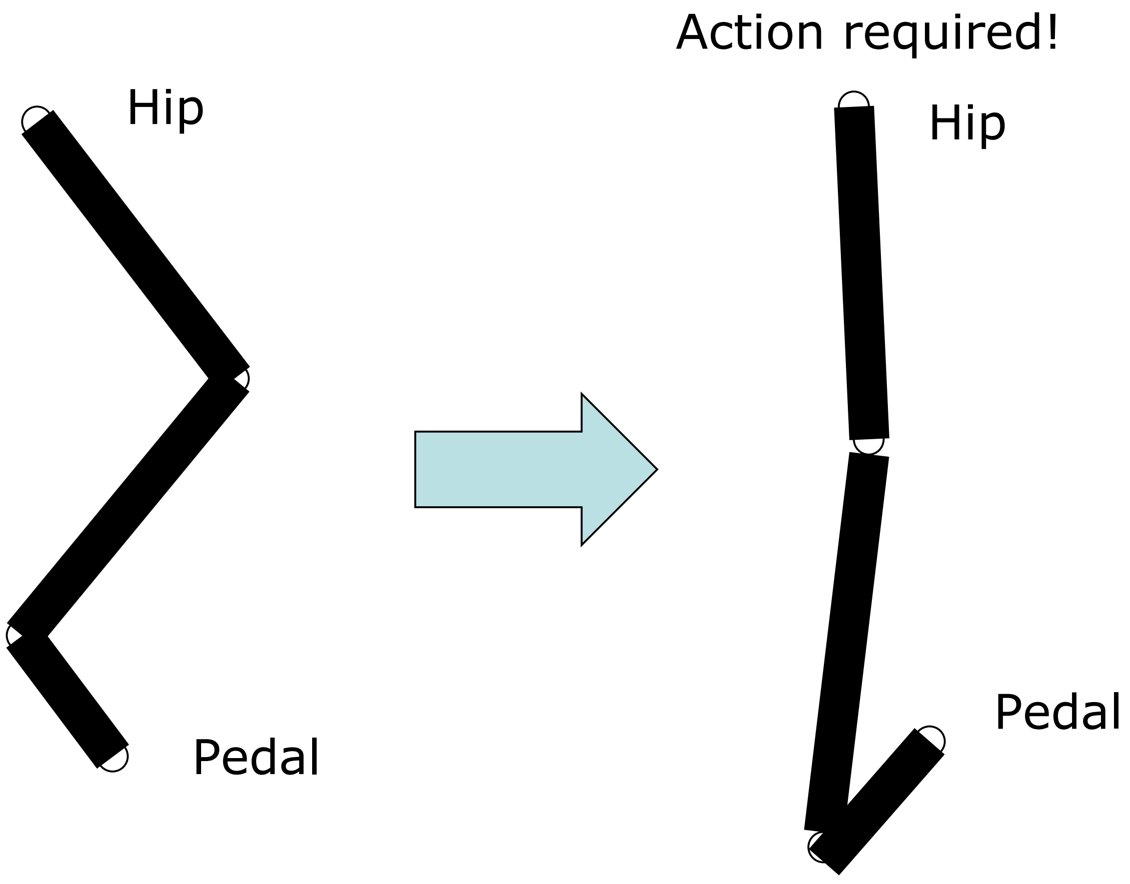
Non-muscular leg

Unknown:

$$a_{11}F_{PyI} + a_{12}F_{PxI} = C_1$$
$$a_{21}F_{PyI} + a_{22}F_{PxI} = C_2$$
$$a_{31}F_{PyI} + a_{32}F_{PxI} = C_3$$

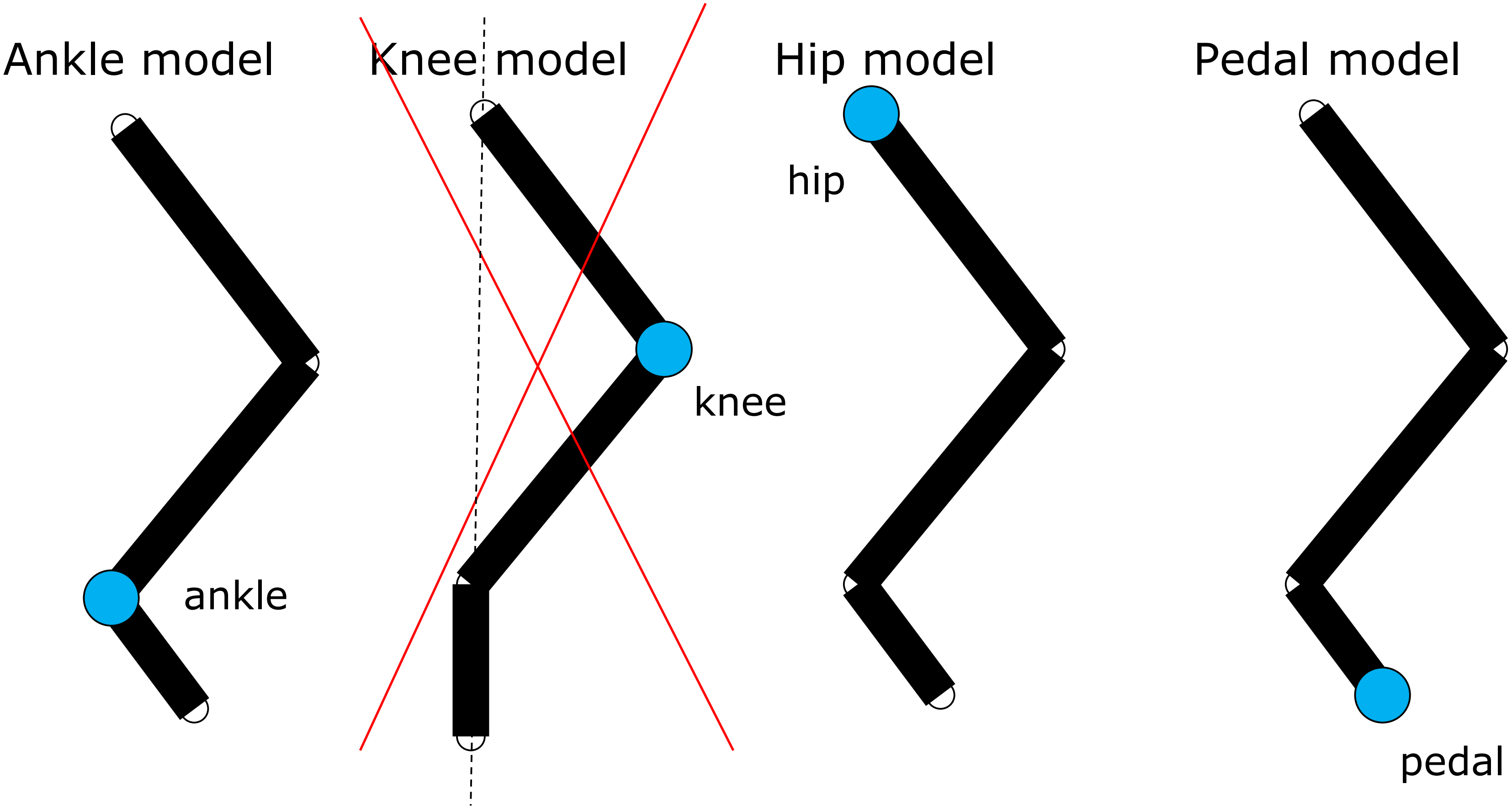
IM: Internal Mechanical

non-muscular leg



Solutions for “non-muscular” leg

(single-moment models)



Results non-muscular (mechanical) leg

	Ankle Model (AM)	Pedal Model (PM)	Hip Model (HM)	Required
MeanTangential Force (N)	5.3	13.3	5.3	0
MeanRadial Force (N)	80	61	7.8	..

PBA power balance approach

Principle:

power produced at the joints = muscular power available at the pedal

- Muscular power at pedal = Ankle_power+Knee_power+Hip_power

  (leads to solution for muscular tangential pedalforce)

- Non-muscular power at pedal = Total pedal_power - Muscular power at pedal

  (leads to solution for non-muscular tangential pedalforce)

→ **Tangential forces are known**

PBA power balance approach

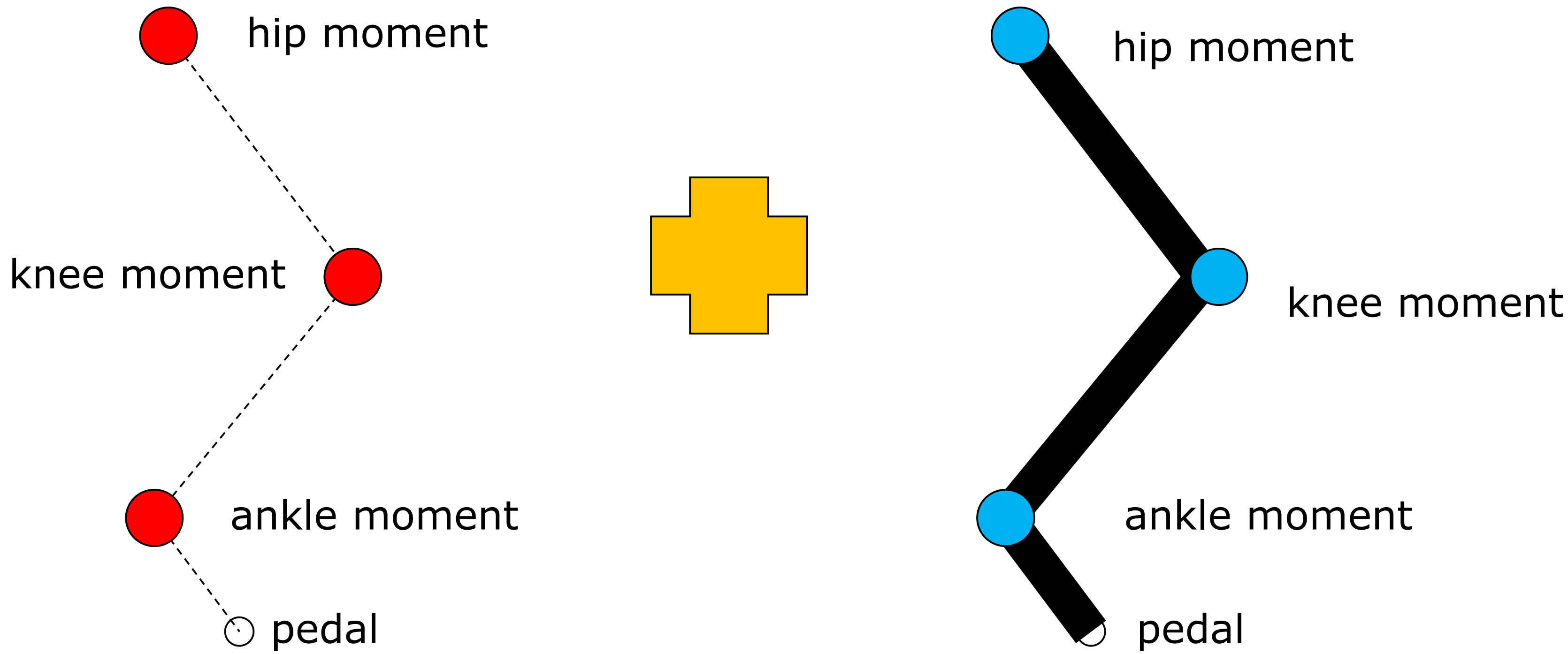
Principle for radial forces:
minimize sum muscular effort of all 3 joints of non-muscular leg

- Minimize RMS of moments in non-muscular subsystem
  (leads to analytical solution for non-muscular radial pedalforce)
- Muscular radial pedalforce = total radial force – non-muscular radial force

→ **Radial forces are known**

PBA

Muscular leg | **"Non-muscular" leg**

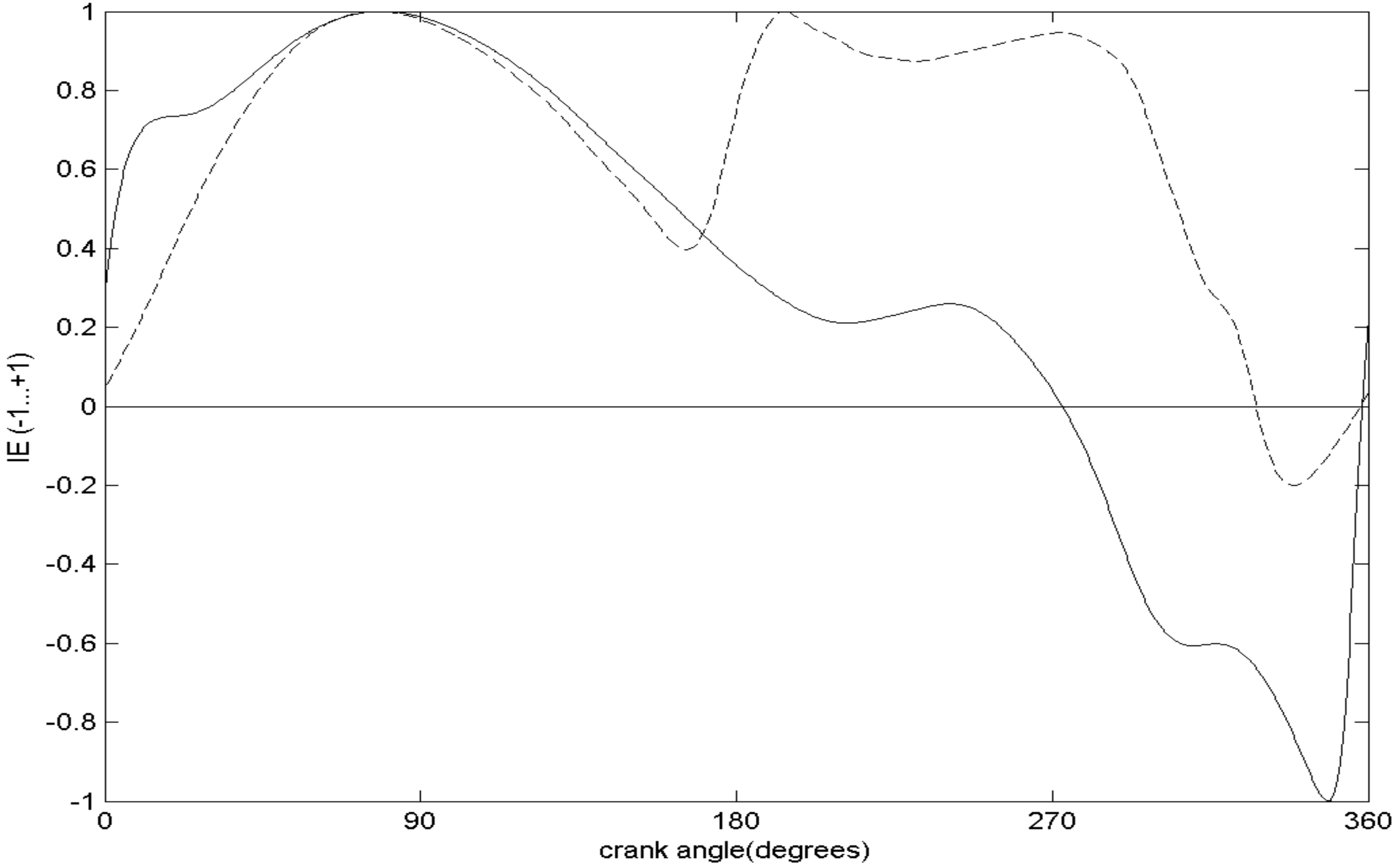


all cycling power | **0 cycling power**

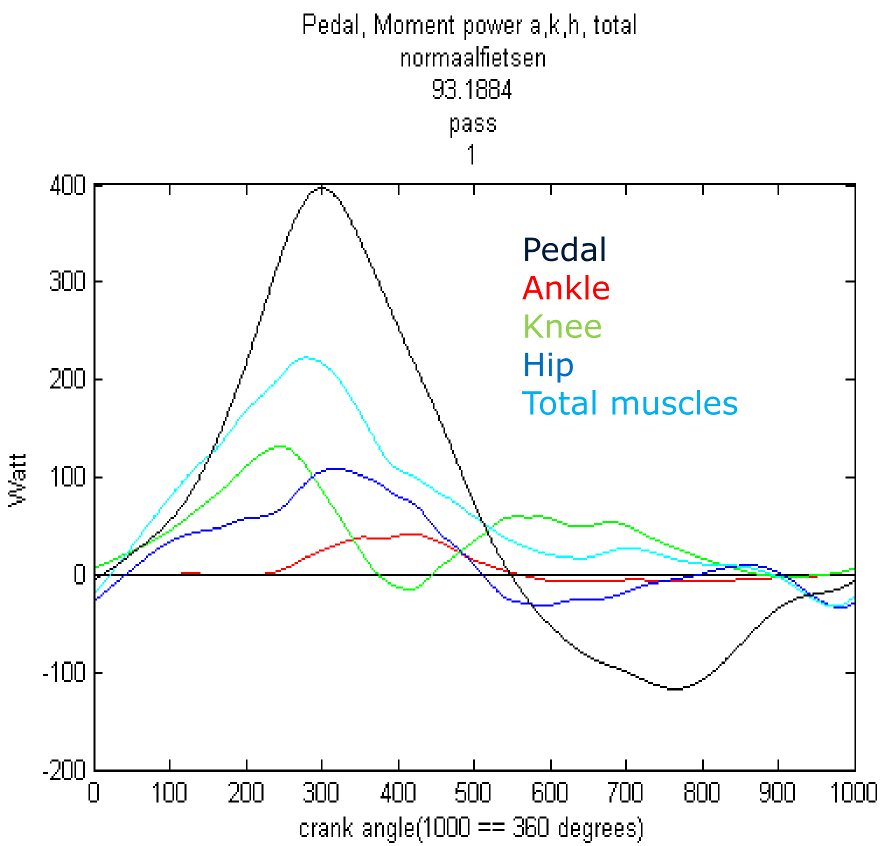
Results non-muscular (mechanical) leg

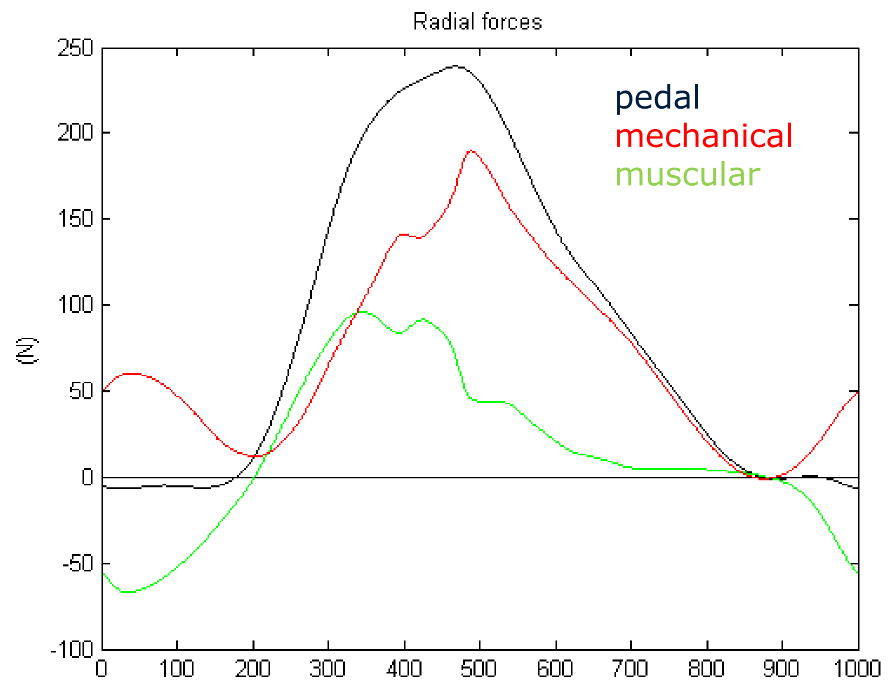
	Ankle Model (AM)	Pedal Model (PM)	Hip Model (HM)	**PBA**
MeanTangential Force (N)	5.3	13.3	5.3	**0**
MeanRadial Force (N)	80	61	7.8	64

Application: IEpedal and IEmuscular (--)



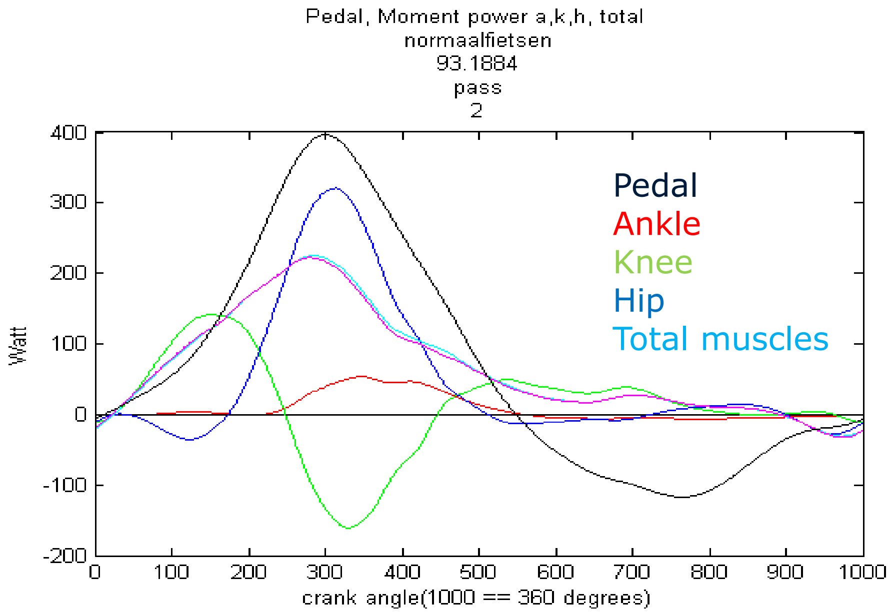
Application



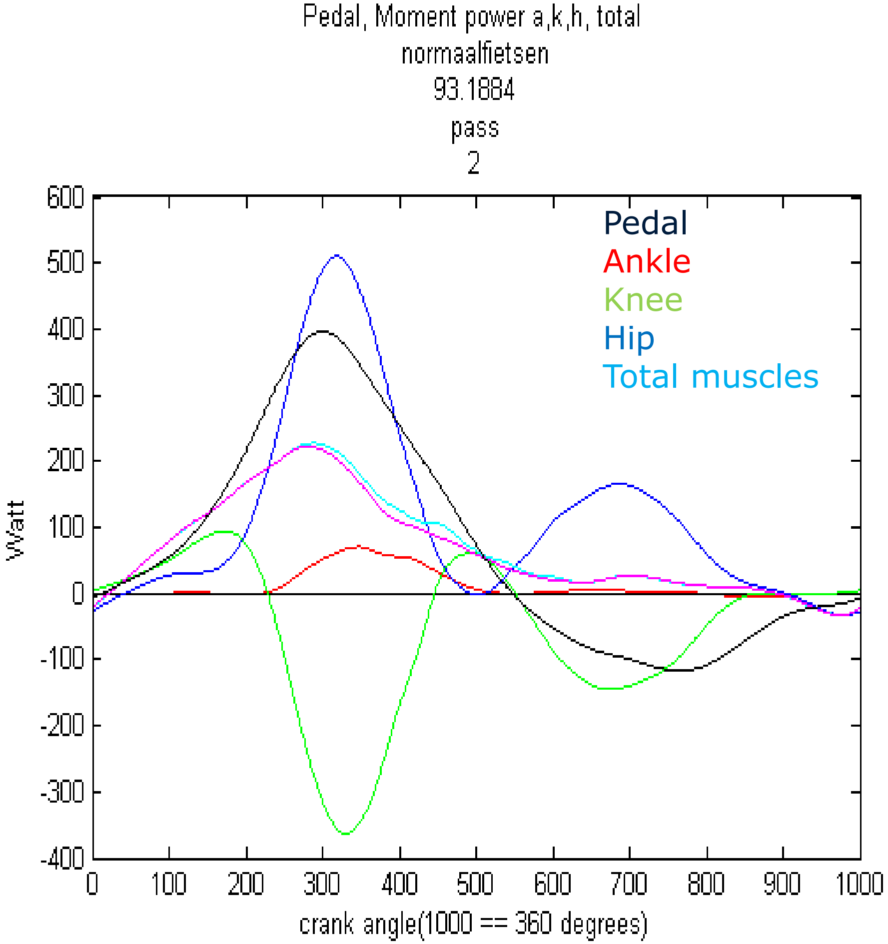


Application: what if ?

muscular radialforce = 0



total radialforce = 0



Application: vector display

Conclusions pedal force analysis

- No split up possible into a muscular and *pure* non-muscular part
- A force based approach (single-moment solutions) leads to energy artefact
- PBA allows a clear power and force split up
- PBA is an indispensable tool for optimizing pedalling technique (e.g. by visual feedback)
- Complete pedal force measurement = force vector + crank + *pedal* angle

Questions?