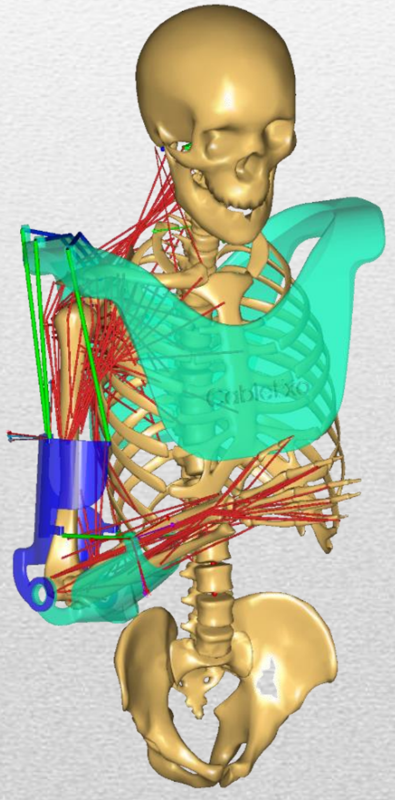
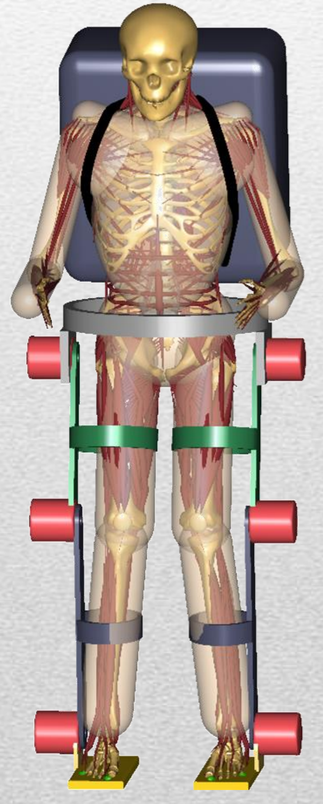
Modeling Human-Exoskeleton Interaction with AnyBody

Prof. John Rasmussen





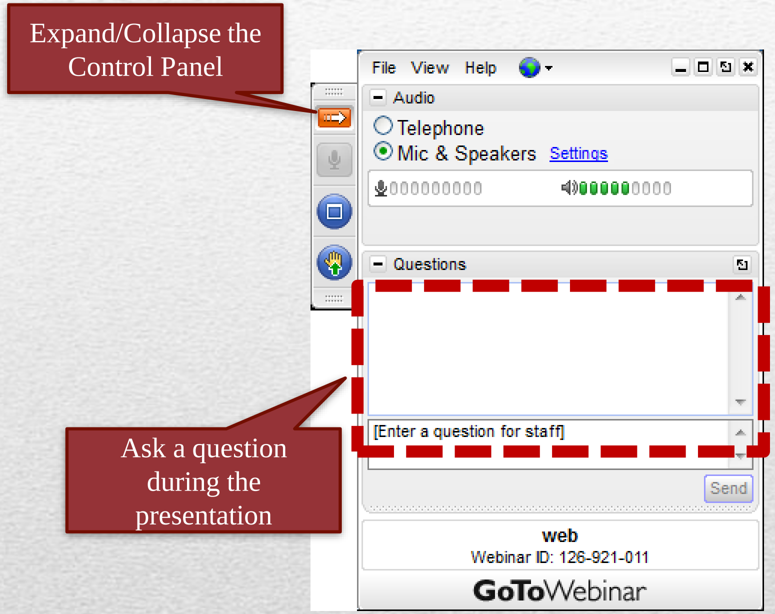
3 November 2016
AnyBody Technology
& Aalborg University

Control Panel

The Control Panel appears on the right side of your screen.

Submit questions and comments via the Questions panel.

Questions will be addressed at the end of the presentation. If your question is not addressed we will do so by email.



Outline:

- Introduction
- Presentation
- Final words
- Questions and answers

Host

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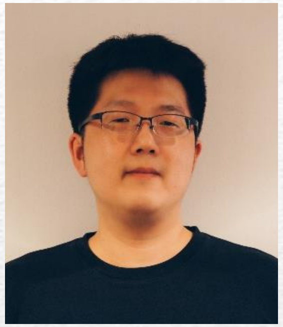
Producer



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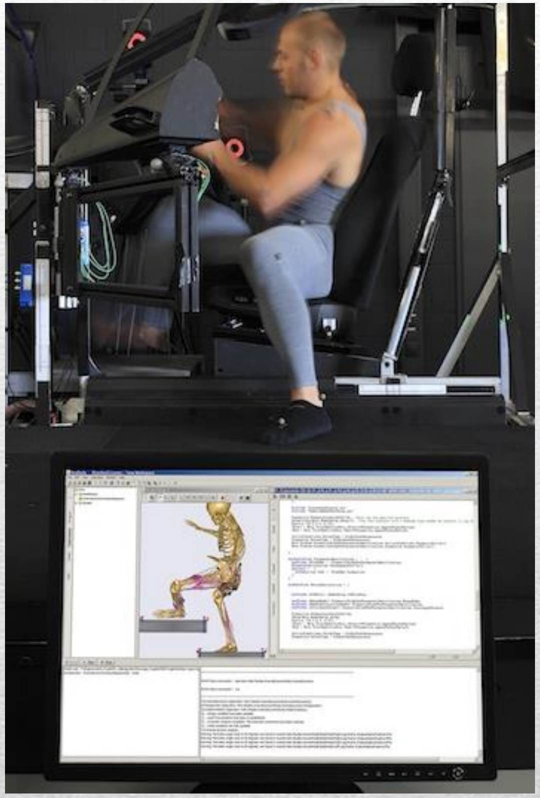
AnyBody Modeling System

- Simulations of Musculoskeletal systems
  - Multibody kinematic and dynamic analyses
- AnyBody Managed Model Repository
  - Applications
  - Open Body Models
- Special simulation features
  - Man-machine interaction simulation
  - Reaction force prediction
  - Imaging → Patient-specific anatomy



Rasmussen et. al. (2011), ORS Annual Meeting

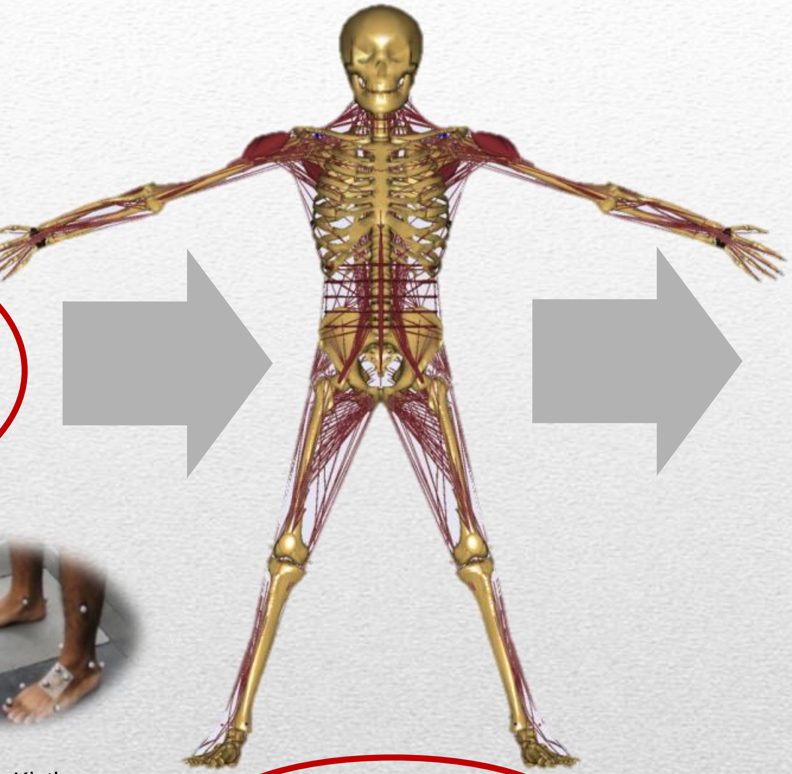
Musculoskeletal Simulation

Input

Task/Motion
(+ External
forces/moments)

Courtesy: Qualysis

Courtesy: Kistler



Body Model

Bones

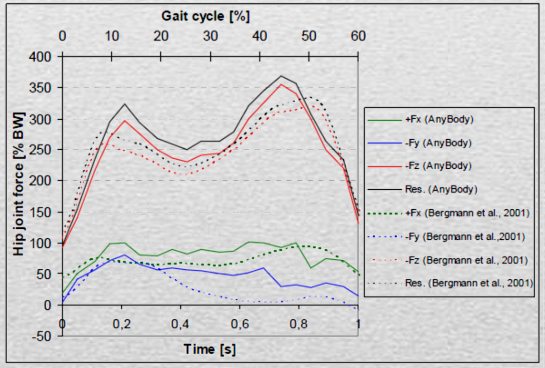
Joints

Muscles

Ligaments

Output

Muscle:
force, activity, power
Joint:
load, moment, ...



Courtesy: Thielen et al., 2009

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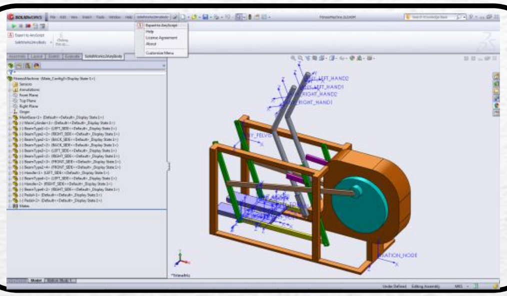
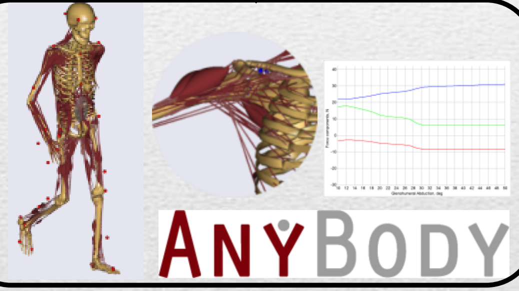
Simulation Work flow



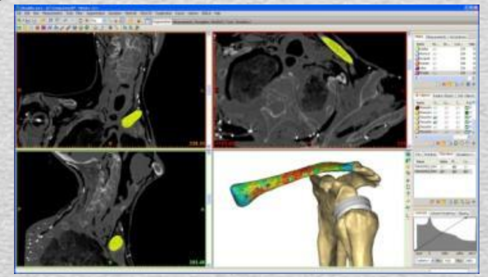
CAD environment model (SolidWorks2AnyBody)

Applications: Activities of daily living

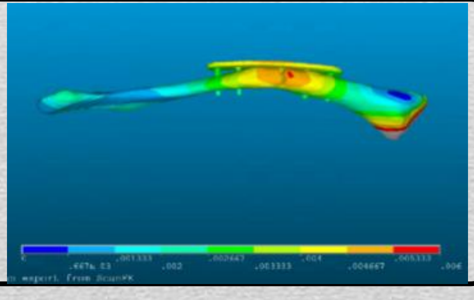


Software interaction:
- Scripting via e.g. Python, MATLAB.
- Optimization/control

Subject information

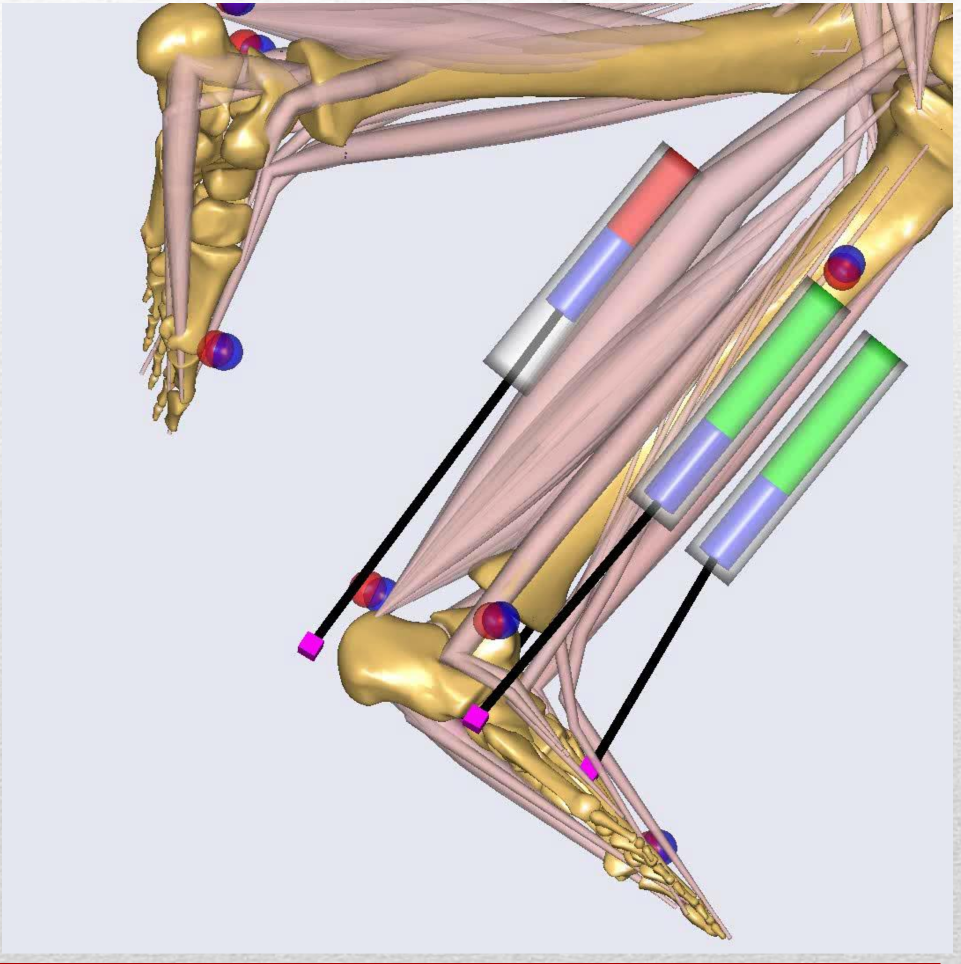


FE-model



Modeling Human-Exoskeleton Interaction with AnyBody

1. The exoskeleton design phases
2. Examples
3. Conclusions



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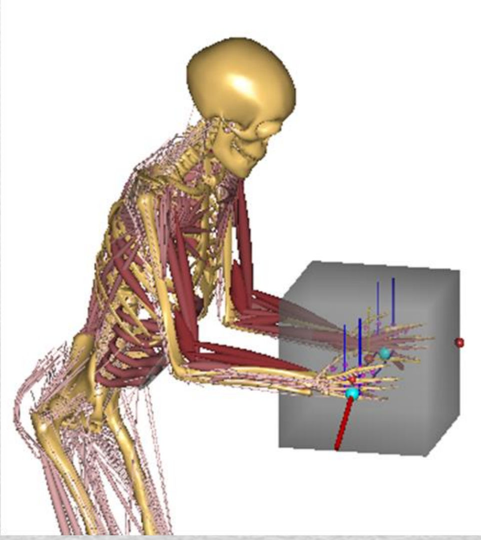
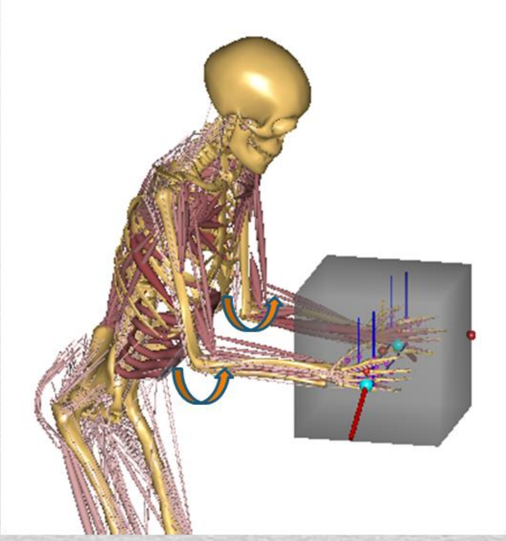
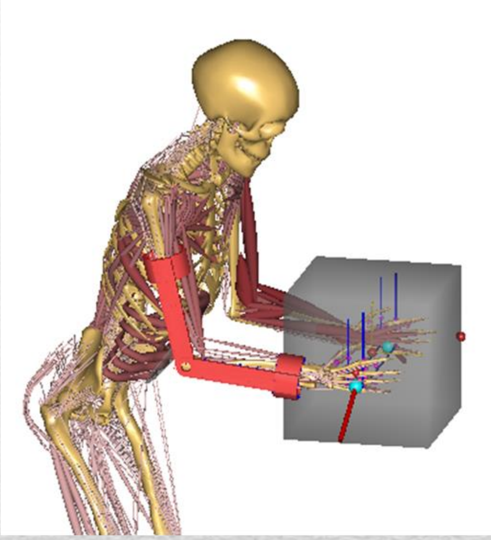
The Exoskeleton Design Phases

1) Baseline: Analysis of the working situation
2) Conceptual: Assessing influence of assistance
3) Detailed design


Model without exoskeleton


With nominal assistive moments

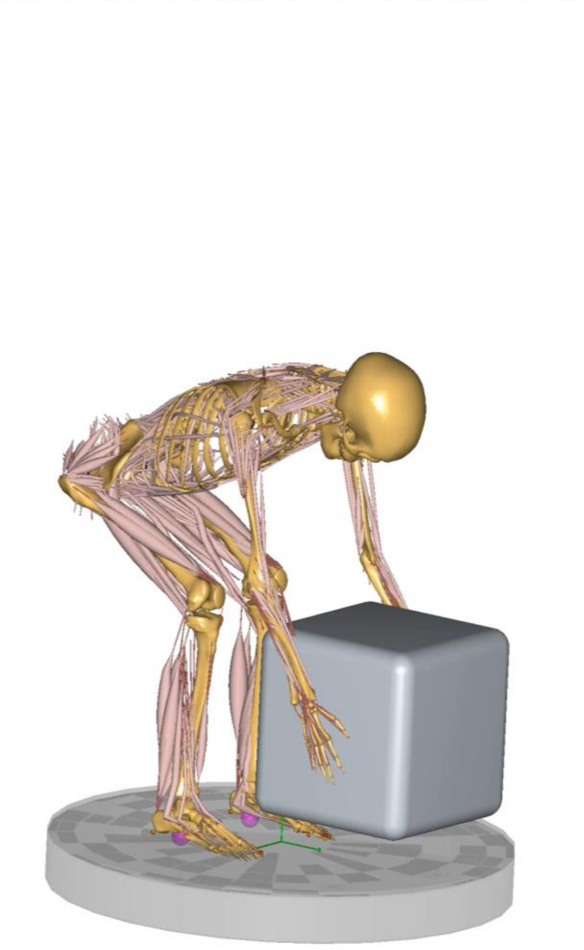

With actual exoskeleton

1. Analysis of the working situation

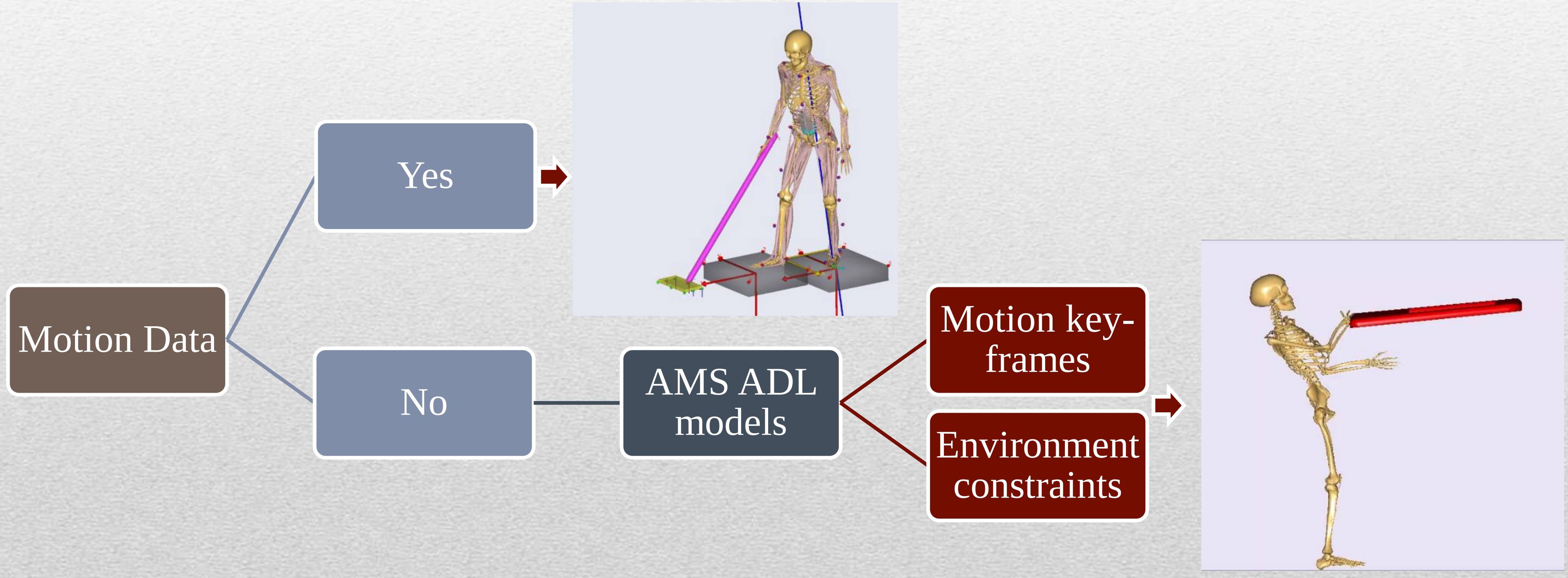
Basic information about the working process is necessary for the conceptual design.

- Which time frames or postures of the working process are strenuous or injury-prone?
- Which parts of the body are highly loaded?
  - Performance bottlenecks
  - Injury risks

Baseline analysis with no exoskeleton. Used for subsequent comparison.

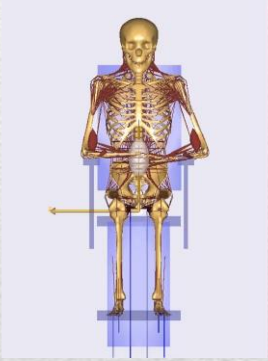


Motion for the Baseline Model



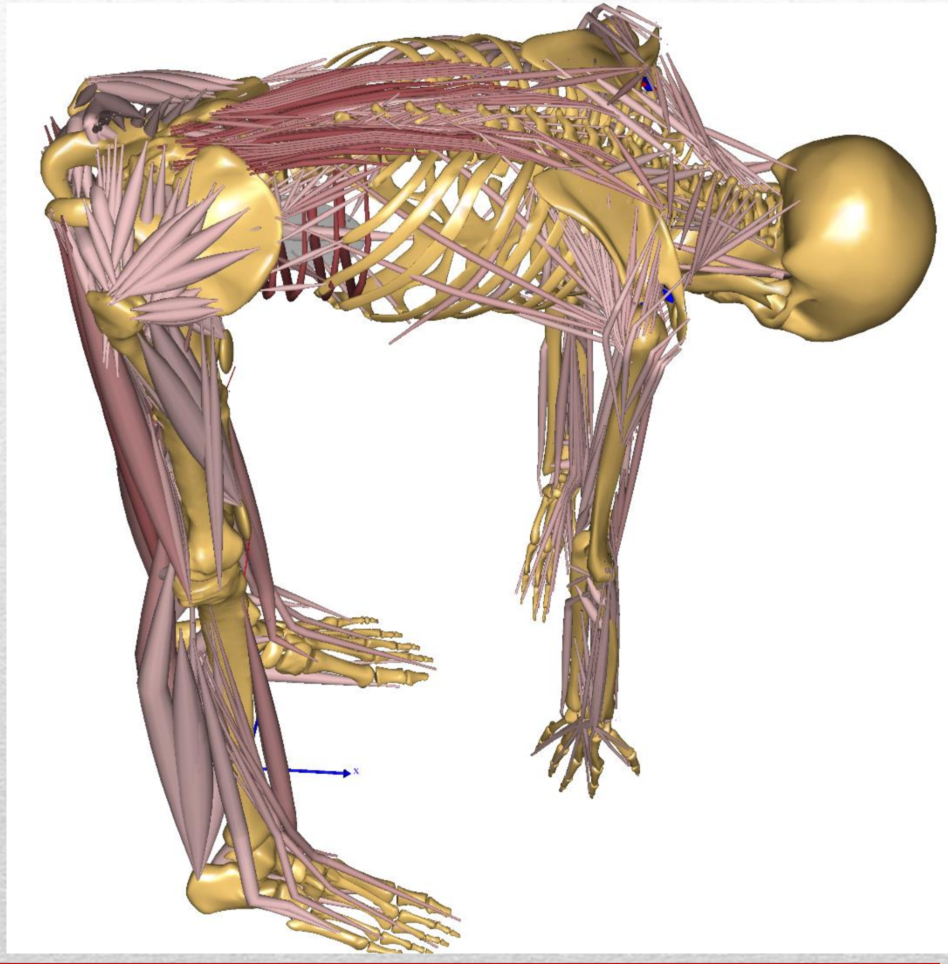
Environment Forces

- External Forces
  - measured
  - Not measured
    - Interaction force prediction
      - GRF prediction
      - Seating force prediction
      - Equipment force prediction



Conclusions on baseline model

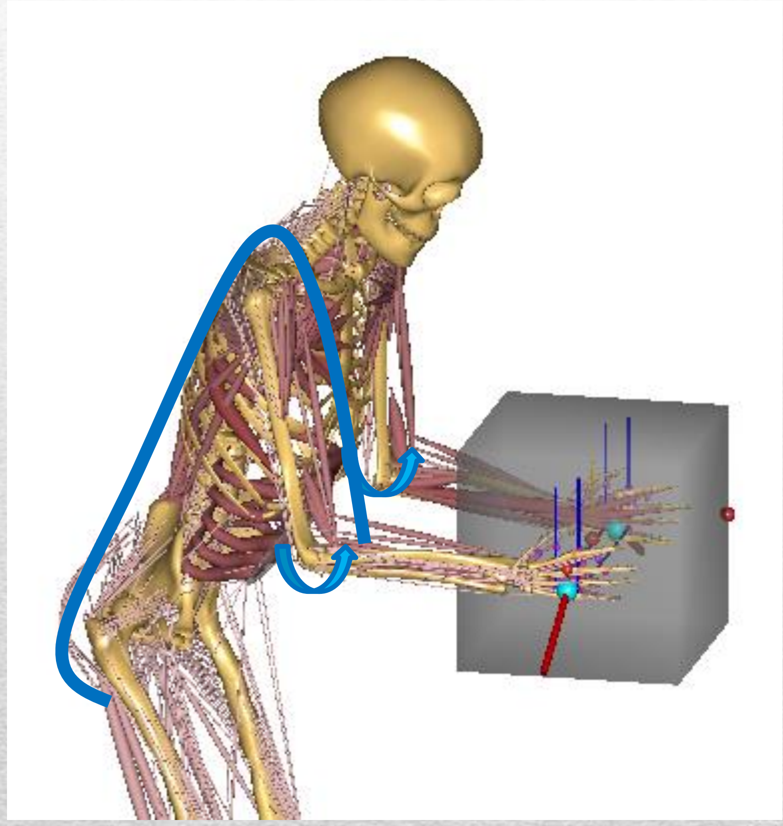
- Full or estimated information about the motion of all body parts, joint angles, etc.
- All joint forces including critical points like the spine for assessment of injury risks.
- Muscle exertion levels for all body parts for identification of strength bottlenecks.
- Metabolism for single muscles and the entire muscle system.



2. Pre-prototyping

We are not designing an exoskeleton just yet. The aim of this phase is to

- Add abstract forces and moments to body parts and joints
- Evaluate their effect on injury risks and performance bottlenecks
  - Highly loaded joints
  - Highly loaded muscles
- Identify clever combinations of moments and forces that have the best effect
- Identify possible negative side effects.



Eample: Metabolic power

(Shourijeh et al., WeRob 2016)

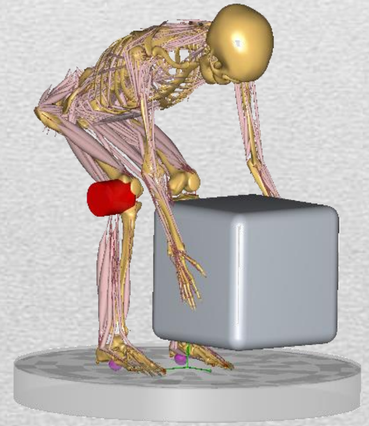
- If we only had ONE spring, which leg joint should it assist?

$$T_{motor} = -K.(\theta - \theta_{ref})$$

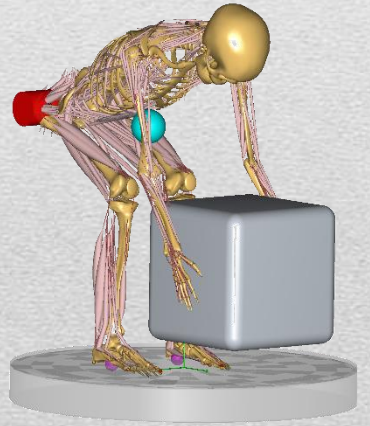
K_{ANKLE} K_{KNEE} K_{HIP}

Case 1 – Ankle spring only

Case 2 – Knee spring only

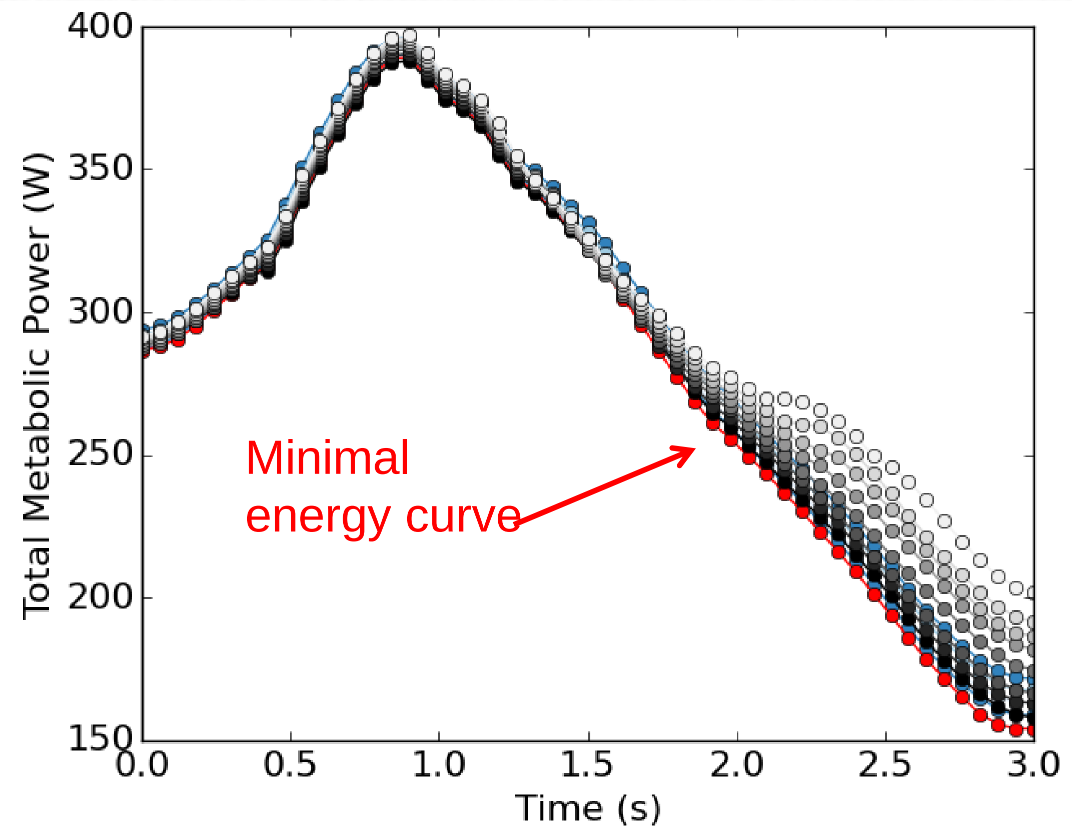


Case 3 – Hip flexion spring only



Case 1: Finding K_{ANKLE}

- Vary K_{ANKLE}
  - -300 → 300 Nm/rad
  - Steps of 50 Nm/rad
- For each K_{ANKLE}
  - Repeat Inverse Dynamics
  - Calculate Metabolic Energy Rate over entire task
  - Parametric study
- Find value with least energy expenditure

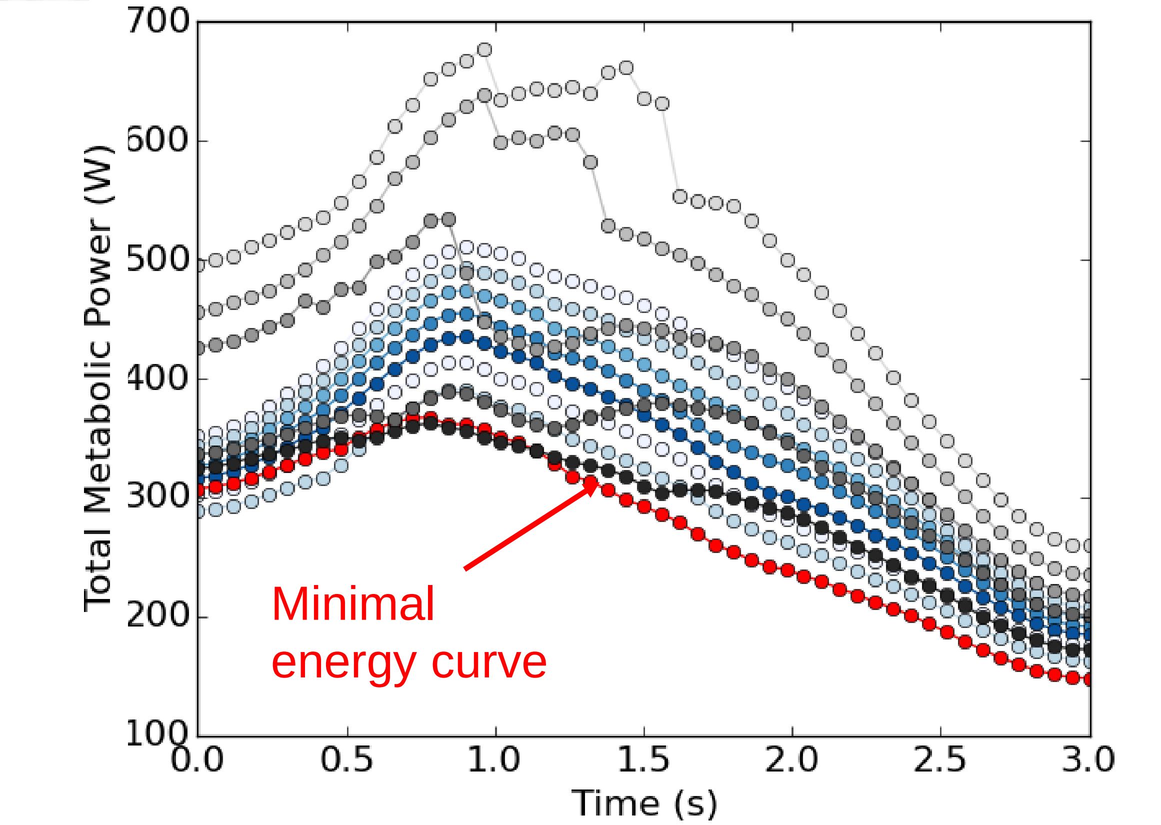


$Optimal\ K_{ANKLE} = -100\ Nm/rad$

Case 2: Finding K_{KNEE}

- Parametric study for knee

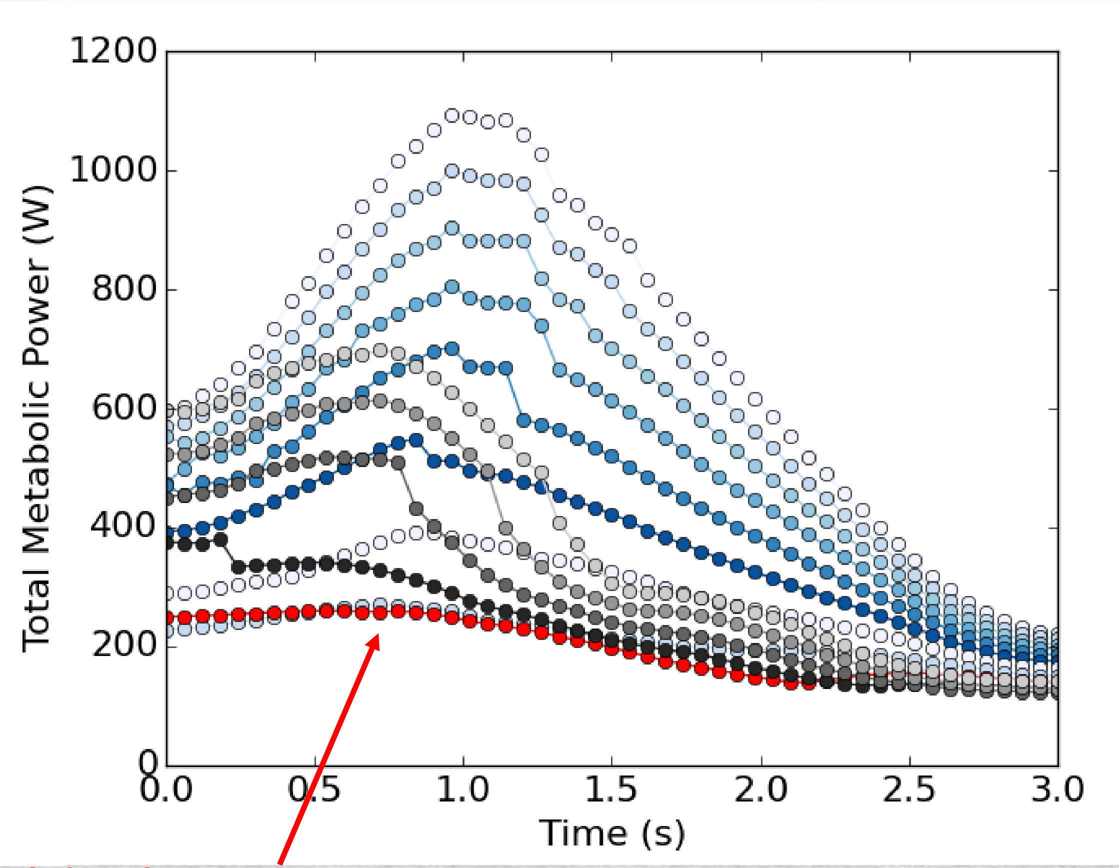
$$Optimal\ \ K_{KNEE} = 50\ Nm/rad$$



Case 3: Finding K_{HIP}

- Parametric study for hip

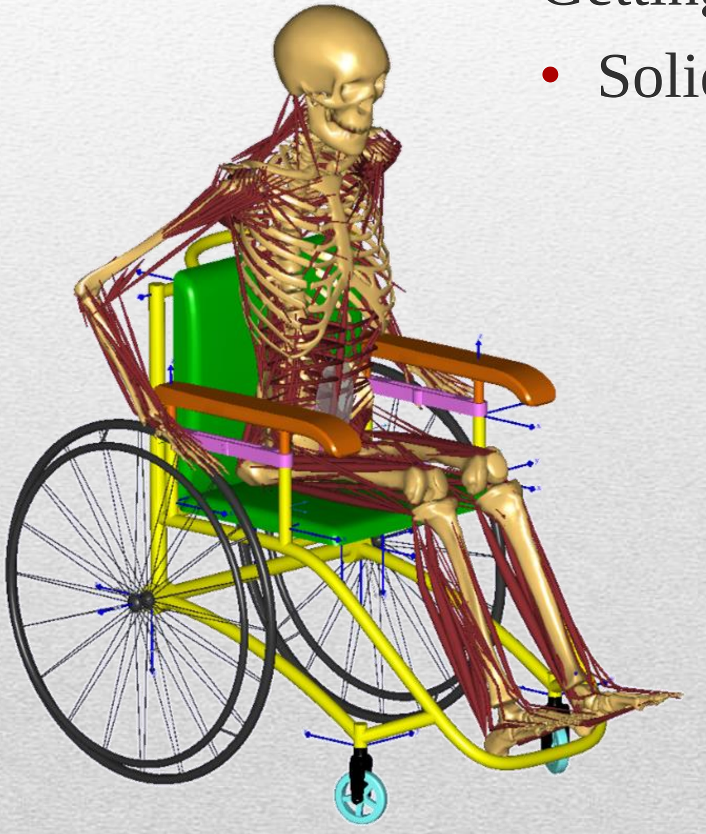
$$Optimal\ \ K_{HIP} = 100\ Nm/rad$$

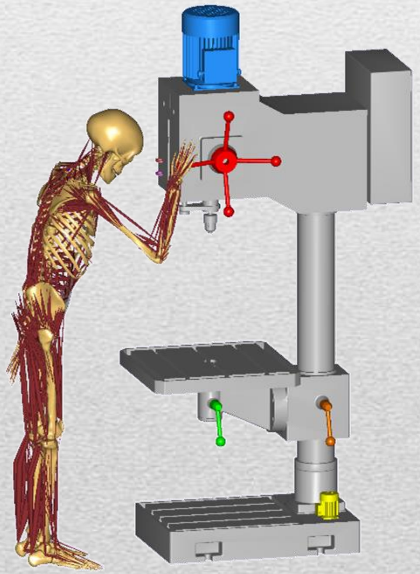


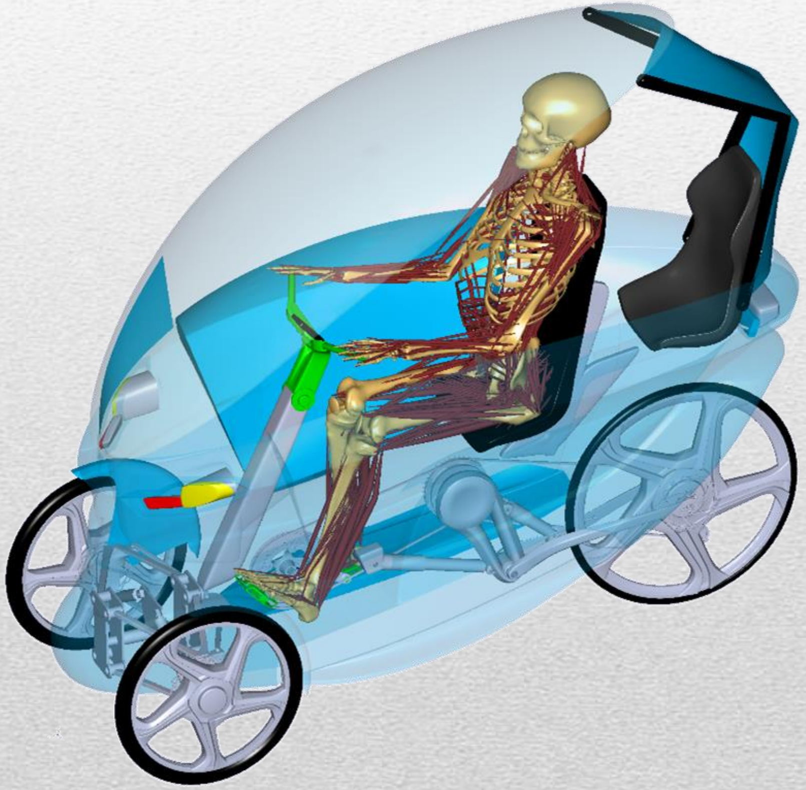
3. Detailed Design

Getting designed parts into AnyBody:

- Solidworks2AnyBody plugin







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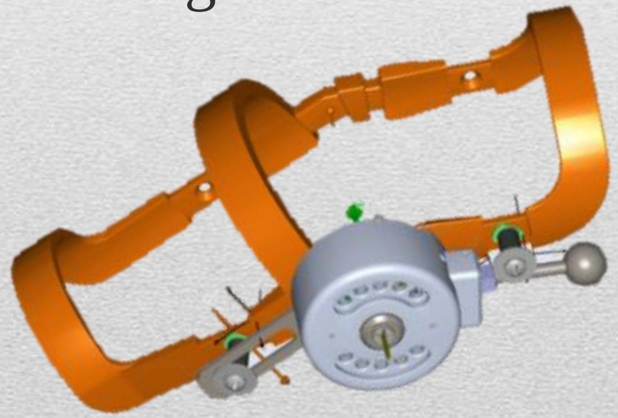
Detailed Design Analysis objectives

Kinematics

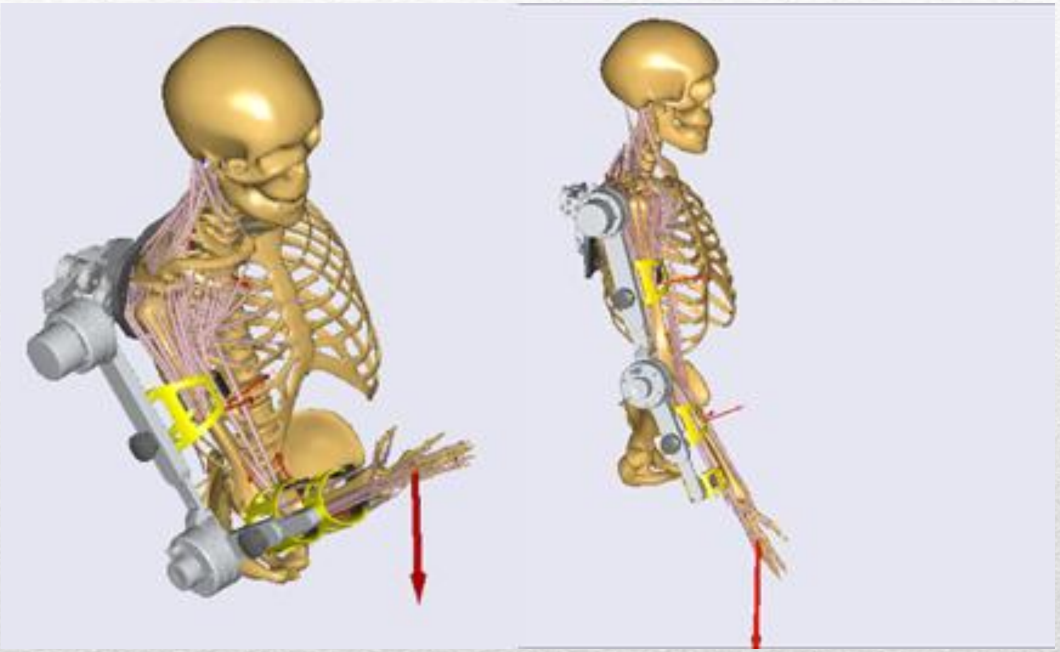
- Kinematic compatibility between exo and human
- Movement of the exo and collisions with the human body
- Actuator range-of-motion



Kinetics

- Contact forces between exoskeleton and human
- Power consumption and peak power for actuators
- Peak forces/moments of actuators
- Metabolic power and energy consumption

Kinematic Compatibility

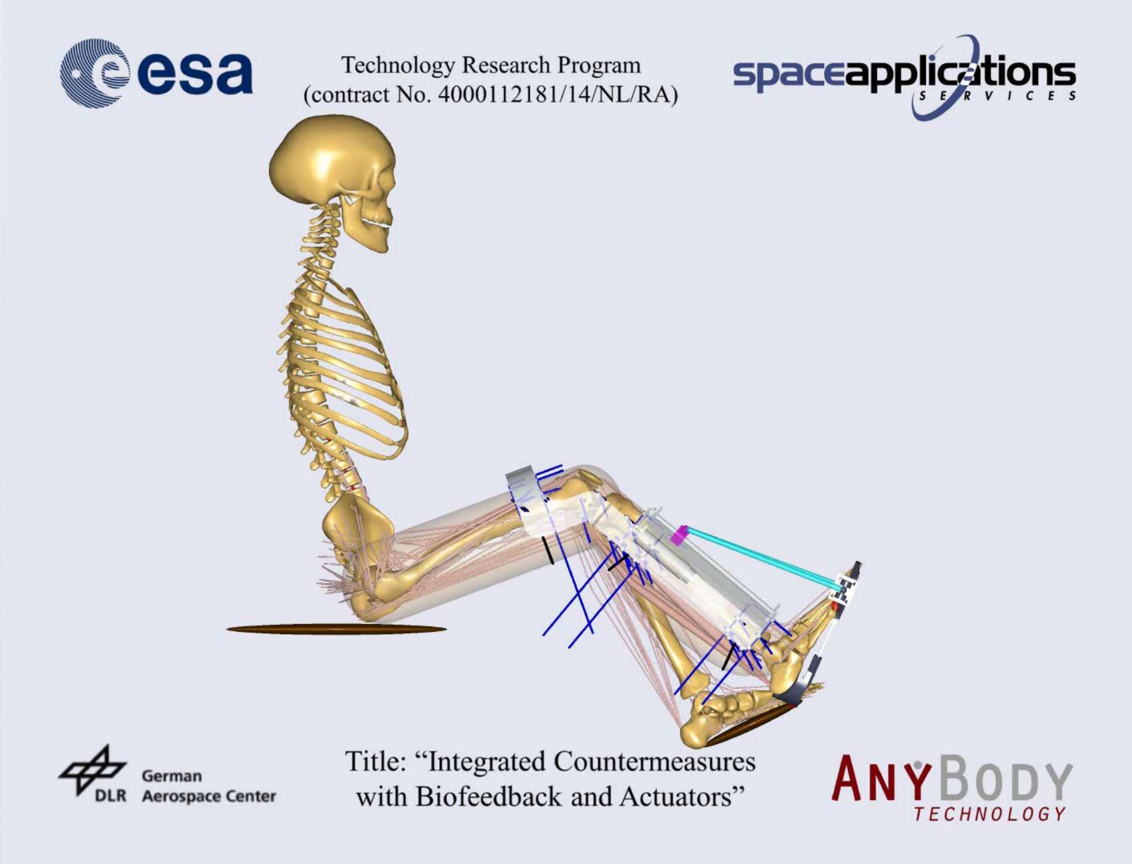


AXO-SUIT project (www.axo-suit.eu)

- The EXO and the human body are parallel systems of kinematic constraints.
- When they get connected, they may not be compatible.
- Compatibility is complicated because human kinematics is complex.
- Incompatibility can lead to locking, chafing and unintentional joint loads.

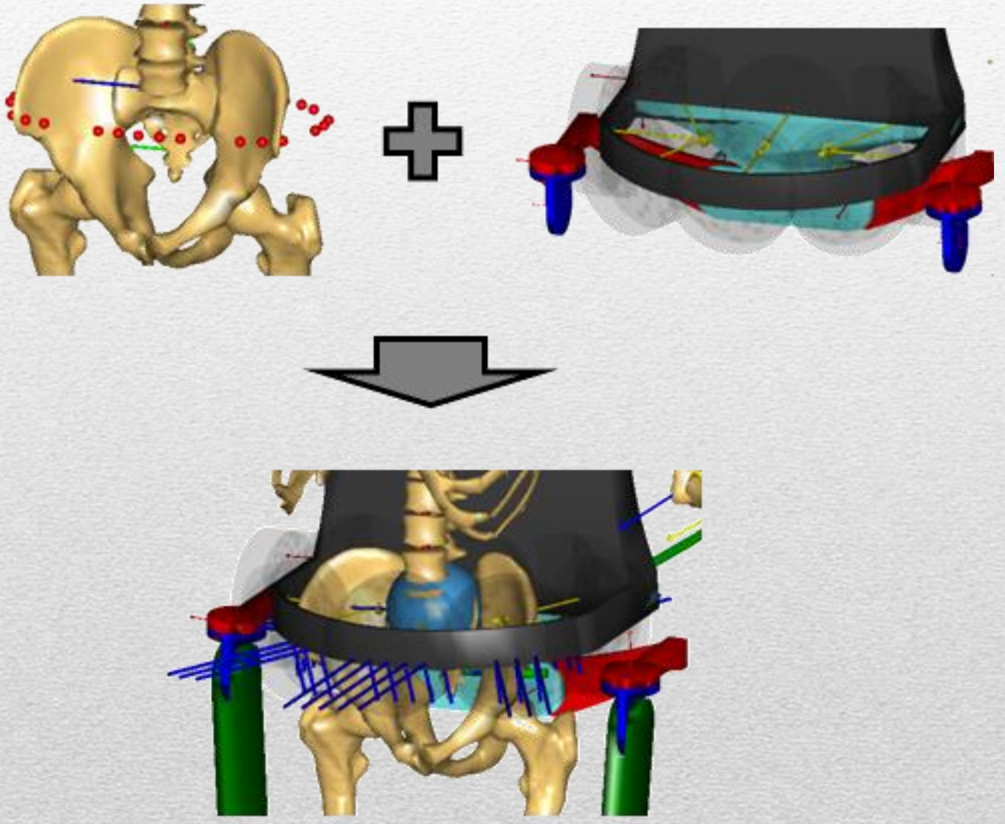
Contact forces and straps

- Any sort of assistive force or moments lead to contact forces with the body.
- Their behavior is complex because they depend on the exo design as well as the human behavior.
- Biomechanical simulation is probably the only way to assess them without building and testing prototypes.
- AnyBody allows for unilateral contact models.



Contact models

- Straps, pressure pads etc. can be modelled with unilateral contact elements.
- This ensures change of contact between opposite sides of limbs with changing forces.
- Contact elements can contain Coulomb friction.



Cho et al. (2012)

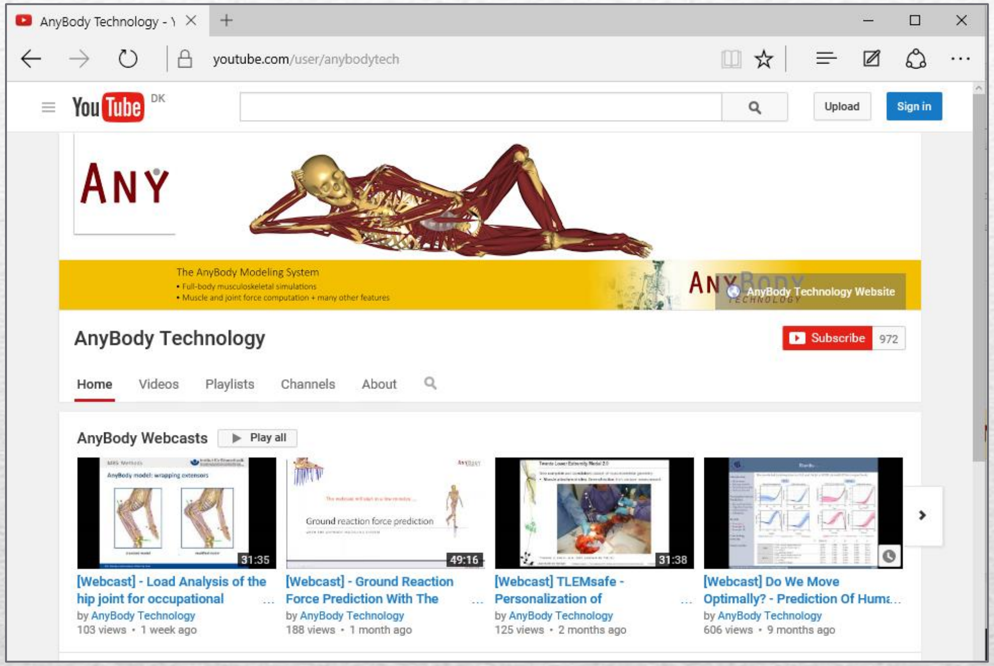
Conclusions

Exoskeleton for wire-winding: www.movaid.edu

- Human-exo interaction is complex.
- Exoskeletons can enhance safety and performance.
- They can also cause discomfort, pain and injury.
- Musculoskeletal simulation can assist in several stages of exoskeleton design.

Webcasts

- Stay tuned to www.anybodytech.com for forthcoming webcasts.
- Links to recorded webcasts, for instance “Modeling and Simulation for Wearable Robots”



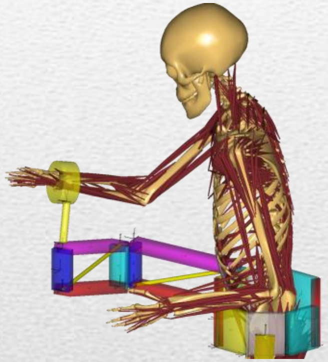
www.anybodytech.com

- Download software
- Request trial licenses
- List of publications

inquiry@anybodytech.com

- Contact for any kind of questions

Time for questions



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