Influence of Perturbed Gait Data on four 3D Inverse Dynamic Methods

Dumas Raphaël, Nicol Elsa, Chèze Laurence

Laboratory of Biomechanics and Human Modeling

University Claude Bernard Lyon 1 - National Institute for Transport and Safety Research

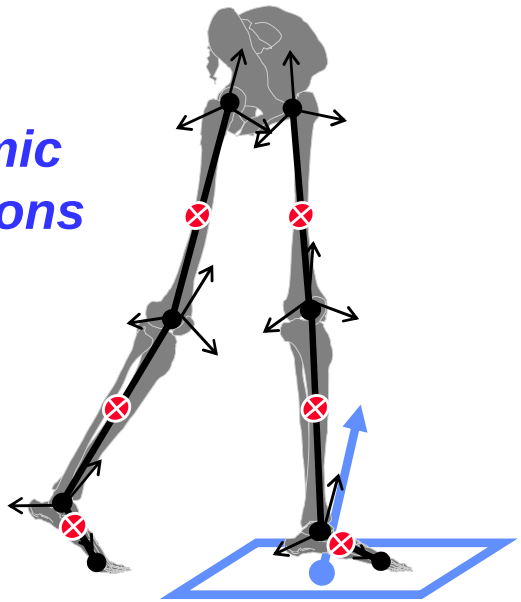
Lyon - France

Introduction

- 3D inverse dynamics widely used in gait analysis
- Joint forces and moments computed recursively

- 3D inverse dynamic methods in the literature
  - Vectors and Cardanic (Euler) angles (*VC*)
  - Wrenches and Quaternions (*WQ*)
  - Homogenous Matrices (*HM*)
  - Generalized coordinates and forces (*GC*)

Different kinematic and dynamic computations



- Computations theoretically equivalent but preliminary study showed differences

Objectives

- To differentiate between the 4 inverse dynamic methods
- To investigate the influence of perturbed gait data on the joint forces and moments computations

Materials & Methods

- Gait at comfortable speed of 9 young healthy subjects
  - Motion Analysis system and AMTI force platform (100 Hz)
  - 13 markers on right lower limb
  - Functional hip joint center
  - Filtering and solidification

  Unperturbed gait data

  - Additional Gaussian Noise (2×SD = 5 mm)

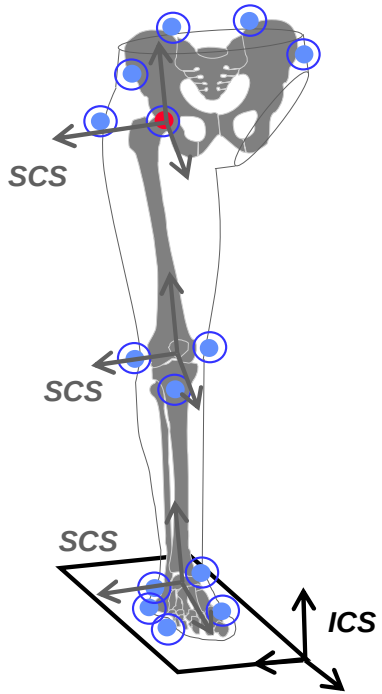
  Perturbed gait data

- Segment Coordinate Systems (SCS)

  Wu et al. 2002

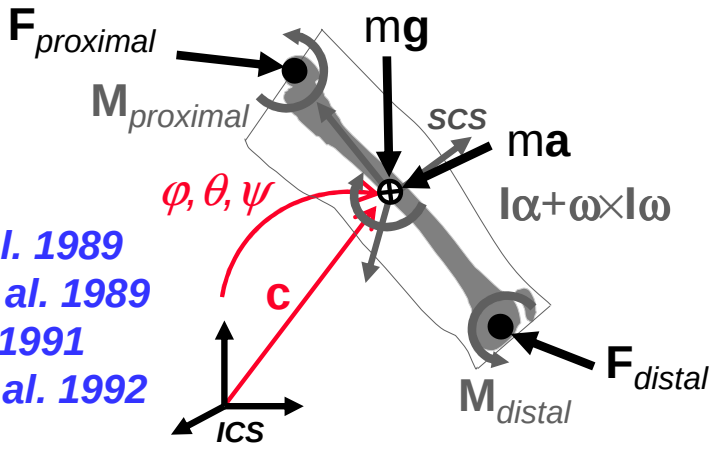
- Body Segment inertial Parameters (BSIP)

  Dumas et al. 2006



Materials & Methods

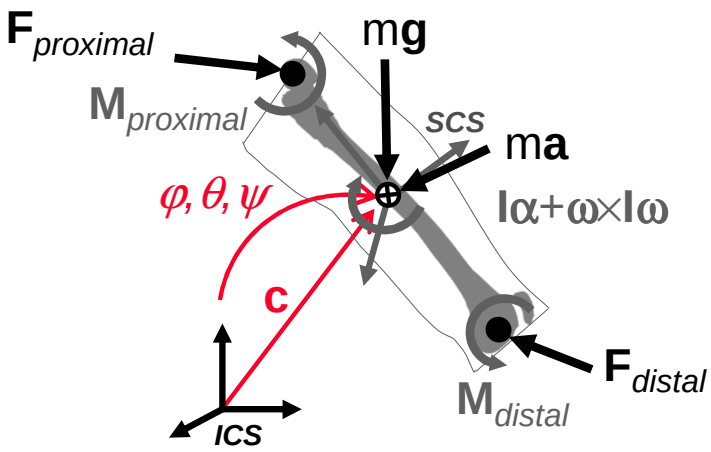
- 3D inverse dynamics

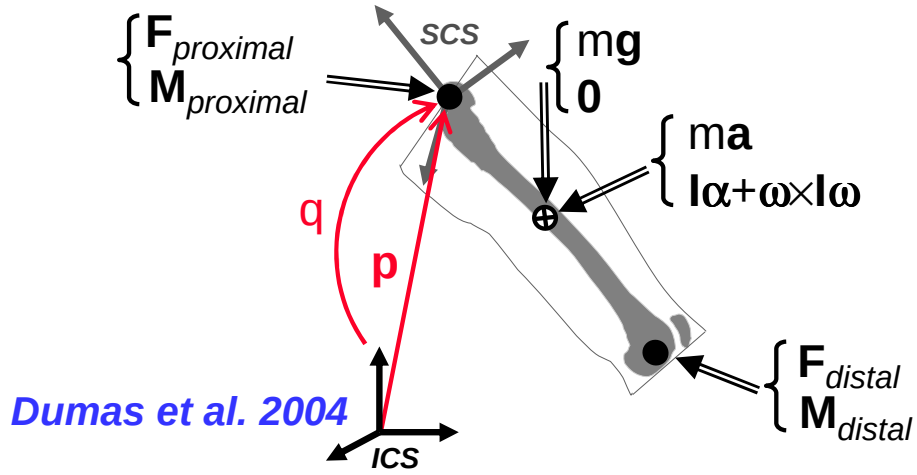


Kadaba et al. 1989
Apkarian et al. 1989
Davis et al. 1991
Vaughan et al. 1992

Materials & Methods

- 3D inverse dynamics

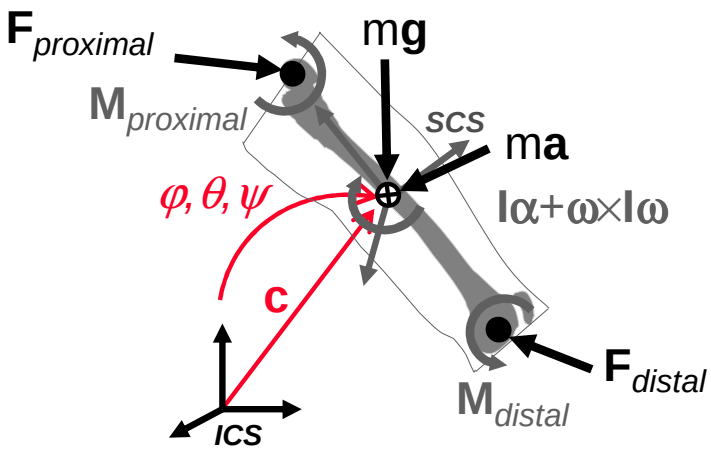


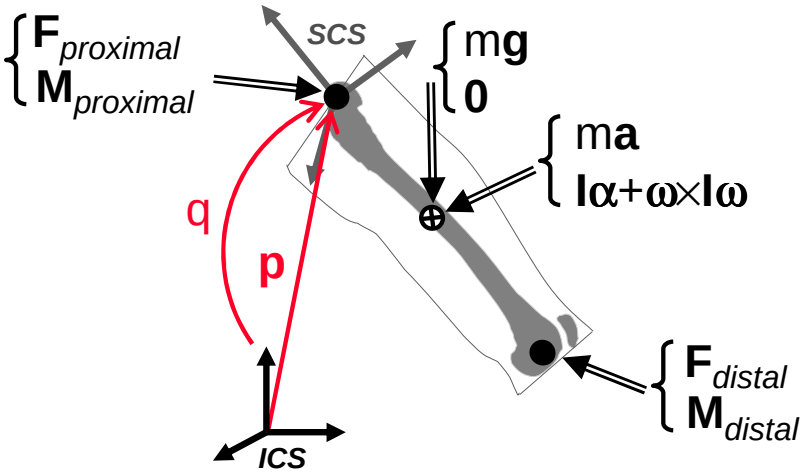


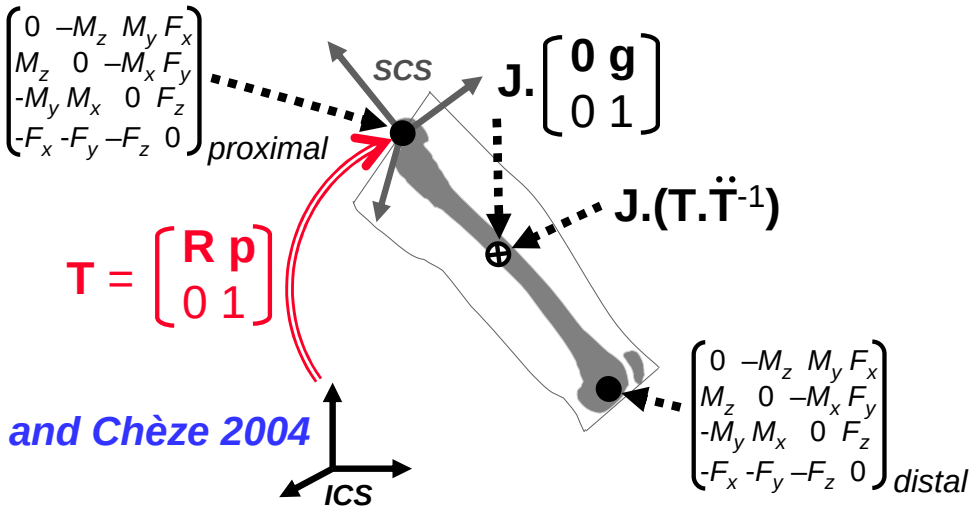
Dumas et al. 2004

Materials & Methods

- 3D inverse dynamics



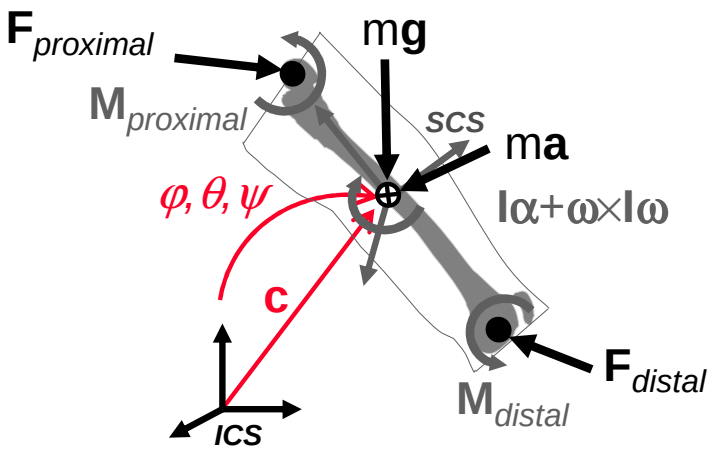


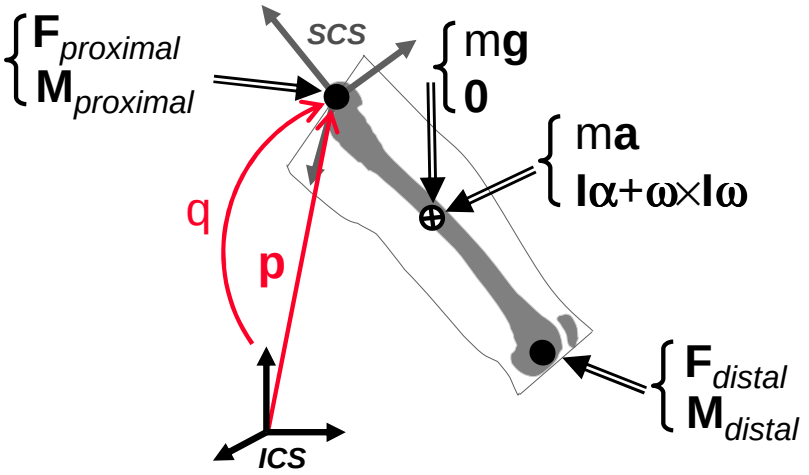


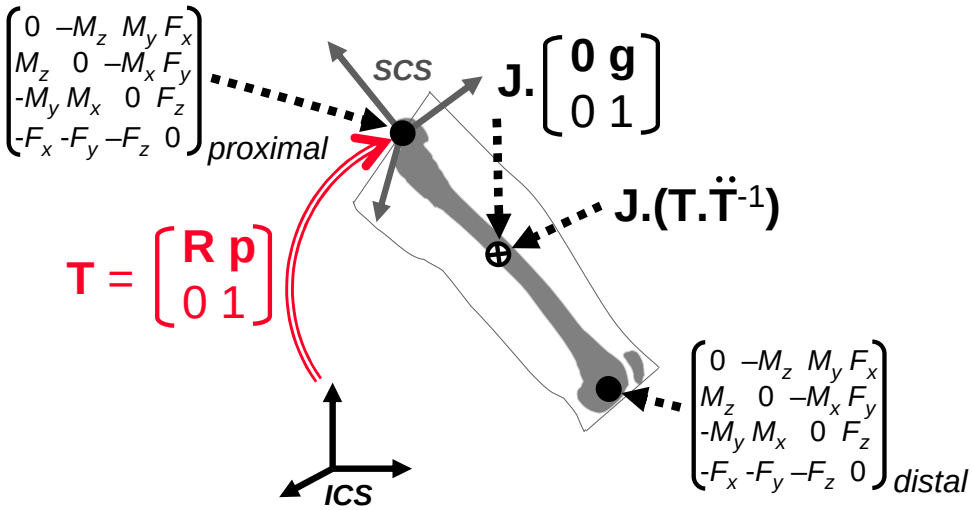
Doriot and Chèze 2004

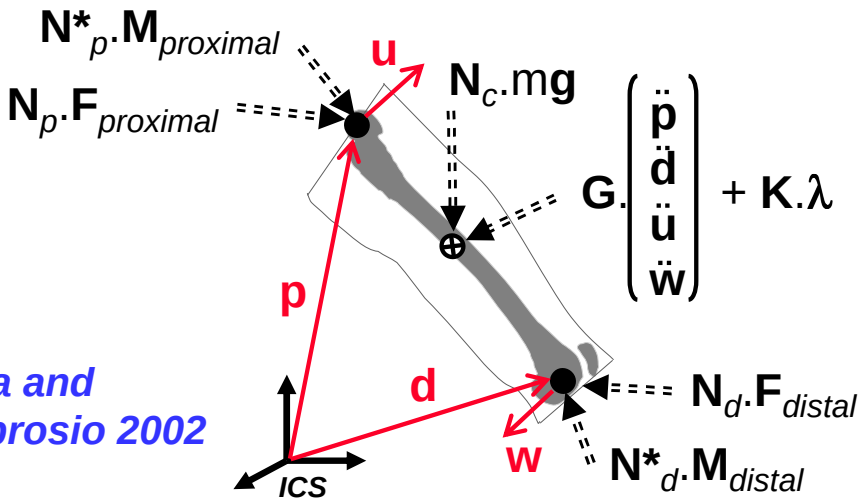
Materials & Methods

- 3D inverse dynamics









Silva and Ambrosio 2002

Materials & Methods

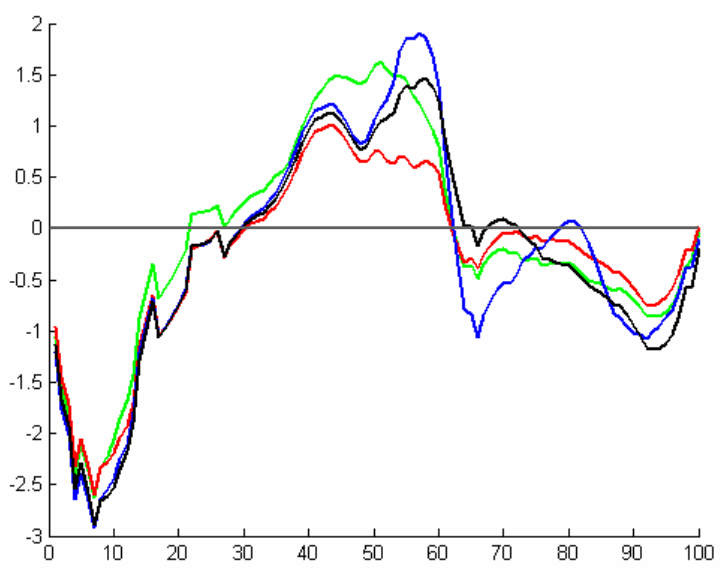
- 3D inverse dynamics
  - Joint moments in the ICS
  - Segment angular velocity in the ICS
    - $\omega = \begin{bmatrix} \dot{\psi} & \dot{\theta} & \dot{\varphi} \end{bmatrix}^T$ (body ZYX sequence)
    - $\omega = 2\dot{q} \otimes q^*$
    - ω skew matrix within $\mathbf{W} = \dot{\mathbf{T}}\mathbf{T}^{-1}$
  - Normalized (in % of Weight×Height)
  - Rescaled (in % of gait cycle)
  - Averaged on the 9 subjects

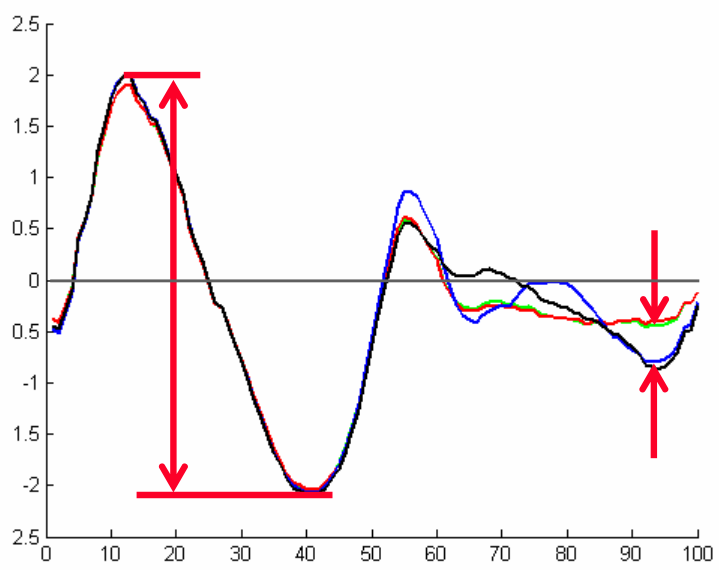
Unperturbed and perturbed gait data

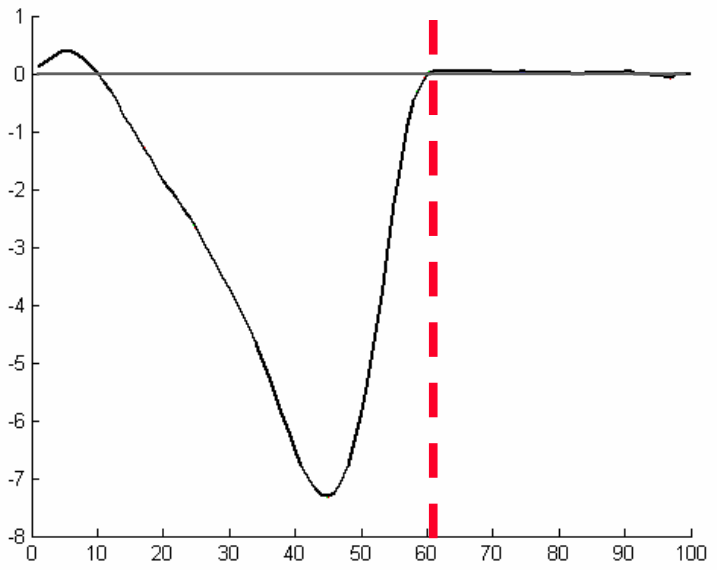
- Matlab 7.0 using double precision, finite differences and classical matrix operators (e.g. square matrix inversion)

Results: unperturbed gait data

- Hip, Knee and Ankle joint moments about Z-axis







VC
WQ
HM
GC

Maximal absolute amplitude

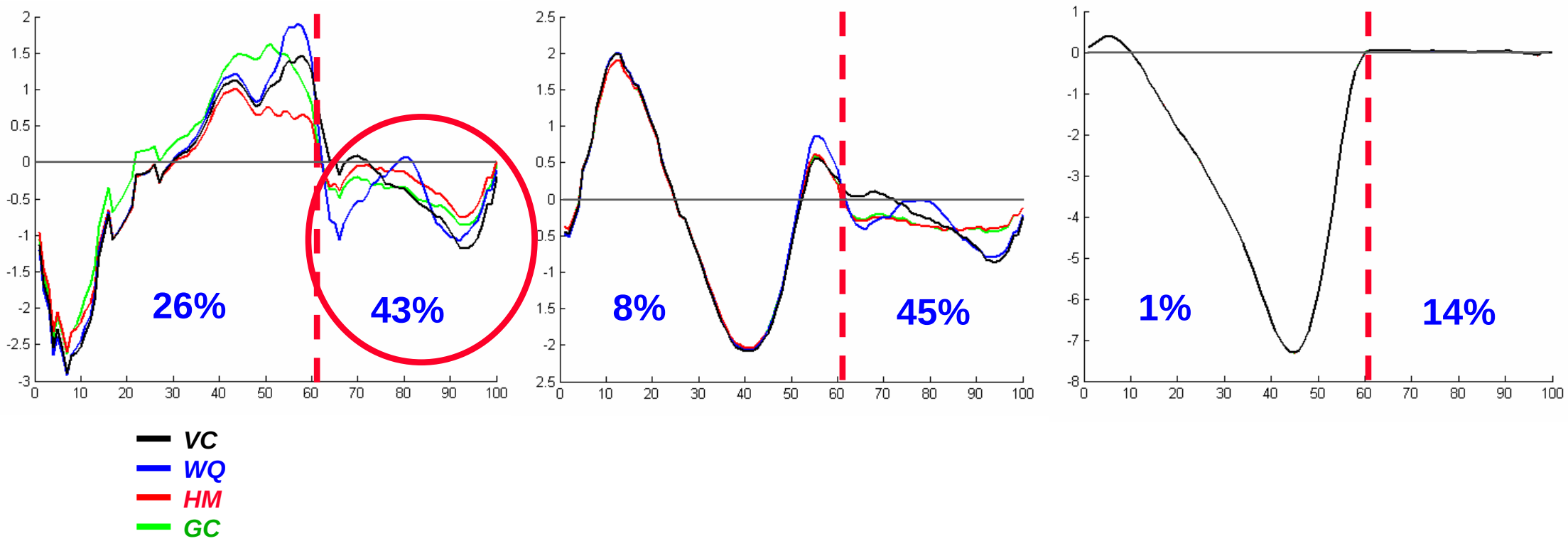
Maximal relative dispersion

Stance phase

Swing phase

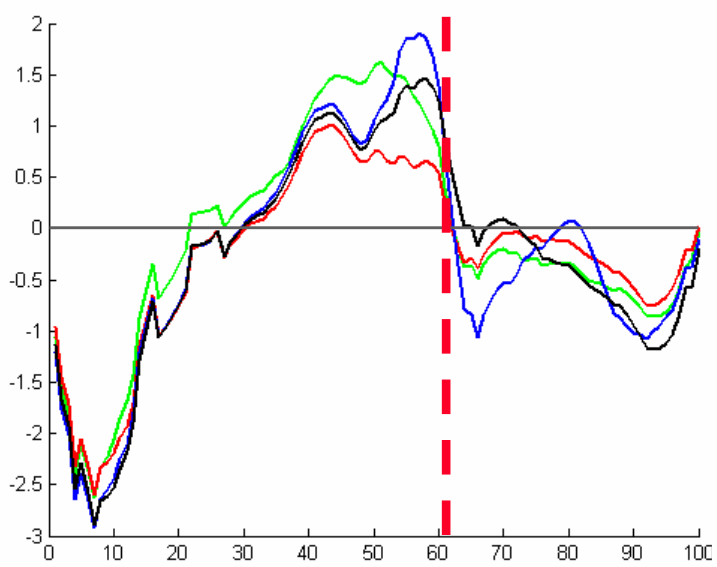
Results: unperturbed gait data

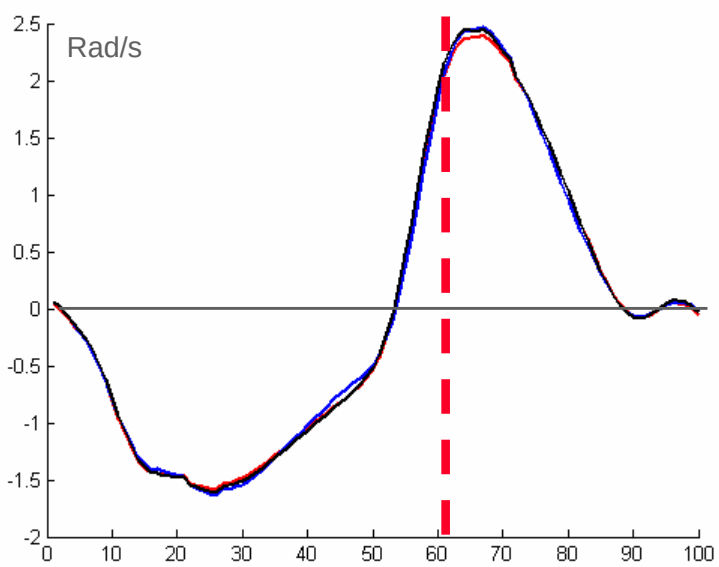
- Hip, Knee and Ankle joint moments about Z-axis
  - Influence of the method *(max. dispersion vs. max. amplitude)*



Results: unperturbed gait data

- Hip, Knee and Ankle joint moments about Z-axis
  - Influence of the method *(max. dispersion vs. max. amplitude)*
  - Joint moments and segment angular velocity



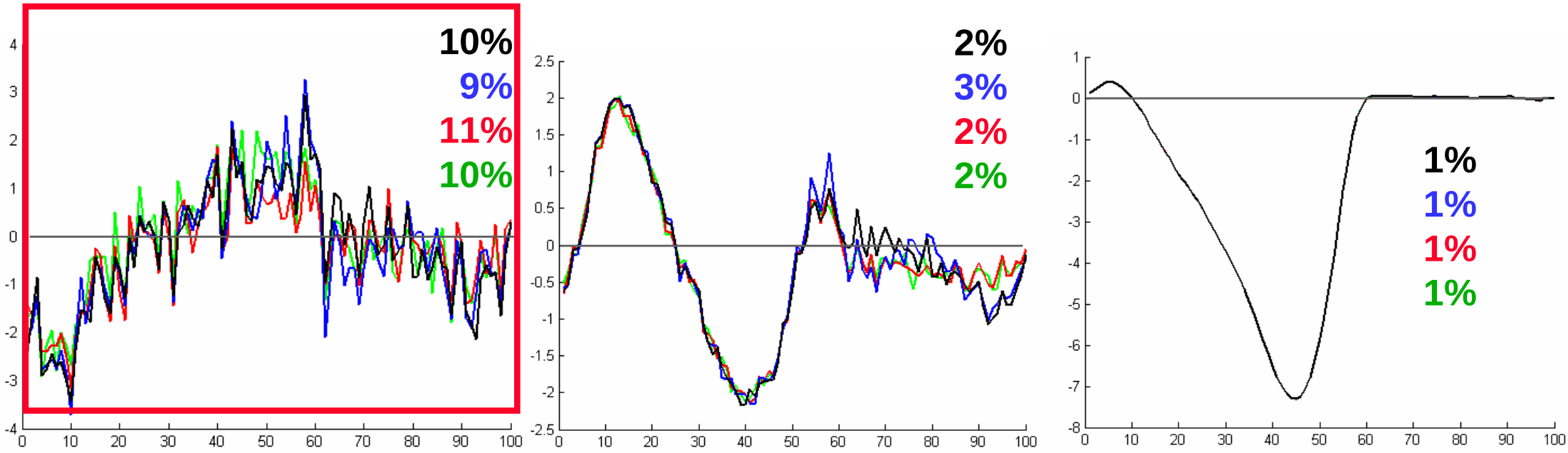


VC
WQ
HM
GC

Hypothesis: influence of the method due to the dynamic computations rather than the kinematic computations

Results: perturbed gait data

- Hip, Knee and Ankle joint moments about Z-axis
  - Influence of the noise *(mean diff. perturbed/unperturbed vs. max. amplitude)*



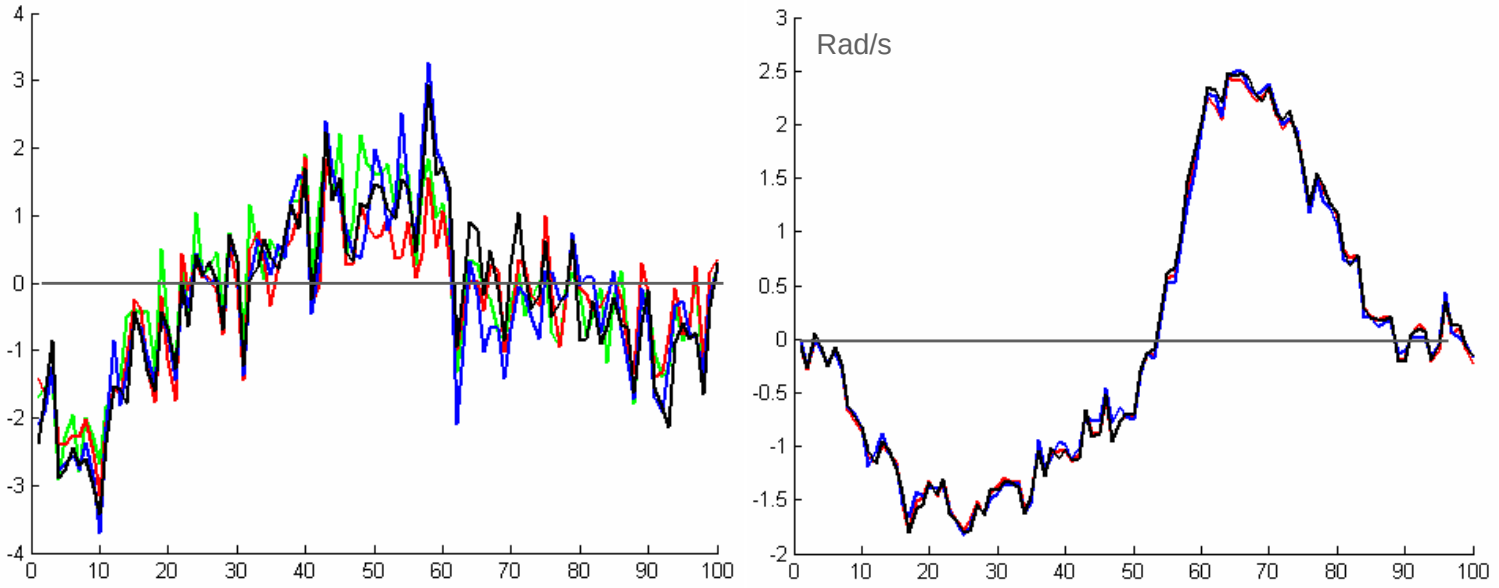
VC
WQ
HM
GC

Up to 49% on the knee moment about Y-axis for GC method

Considering X Y and Z axes, WQ and HM methods appear the less sensitive to noise

Results: perturbed gait data

- Hip, Knee and Ankle joint moments about Z-axis
  - Influence of the noise *(mean diff. perturbed/unperturbed vs. max. amplitude)*
  - Joint moments and segment angular velocity



Hypothesis: influence of the noise due to both dynamic and kinematic computations

VC
WQ
HM
GC

Discussion

- Influence of the method
  - Similar patterns and amplitudes, comparable to literature
  - Up to 40% *Kadaba et al., 1989*
  - Hypothesis: influence due to dynamic computations
    - *VC*: forces and moments computed **consecutively** in ICS and SCS
    - *WQ*: forces and moments computed **simultaneously** in ICS
    - *HM*: forces and moments computed **simultaneously** in ICS, but in a **redundant manner**
    - *GC*: forces and moments computed **simultaneously** in ICS, but with **rigid body constraints** (Lagrange multipliers)

Discussion

- Influence of the noise
  - Up to 50 %
  - Hypothesis: influence due to both kinematic and dynamic computations
    - Dynamic computations previously discussed
    - *VC*: **minimal parameters** (3 vs. 3 angular DoFs)
    - *WQ*: **redundant parameters** (4 vs. 3 angular DoFs)
    - *HM*: **redundant parameters** (9 vs. 3 angular DoFs)
    - *GC*: **redundant parameters** (12 vs. 6 linear and angular DoFs), but with **explicit constraints** (Lagrange multipliers)

Conclusion

- 4 inverse dynamic methods
  - Similar patterns and amplitudes
  - Different curves and different sensitivity to noise (due to both kinematic and dynamic computations)

- A choice ?
  - *VC:* useful for angle interpretation but not expedient
  - *WQ* and *HM* : convenient (algebra) and more robust to noise
  - *GC:* very specific (e.g. non ortho-normal segment axes)