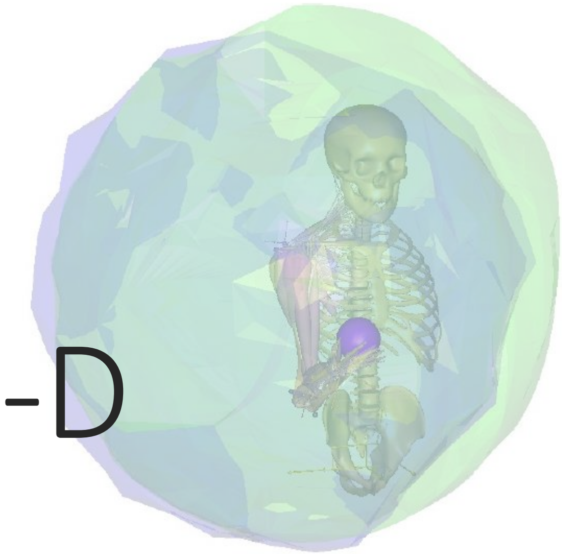
The webcast will start in a few minutes….

Model validation using the 3-D reachable workspace



AN EXPERIMENTAL + COMPUTATIONAL APPROACH

Outline

- Short introduction to the AnyBody Modeling System.
- Presentation by Miguel
  - Kinematic measurement – 3D reachable workspace
  - Force measurement – Max directional capability
  - Validation of a musculoskeletal model
- Questions and answers

Miguel Nobre Castro, PhD Student

AnyBody Research Group,
Dept of Mechanical and Manufacturing Engg
Aalborg University (DK)

Host:
Ananth Gopalakrishnan
Product Specialist
AnyBody Technology

Control Panel

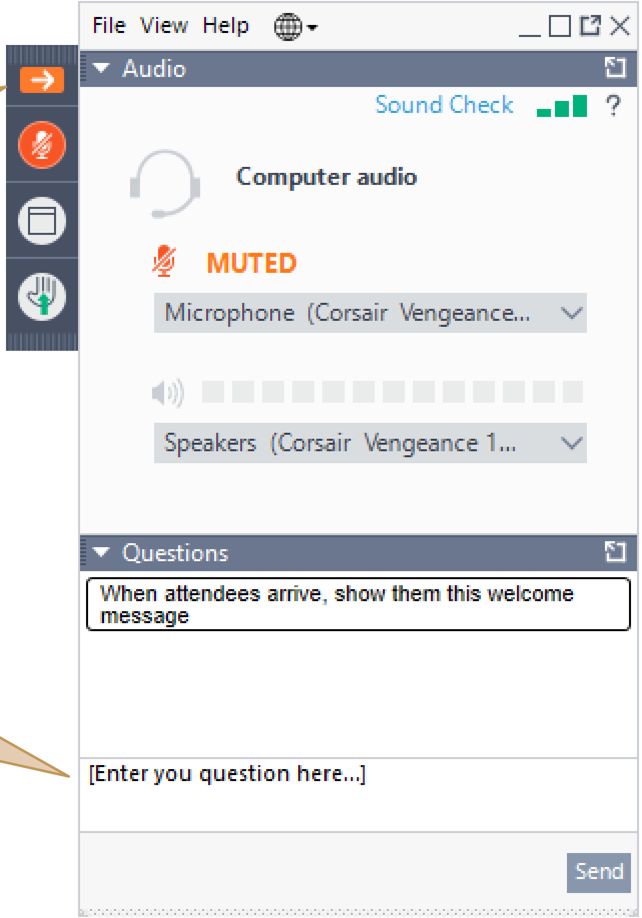
The Control Panel appears on the right side of your screen.

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.

Expand/Collapse the Control Panel

Ask a question during the presentation



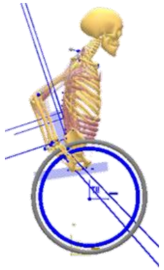
Musculoskeletal Simulation

Motion data
Kinematics + Forces

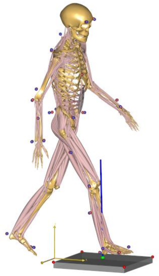
→ **ANYBODY Modeling System** →

Body Loads
- Joint moments
- Muscle forces
- Joint reaction forces

AnyBody Technology



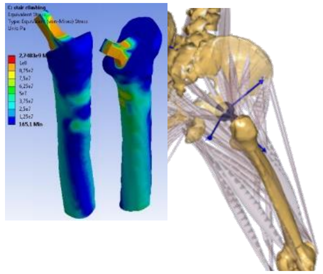
Product Design Optimization



Movement Analysis

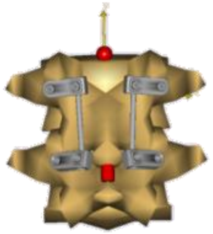
AnyBody Modeling System

Ergonomic Analysis



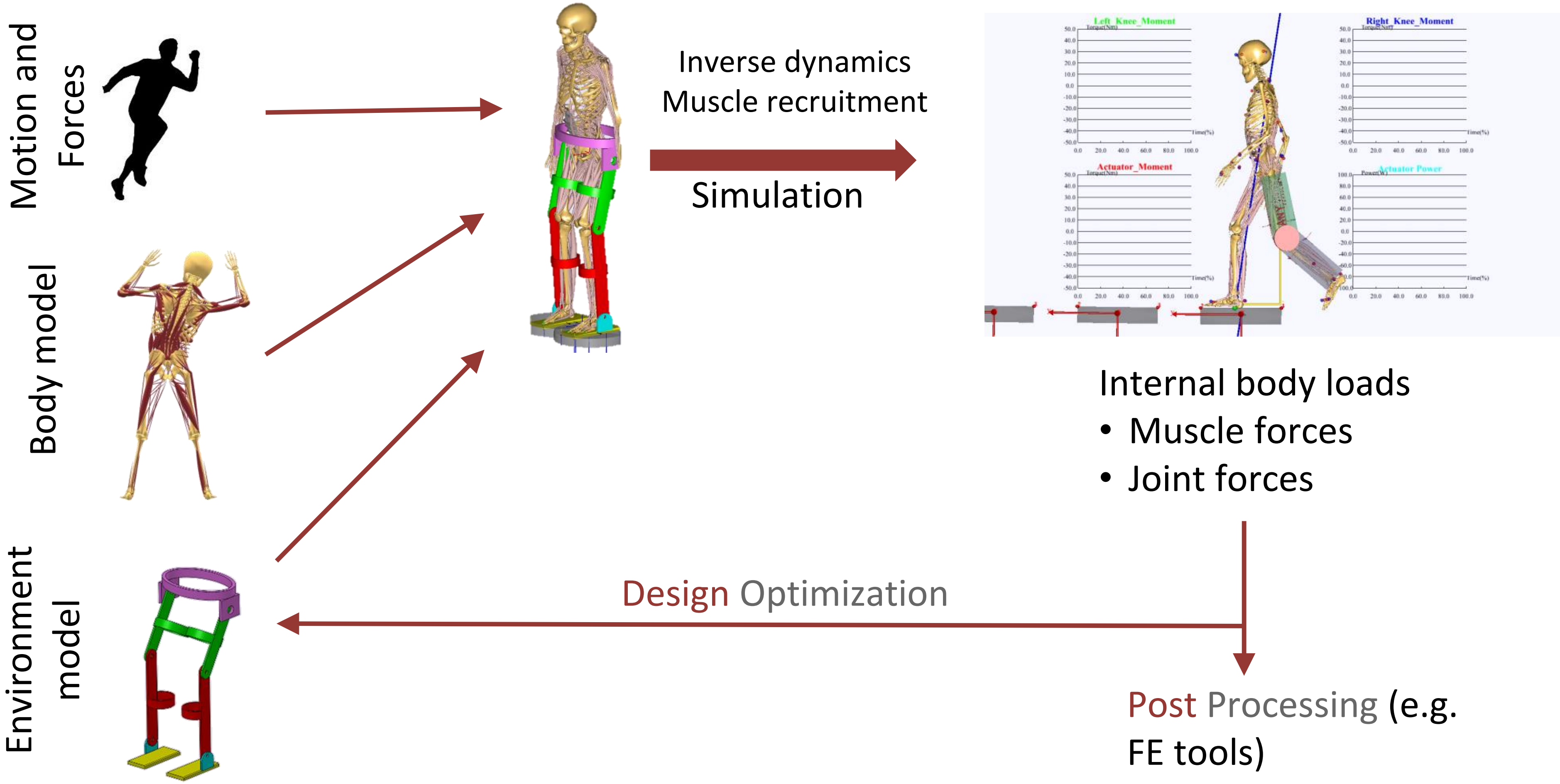
Load Cases for Finite Element Analysis

Surgical Planning and Outcome Evaluation



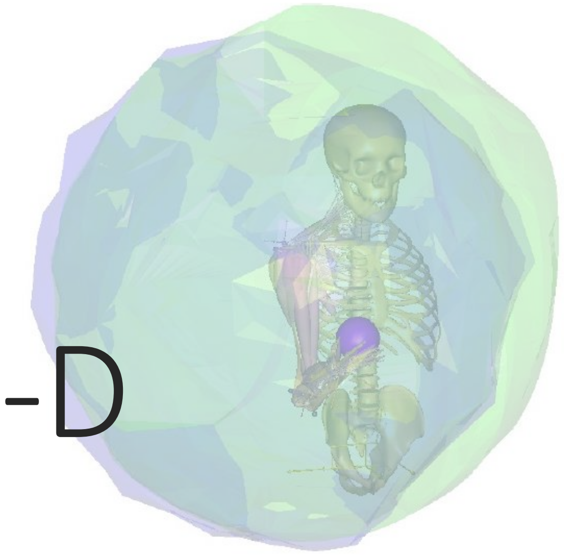
ANYBODY TECHNOLOGY

AnyBody Modeling System

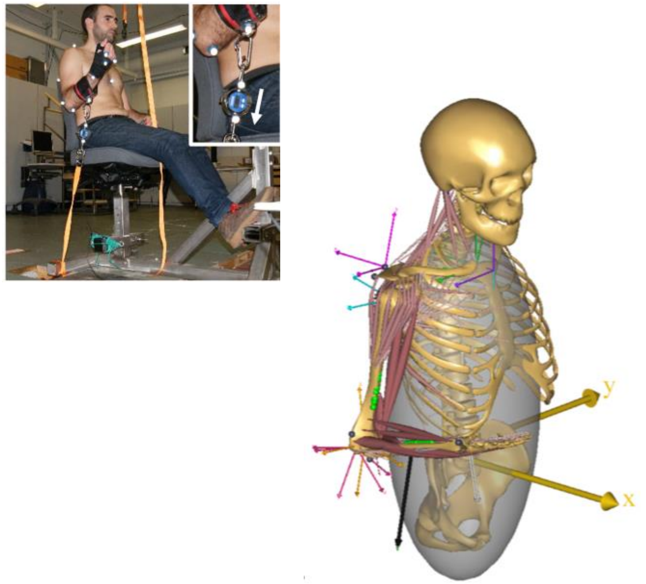


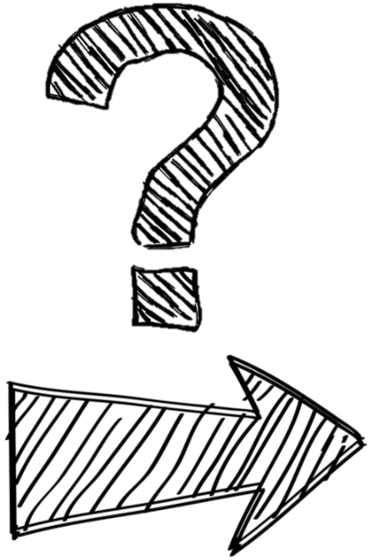
Model validation using the 3-D reachable workspace

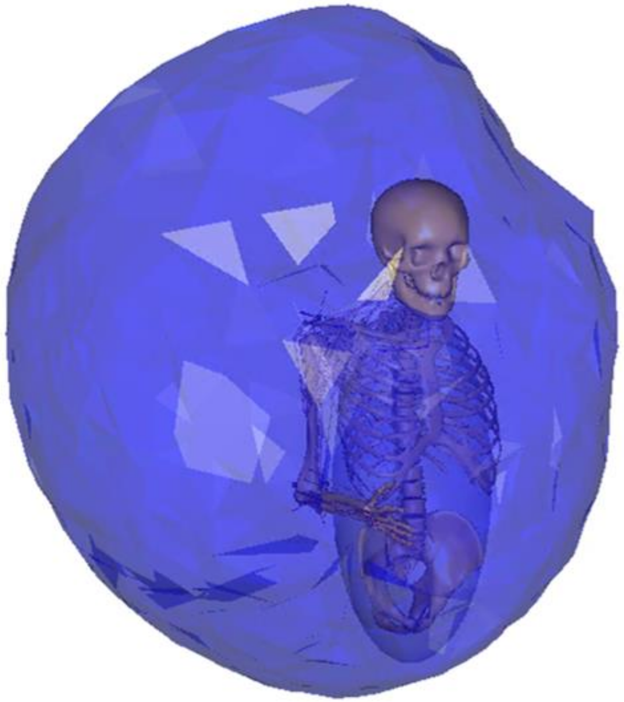
AN EXPERIMENTAL + COMPUTATIONAL APPROACH



ON THE VALIDATION OF MUSCULOSKELETAL MODELS USING THE ANATOMICAL 3-D REACHABLE WORKSPACE







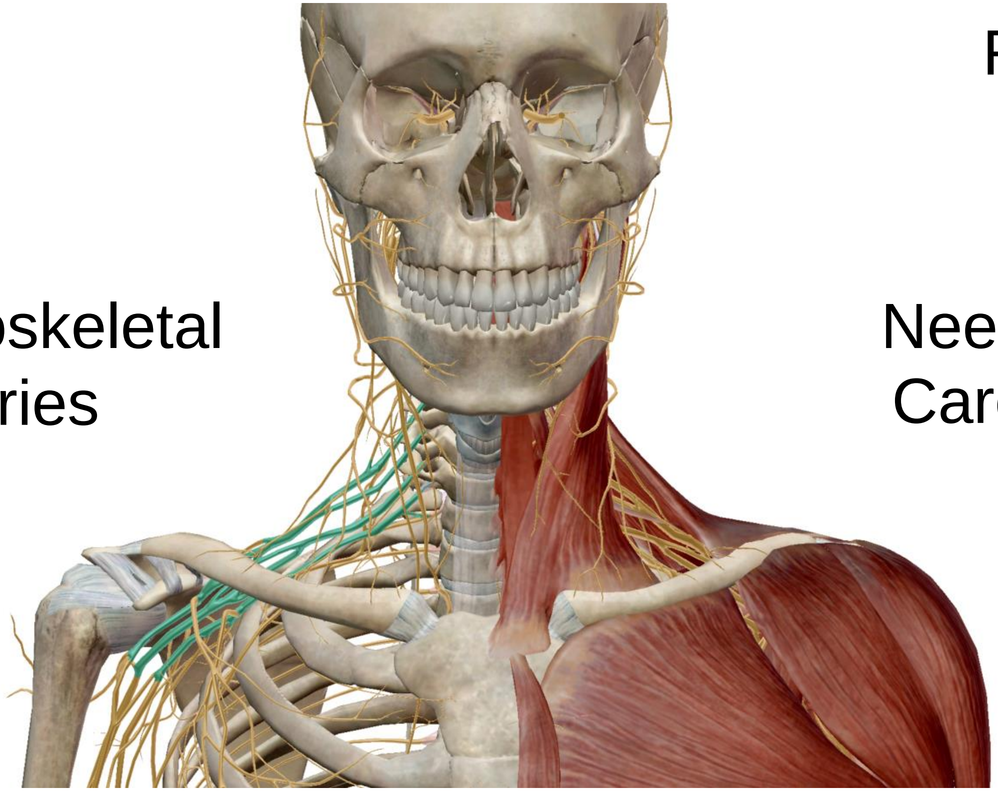
MIGUEL NOBRE CASTRO[1], JOHN RASMUSSEN[1], SHAOPING BAI[1], MICHAEL SKIPPER ANDERSEN[1]
[1]Dept. Mechanical & Manufacturing Engineering, Aalborg University, Denmark

Background

Neuromuscular Disorders

Musculoskeletal Injuries

Progressing Atrophy



Residual Muscle Function

Need for a Caregiver

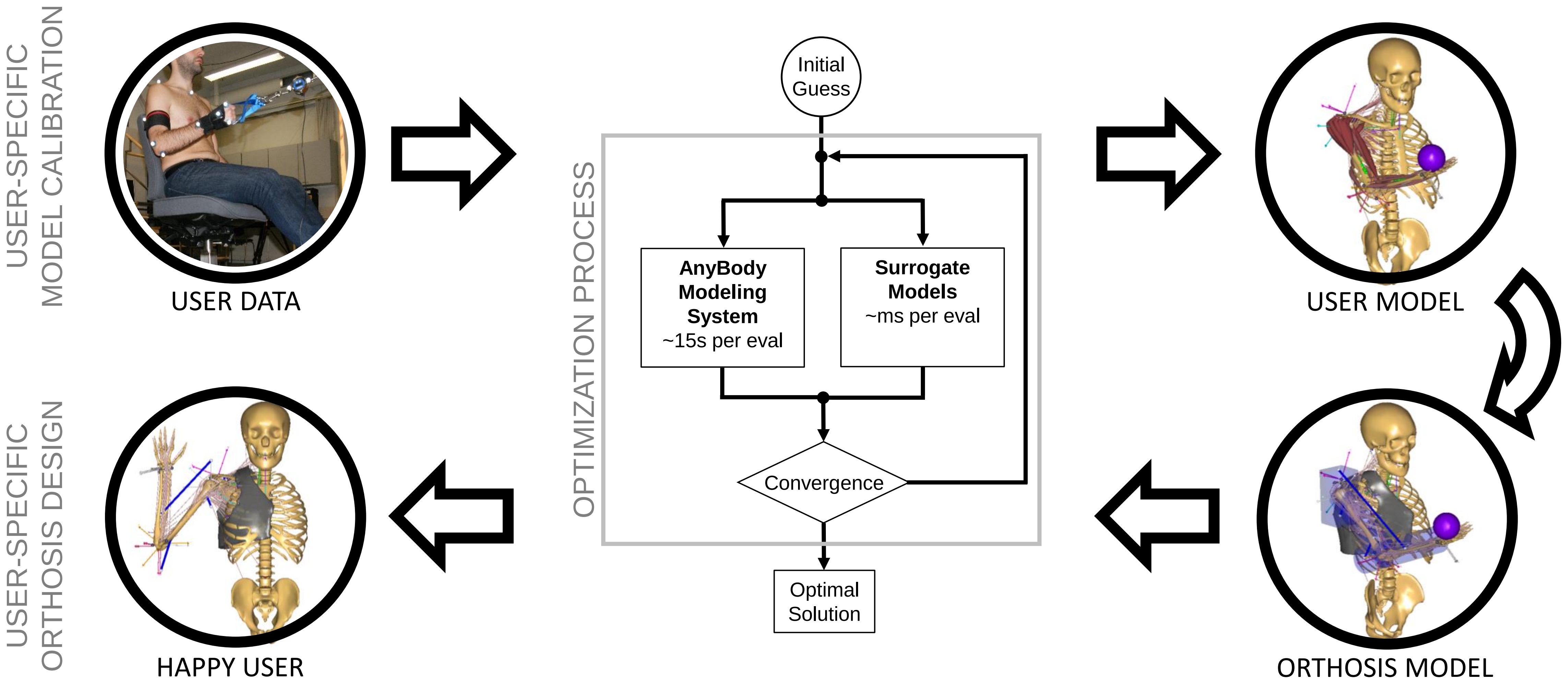
Lack of Autonomy

INDIVIDUAL LEVEL OF IMPAIRMENT

Motivation

Can musculoskeletal modeling help designing these?

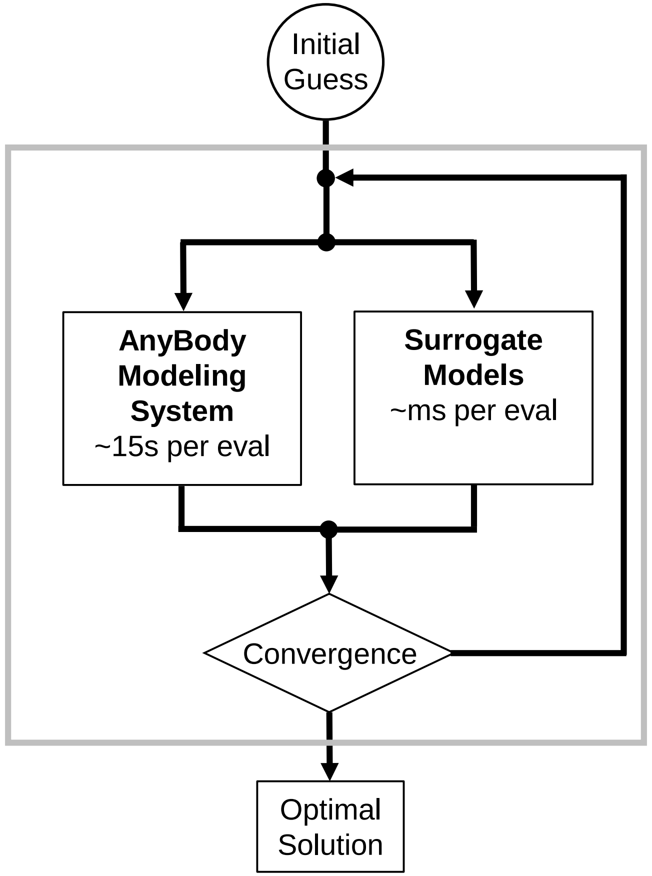
Workflow

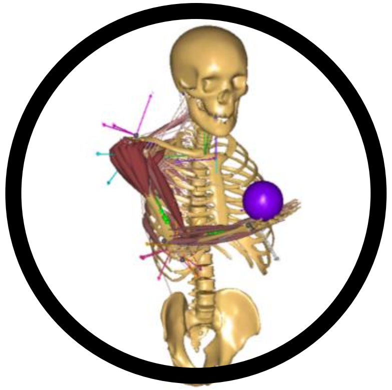

USER-SPECIFIC
MODEL CALIBRATION
USER DATA
OPTIMIZATION PROCESS
Initial Guess
AnyBody Modeling System
~15s per eval
Surrogate Models
~ms per eval
Convergence
Optimal Solution
USER MODEL
ORTHOSIS MODEL
USER-SPECIFIC
ORTHOSIS DESIGN
HAPPY USER

Subject-specific Modelling

USER-SPECIFIC
MODEL CALIBRATION

USER DATA



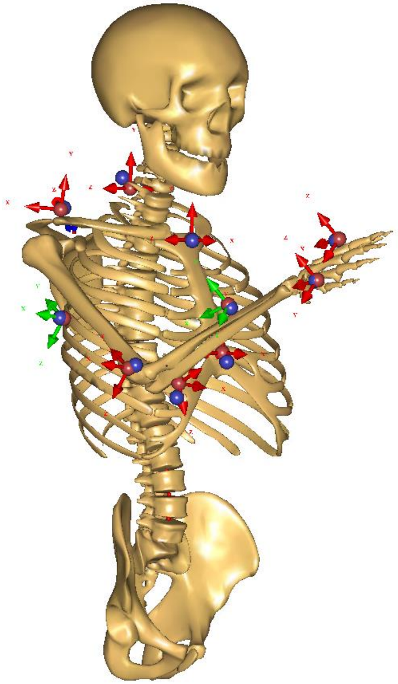


USER MODEL

What is the reachable workspace?

The reachable 3-D workspace of a manipulator is described as the region that the origin of the end-effector's frame (a point in the hand for the case of the upper extremity) can reach with at least one orientation, and this volume is typically used as a robot performance metric (Siciliano et al., 2009).

Anatomically speaking, the human RWS can be estimated from a reference point in the hand or wrist (Lenarcic and Umek, 1994).

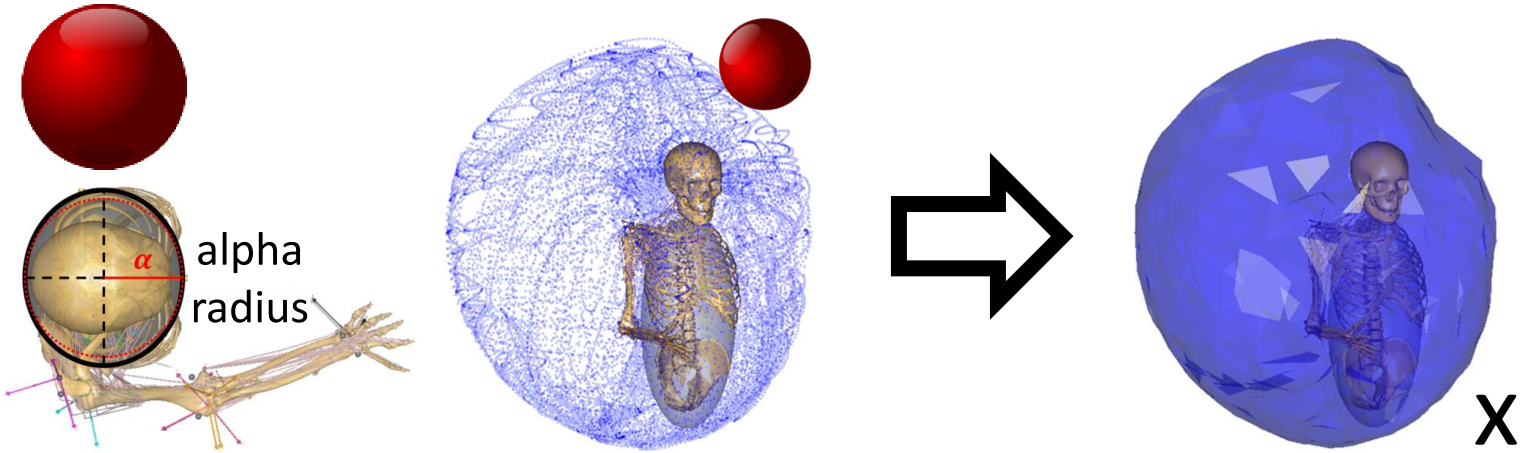


A novel protocol to measure the RWS

1. FIVE REACHING TASKS

Vertical | Horizontal | Shower | Curls | Free Motion

2. ALPHA SHAPE POINT CLOUD



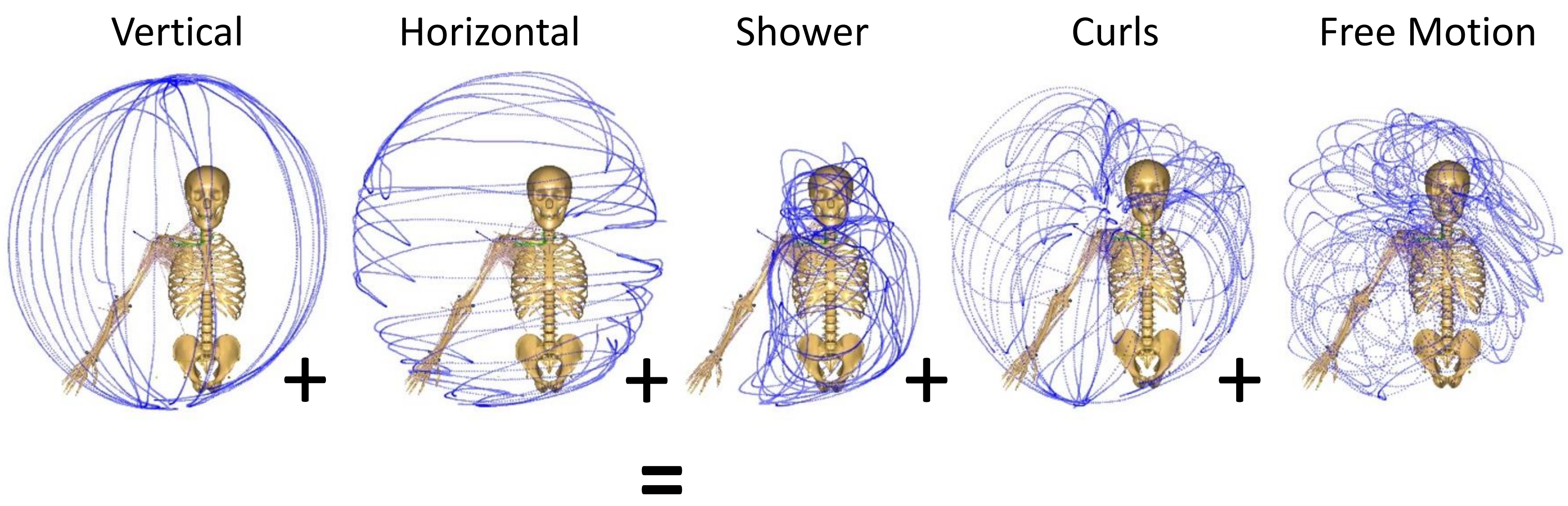
FOUR LOAD CASES

- No Payload
- Load Case 1
- Load Case 2
- Load Case 3

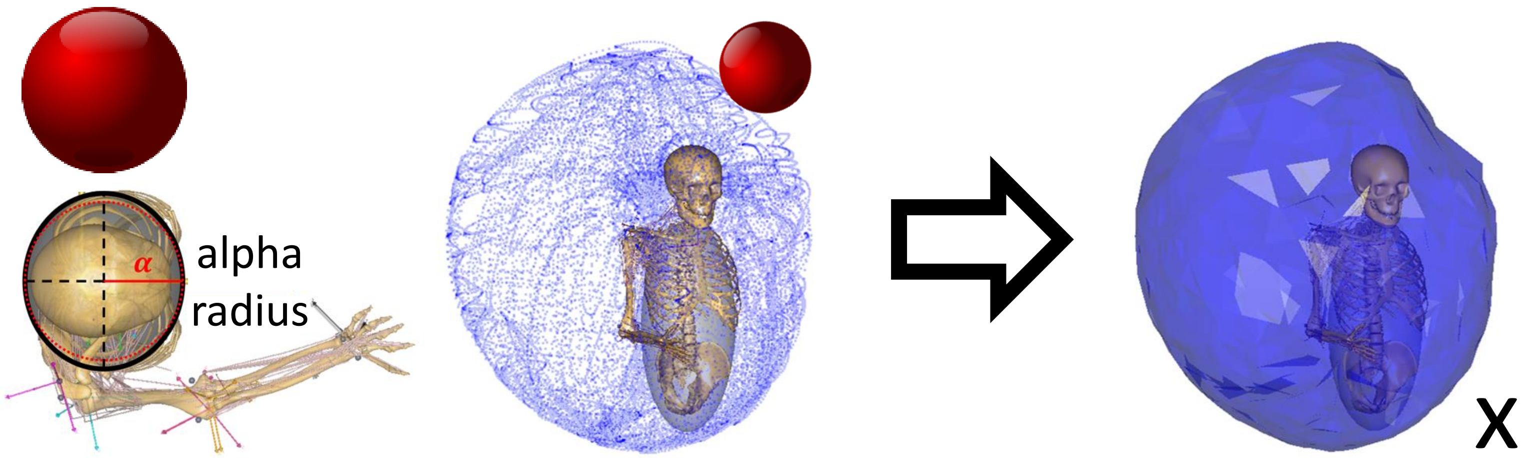
[Castro et al., J App Erg. 2018 – Under Review]

New protocol to measure the RWS

1. FIVE REACHING TASKS



2. ALPHA SHAPE POINT CLOUD



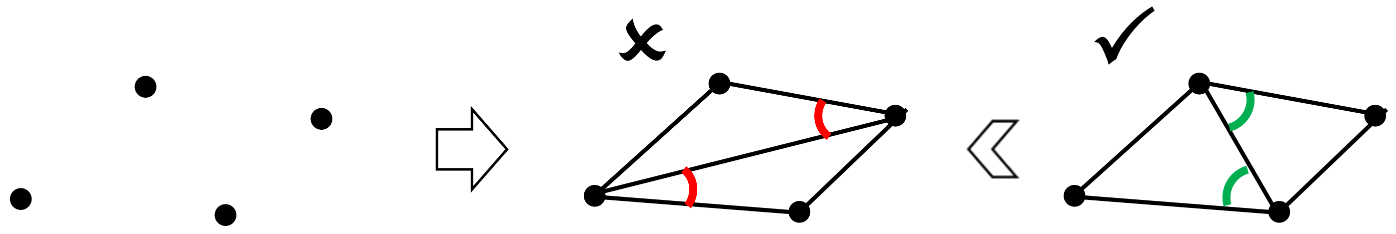
FOUR LOAD CASES

- No Payload
- Load Case 1
- Load Case 2
- Load Case 3

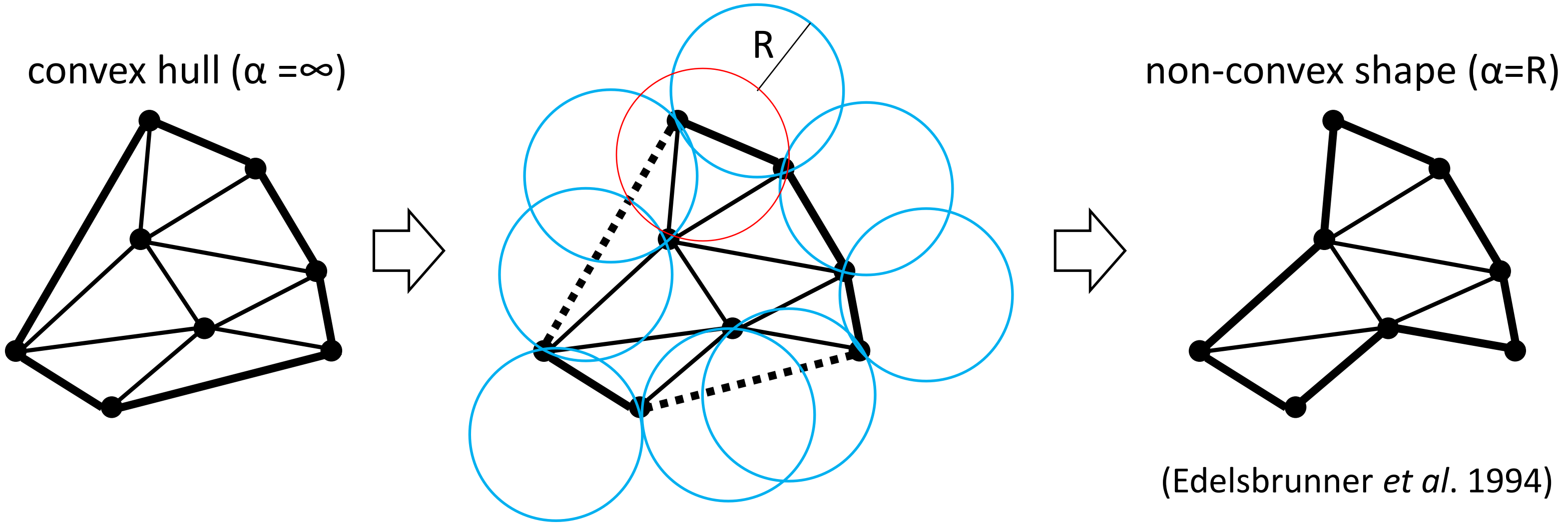
[Castro et al., J App Erg 2018 – Under Review]

The alpha shape of a point cloud

Maximize the minimum angle over the triangles

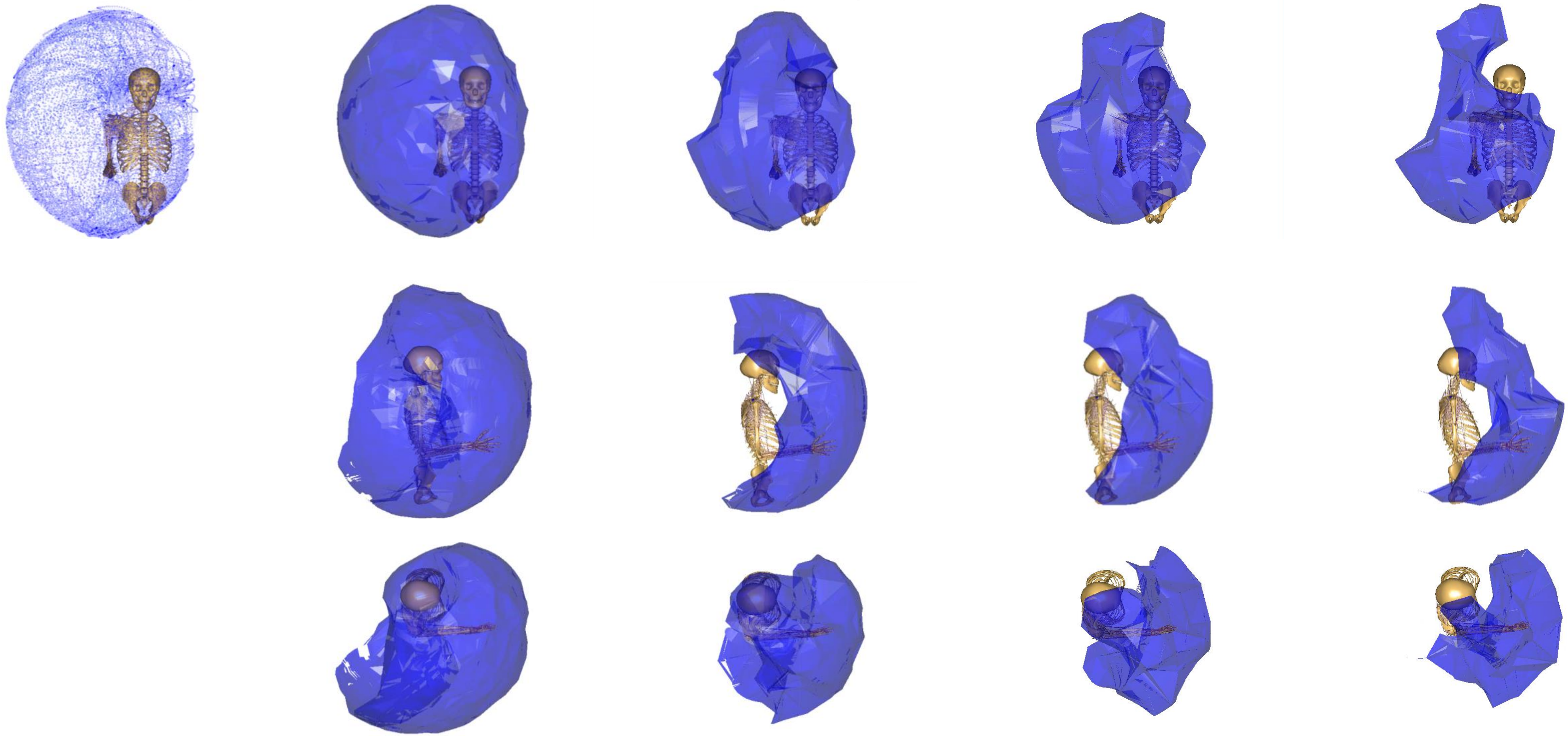


A carving sphere exposes the inner edges of the polygon



(Edelsbrunner *et al*. 1994)

Experimental RWS assessment



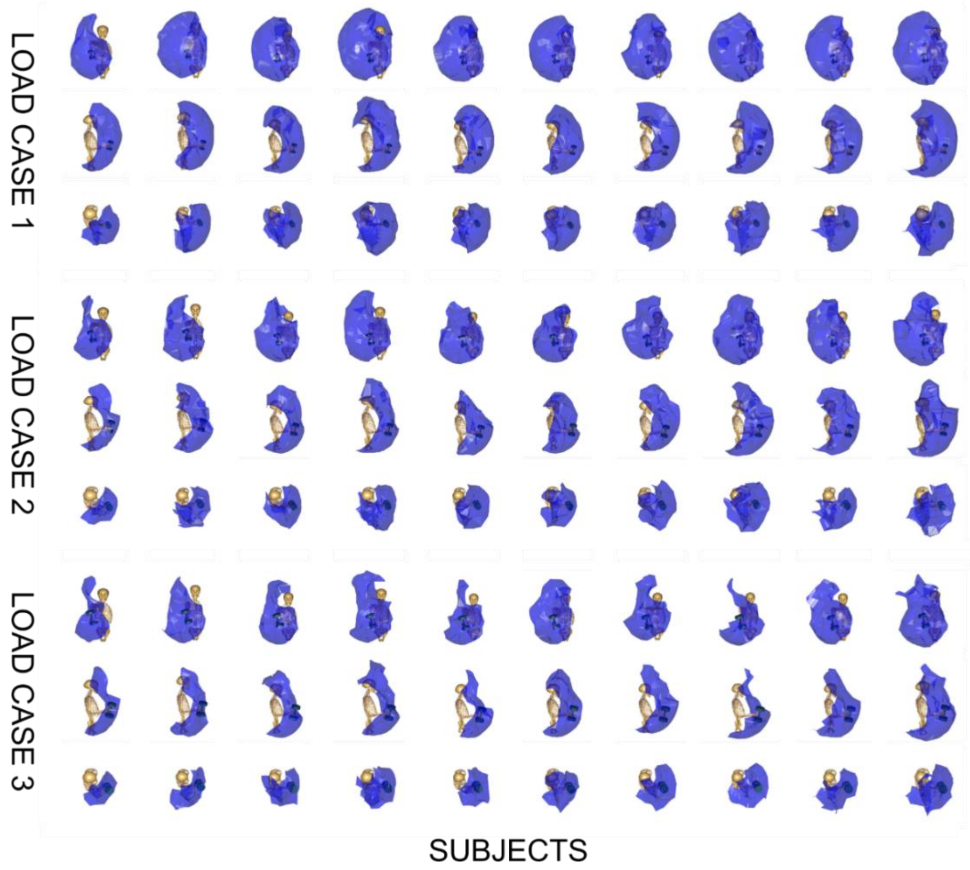
No Payload

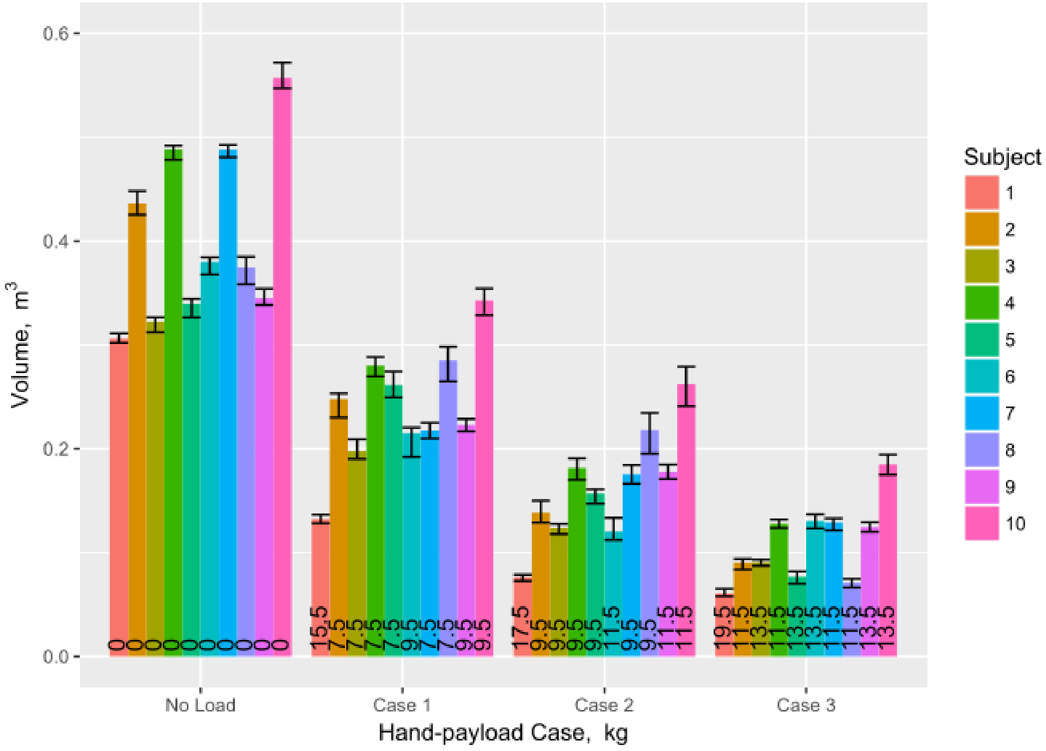
Load Case 1 (7.5 kg)

Load Case 2 (9.5 kg)

Load Case 3 (11.5 kg)

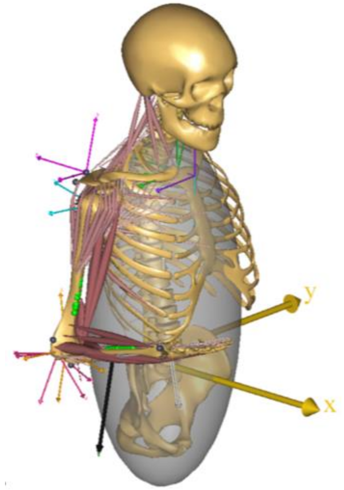
Experimental RWS assessment

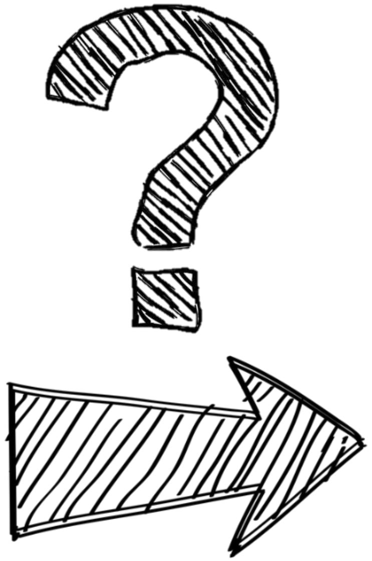


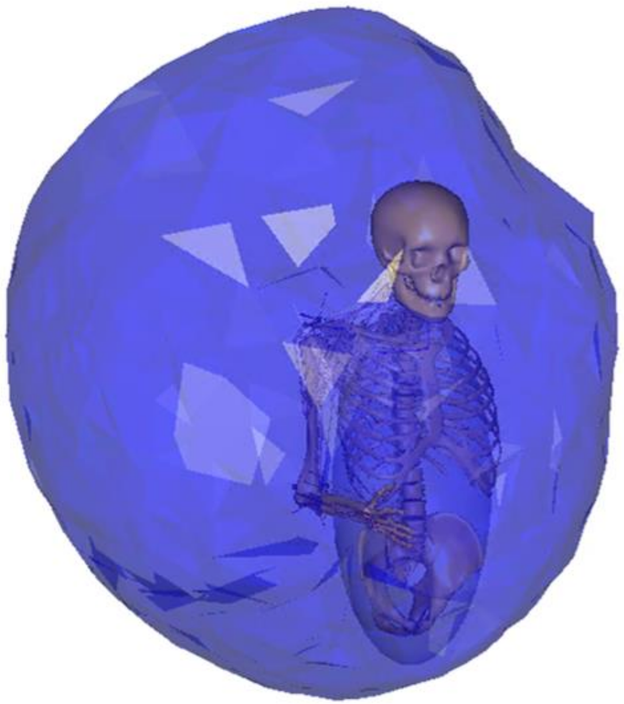


[Castro et al., J App Erg. 2018 – Under Review]

Can we predict the RWS from strength data?





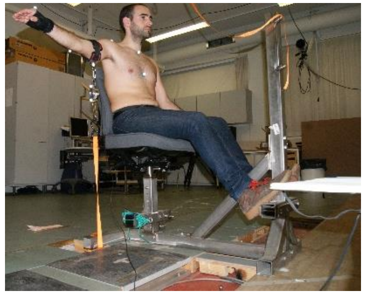


Three force measurements across 12 directions

SC Elevation

GH Flexion

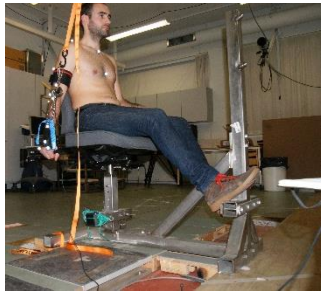
GH Abduction



GH Ext Rot

E Flexion

Push



SC Depression

GH Extension

GH Adduction

GH Int Rot

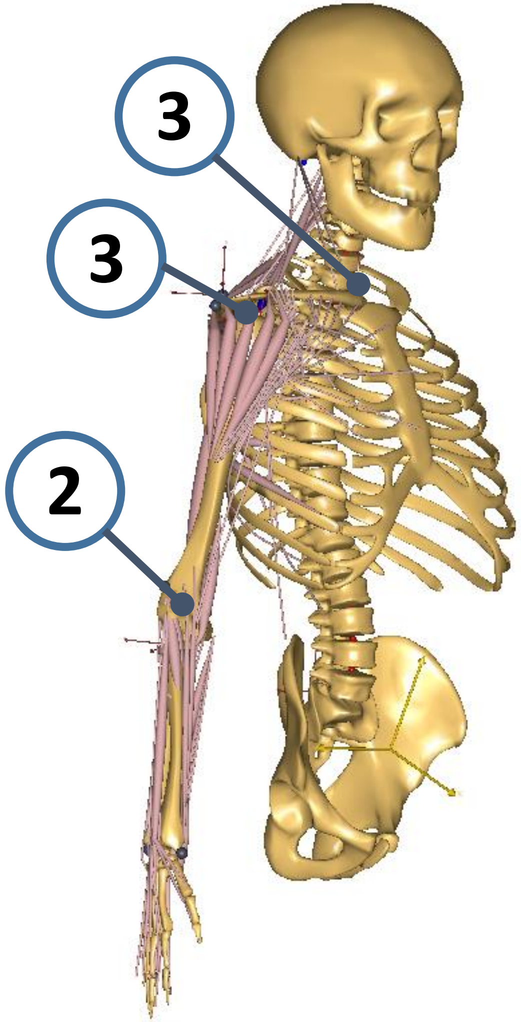
E Extension

Pull

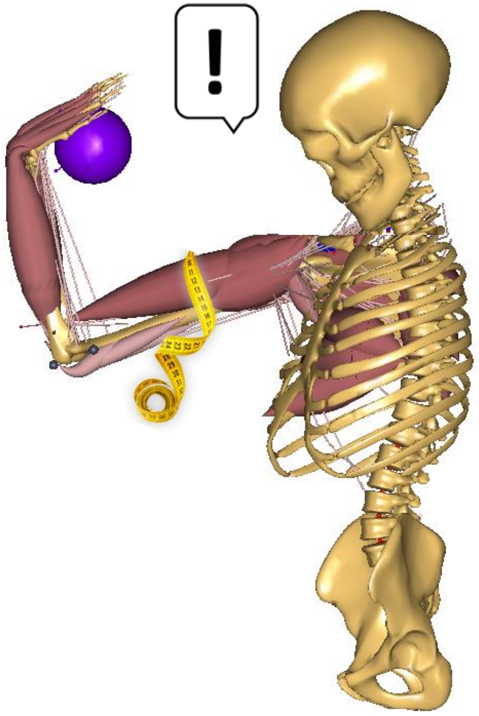
36 measurements

Muscle recruitment criteria

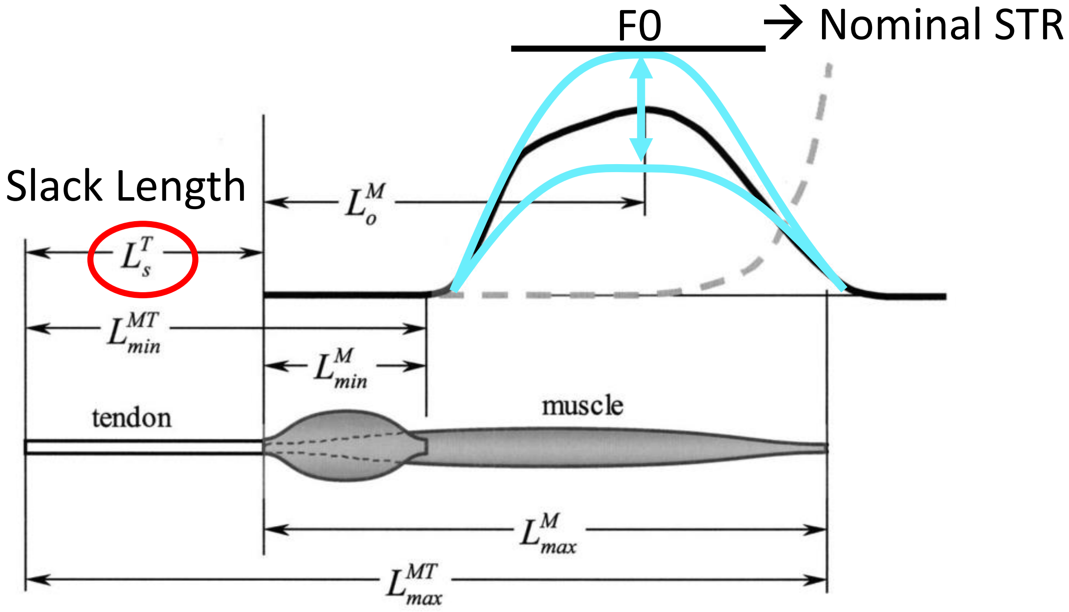
- Right arm model of ‘*Standing Model*’
- *8 degrees-of-freedom (DOF)*
- *Length-Mass-Fat scaling law*
- 3-elements muscle model
- Min/Max polynomial criterion (p=3)
- One step tendon length calibration



Calibrating and adjusting the model…




```
AnyMuscleModel3E biceps_brachii_caput_longum = {
  AnyVar JSF = DesignVar(1.0); //MNC
  AnyVar PCSA = 178.000000; // mm^2 VU study
  F0 = JSF*.StrengthScaleHumerus*PCSA*.ConstParam.MusStress;
  Lmbar = 0.10000; // Yamaguchi
  Lt0 = 0.1; // Estimated
  Gammabar = (pi/180)* 2.000000; // Estimated
  Epsilonbar = EpsilonbarTemp;
  K1 = K1Temp;
  K2 = K2Temp;
  Fcfast = FcfastTemp;
  Jt = JtTemp;
  Jpe = JpeTemp;
  PEFactor = PEFactorTemp;
};
```



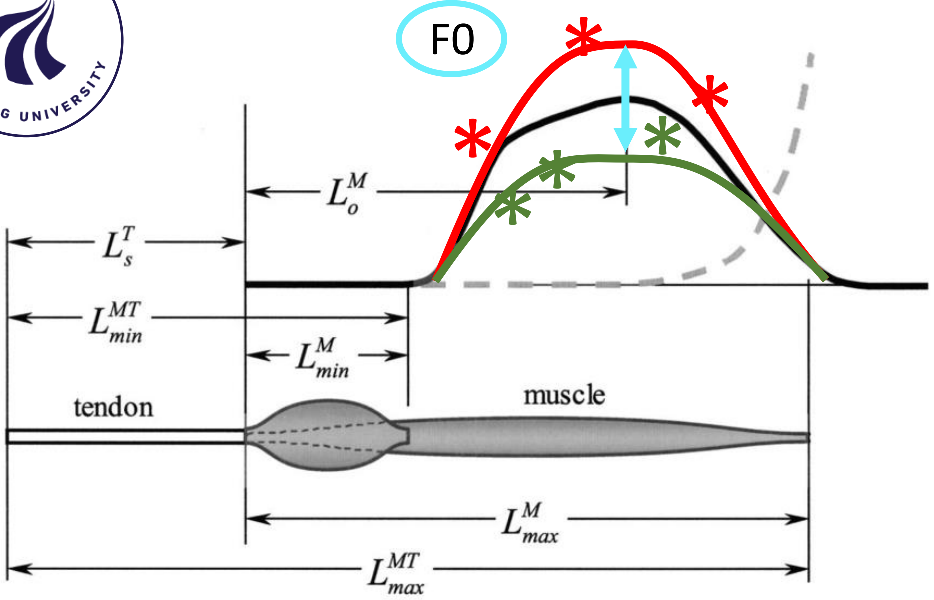
Adapted from Garner and Pandy (2003)

Grouping Muscles by JSF

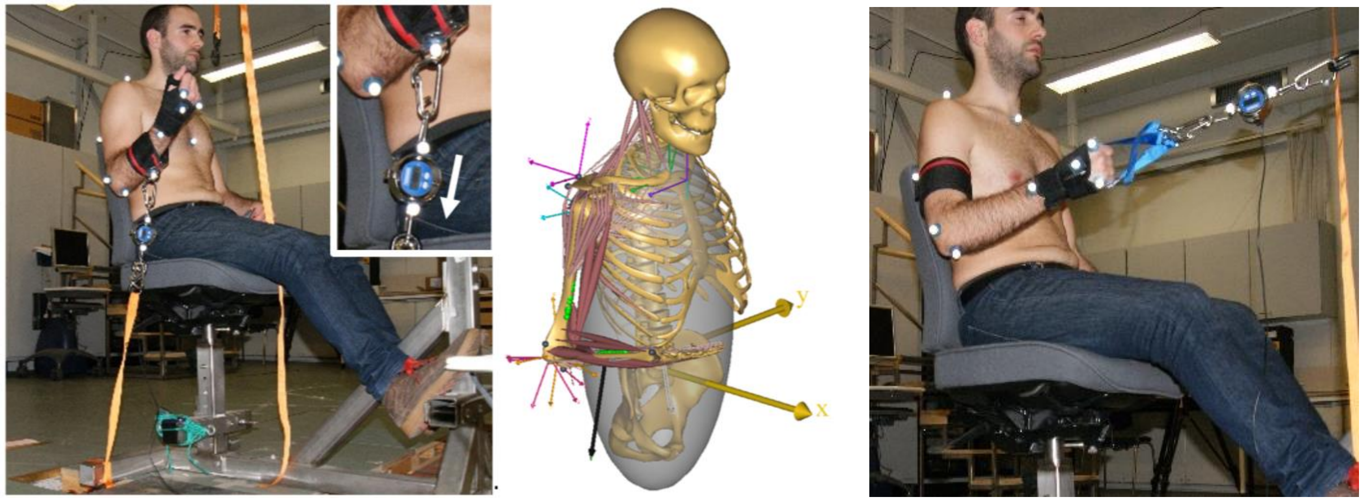
```
//Global
AnyVar JSF_Global = DesignVar(1.0);

//Arm
AnyVar JSF_ScaStabAnt = DesignVar(1.0);
AnyVar JSF_ScaStabPos = DesignVar(1.0);

AnyVar JSF_SCPro = DesignVar(1.0);
AnyVar JSF_SCRet = DesignVar(1.0);
AnyVar JSF_SCEle = DesignVar(1.0);
AnyVar JSF_SCDep = DesignVar(1.0);

AnyVar JSF_GHFle = DesignVar(1.0);
AnyVar JSF_GHExt = DesignVar(1.0);
AnyVar JSF_GHAbd = DesignVar(1.0);
AnyVar JSF_GHAdd = DesignVar(1.0);
AnyVar JSF_GHExtRot = DesignVar(1.0);
AnyVar JSF_GHIntRot = DesignVar(1.0);

AnyVar JSF_EFle = DesignVar(1.0);
AnyVar JSF_EExt = DesignVar(1.0);
AnyVar JSF_EPro = DesignVar(1.0);
AnyVar JSF_ESup = DesignVar(1.0);

AnyVar JSF_WStab = DesignVar(1.0);
```

= 18-D problem!

```
// Biceps brachii long head #1
AnyVar biceps_brachii_caput_longum_prod = MSF_biceps_brachii_caput_longum * JSF_Global * (JSF_GHFle * JSF_EFle * JSF_ESup);

// Run JSF BasicOptStudy
AnyOperationSequence RunJSF_BasicOptSequence = {
  AnyOperationMacro load = {MacroStr={ "classoperation Main.MuscleStrengthSettings.DefaultMuscleStrengthStudy " + strquote("Load design") + " --file=" + strquote(SUBJECT_PATH + "Calib3E.txt")};};
  AnyOperation& SetJointStrengthFactors = .SetJointStrengthFactors;
  AnyOperationMacro update = {MacroStr={ "classoperation Main " + strquote("Update Values") };};

  AnyOperation& InvDyn = ..Study.InverseDynamics;

  AnyOperationMacro dump1 = {MacroStr = { "classoperation Main.Study.MaxMuscleActivity"+ strquote("Dump")};};
  AnyOperationMacro dump2 = {MacroStr = { "classoperation Main.Study.NodesOfInterest.PalmNode_Thorax.Pos"+ strquote("Dump")};};
  AnyOperationMacro dump3 = {MacroStr = { "classoperation Main.Study.NodesOfInterest.ElbowNode_Thorax.Pos"+ strquote("Dump")};};
};
```



* Posture A * Posture B

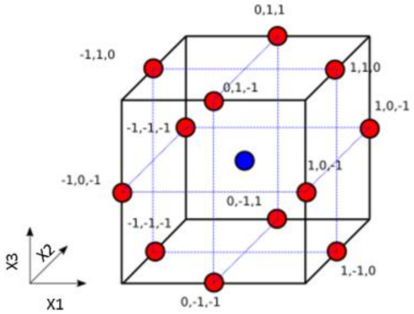


(2x3 postures about the direction of each 6 DOFs)
=36 measurements

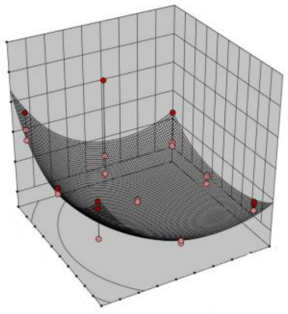
OPTIMIZATION GOAL

$$\min_{\boldsymbol{x}^*_{JSF}} f(\boldsymbol{x}) = \sum_{i=1}^{36} (MMACT_i - 1)^2$$

Box-Behnken design



Quadratic Response Surface



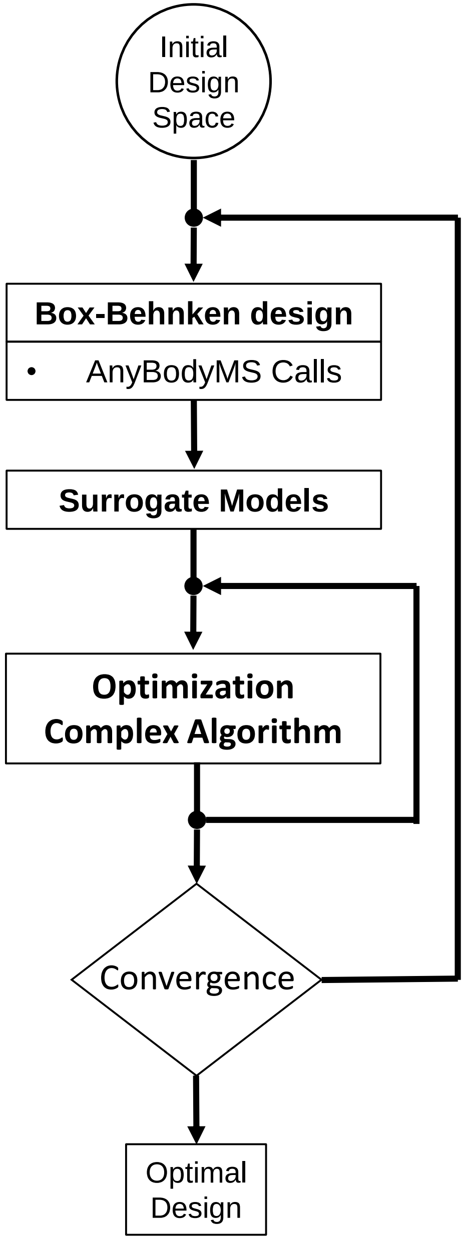
3 Design Variables ➢ 10 coefficients ➢ 13 samples

$$y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4\,x_1x_2 + a_5x_1x_3 + a_6x_2x_3 + a_7\,x_1^2 + a_8x_2^2 + a_9x_3^2$$

18 Design Variables ➢ 343 coefficients ➢ 624 samples…

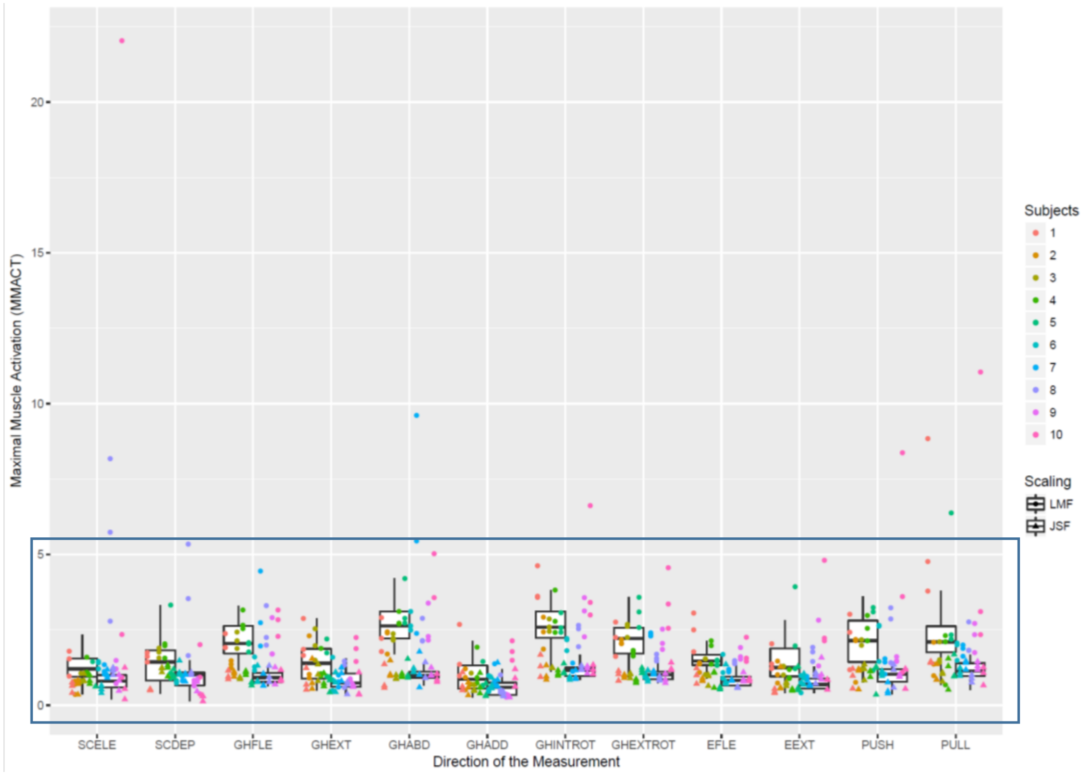
… x**36** = **22,464 samples!!! (…or AMS calls)**

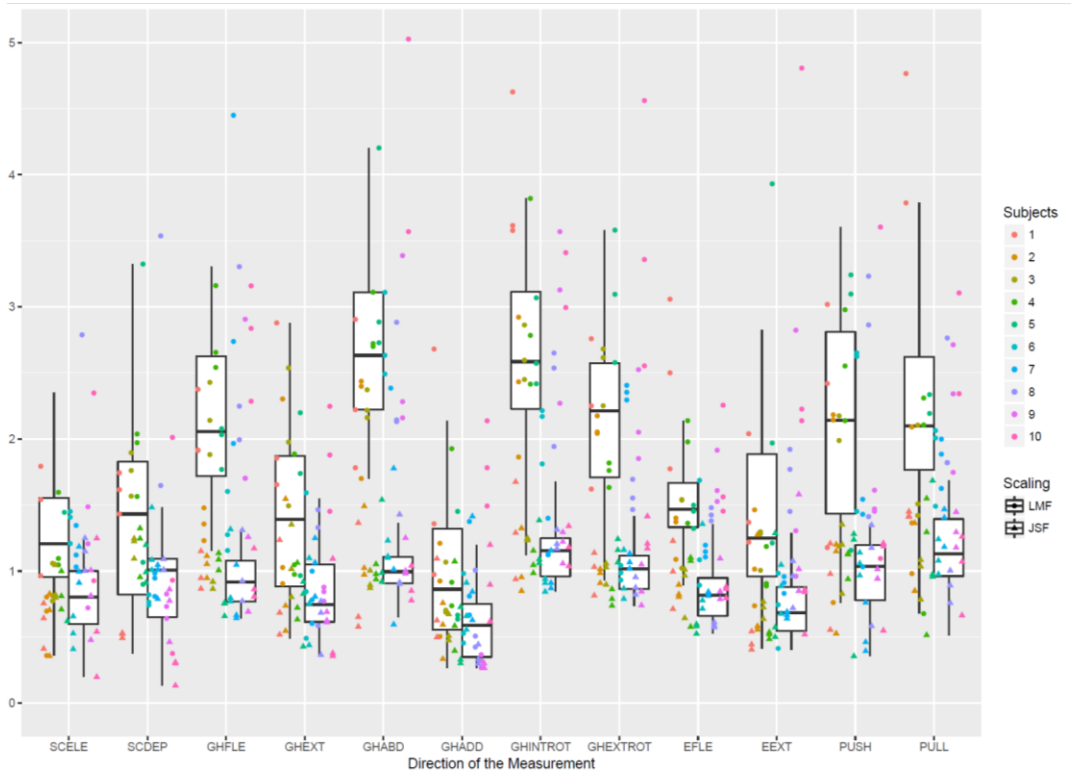
Optimization Step



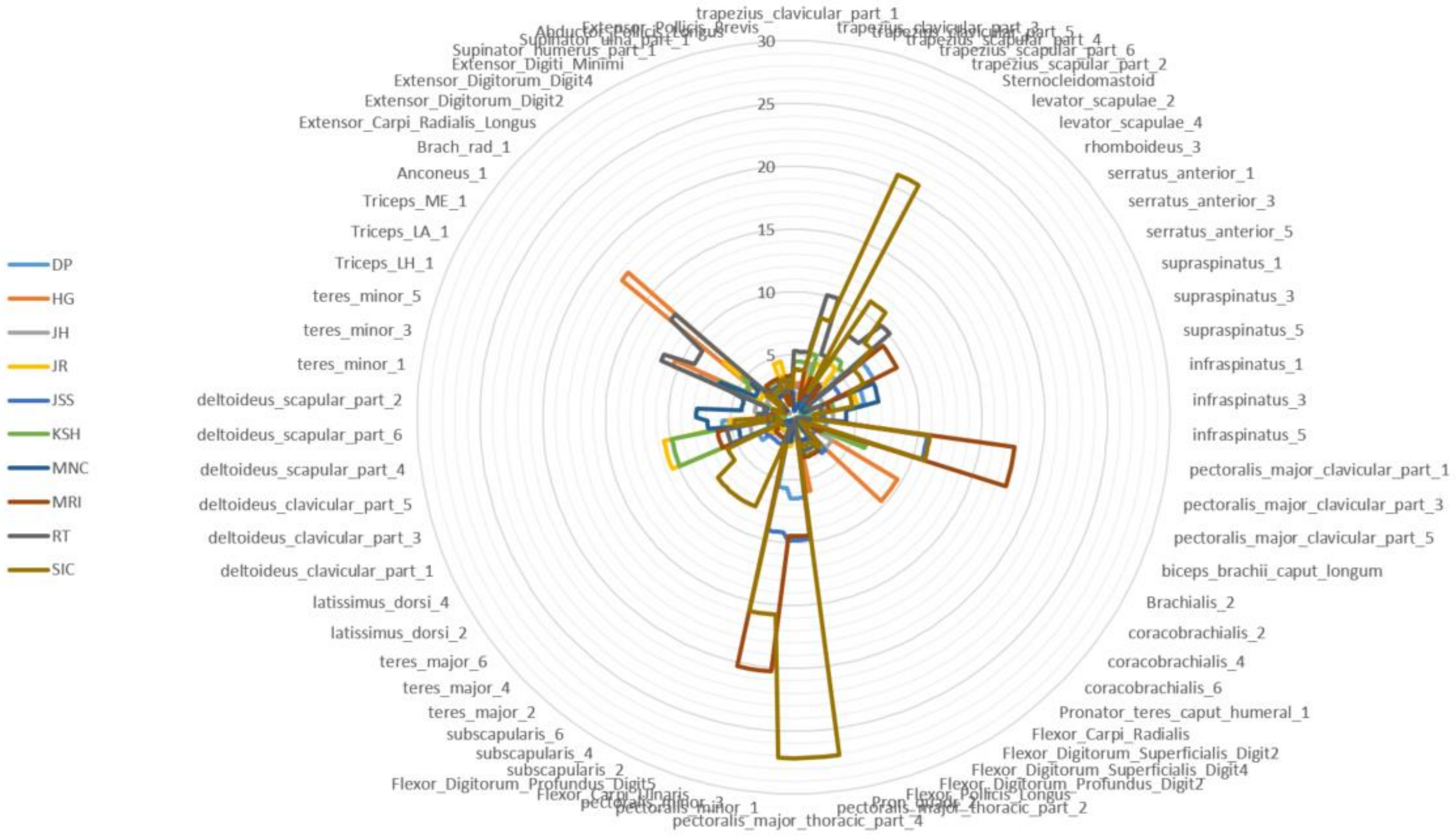
The MMACT for the 36 postures across subjects

$$\min_{\boldsymbol{x}^*_{JSF}} f(\boldsymbol{x}) = \sum_{i=1}^{36} (MMACT_i - 1)^2$$





The optimized Joint Strength Factors (JSF)



How to simulate the RWS? How to compare them?

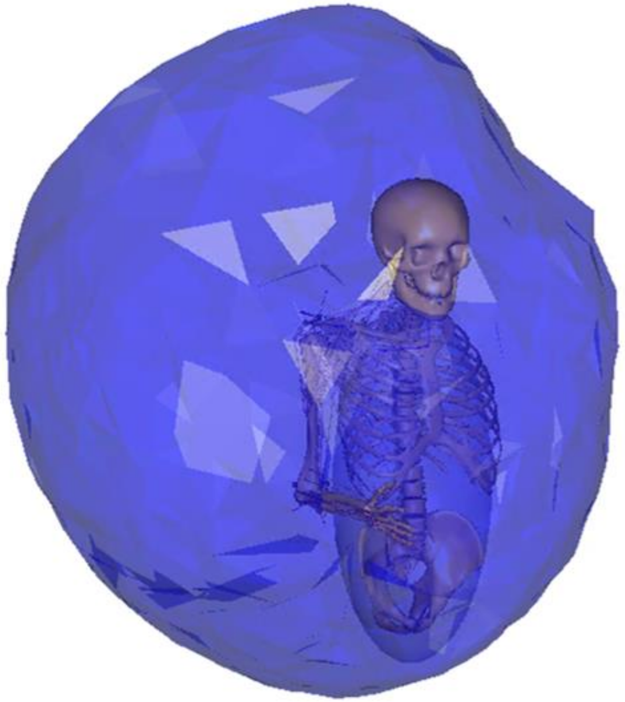
Experimental RWS

X

"Length-Mass-Fat (LMF) only scaled" model RWS

X

"Joint Strength Factor (JSF) scaled" model RWS

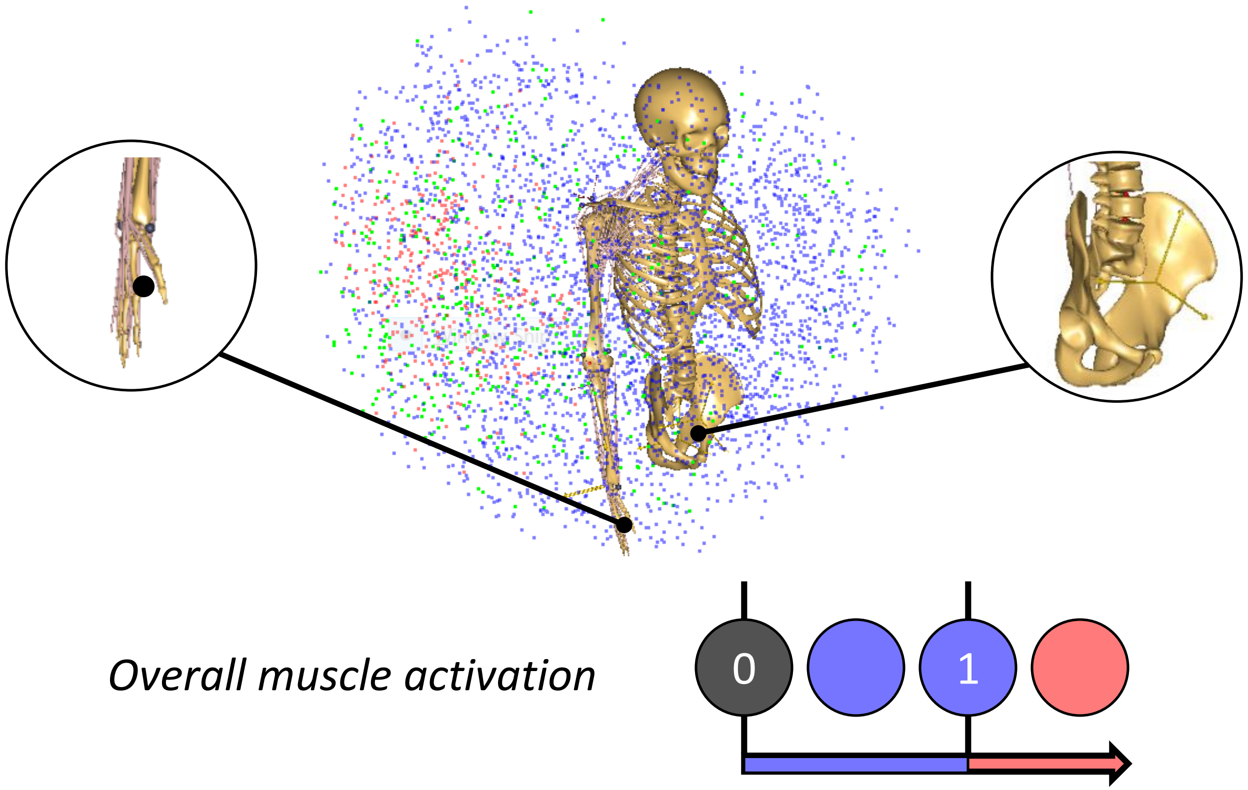


How to simulate the RWS?

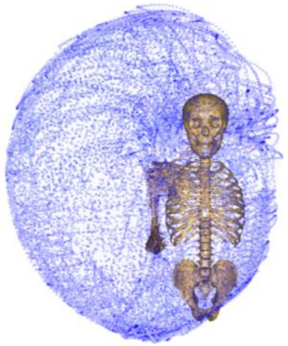
Inverse

Dynamic

Analyses

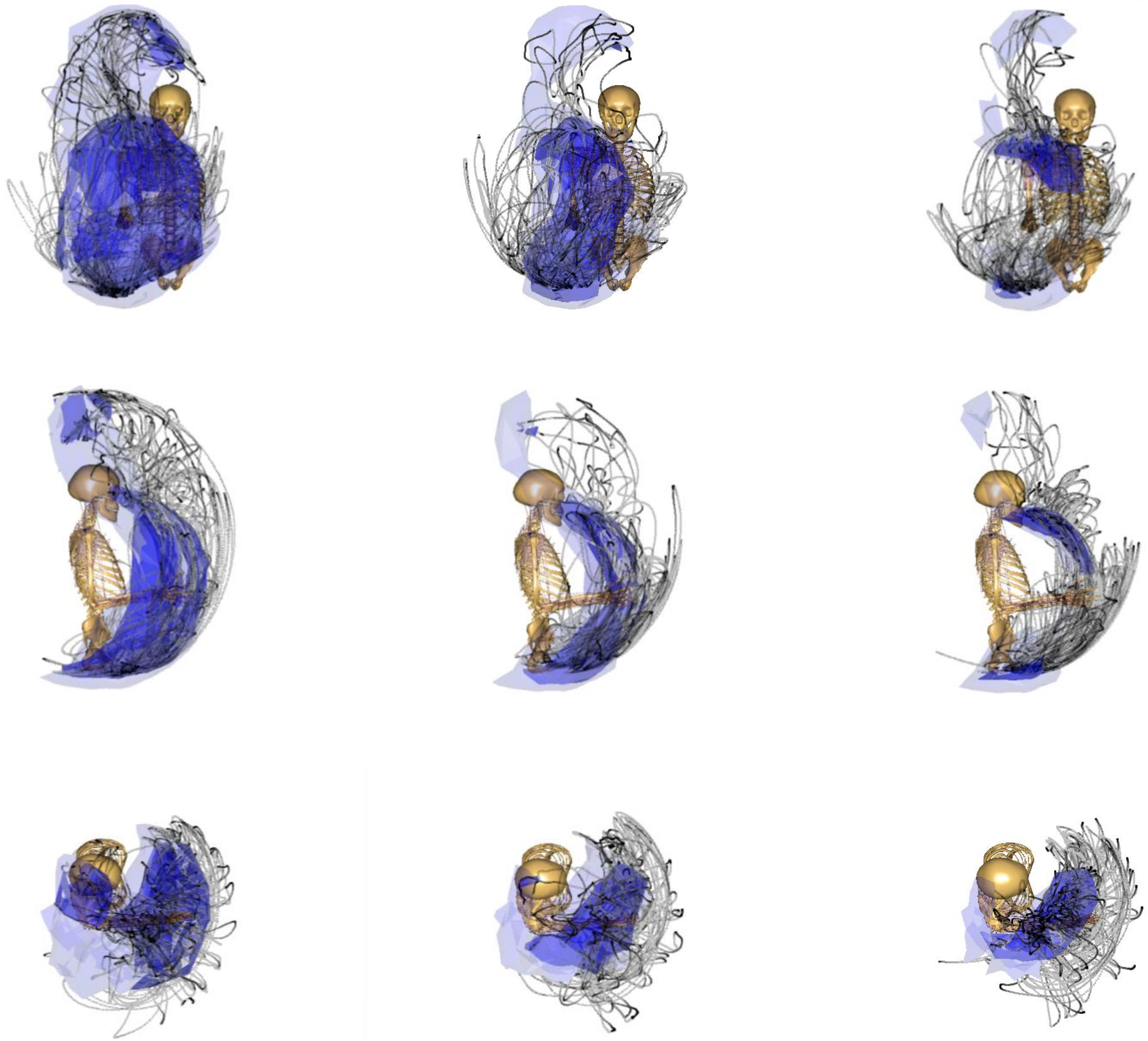


The RWS for a model only LMF scaled



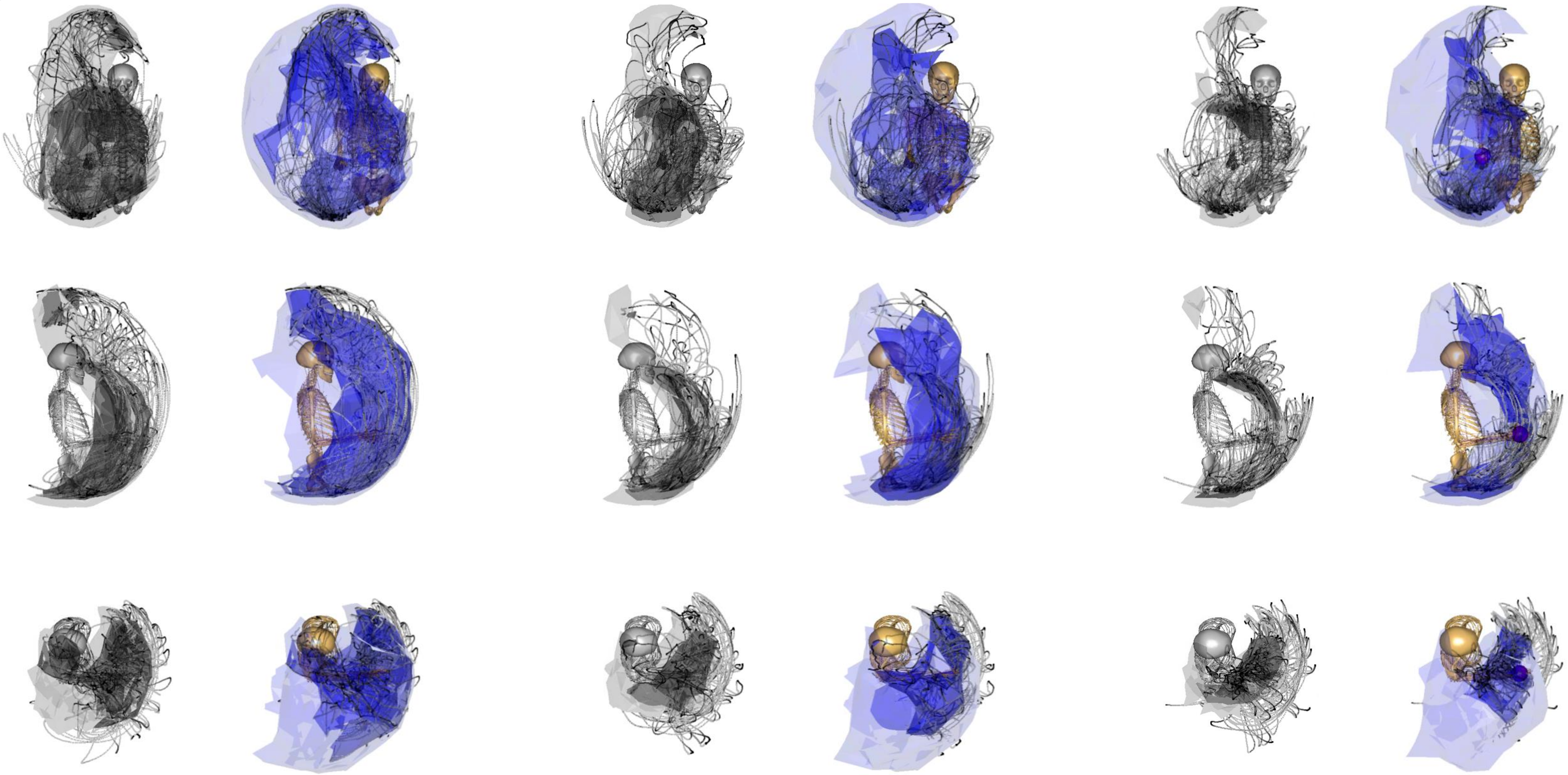
ROM000

- Case Mocap
- Case ROM
- Full ROM



Load case 1 | Load Case 2 | Load Case 3

The RWS for a model LMF and JSF scaled



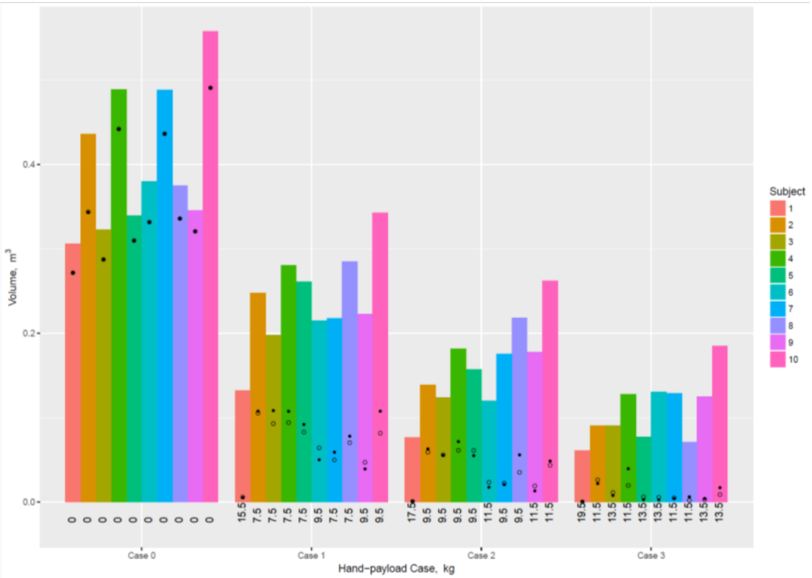
Load case 1

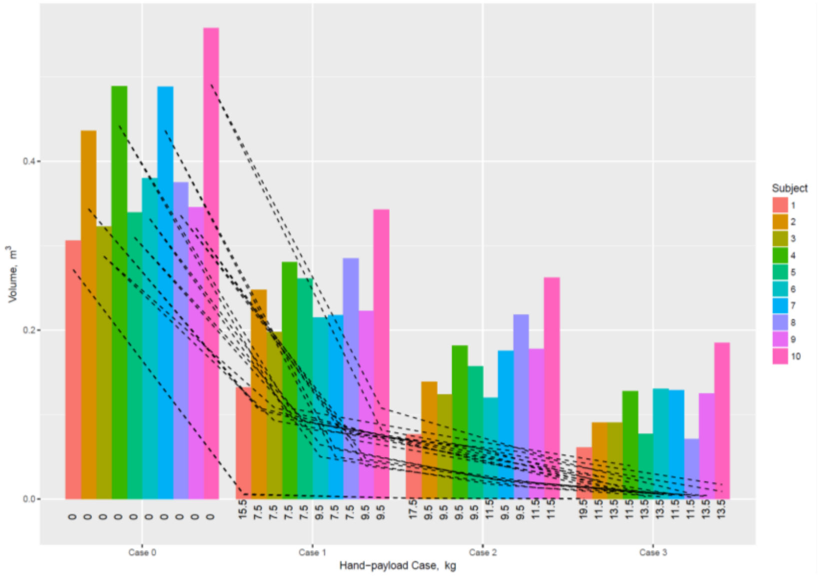
Load Case 2

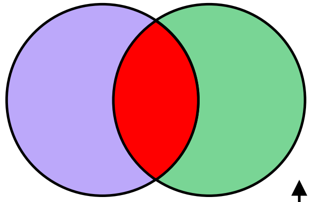
Load Case 3

How well does the predicted volume match the experimental?

LMF

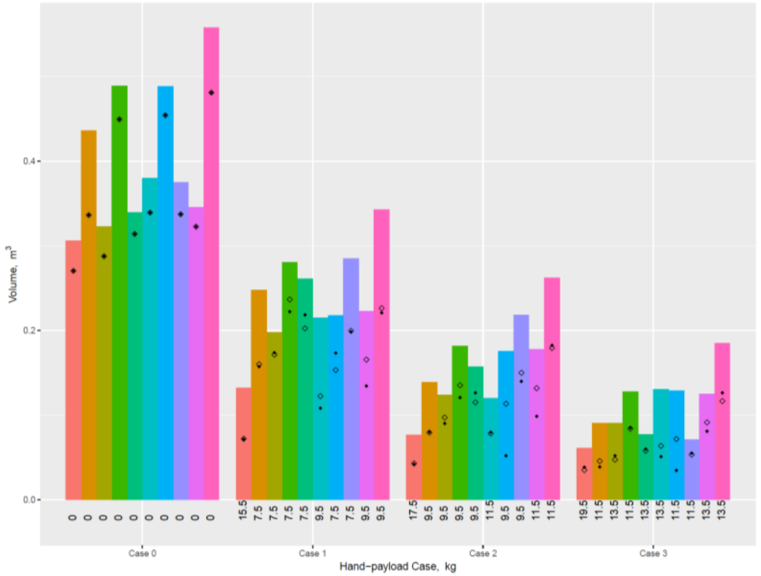


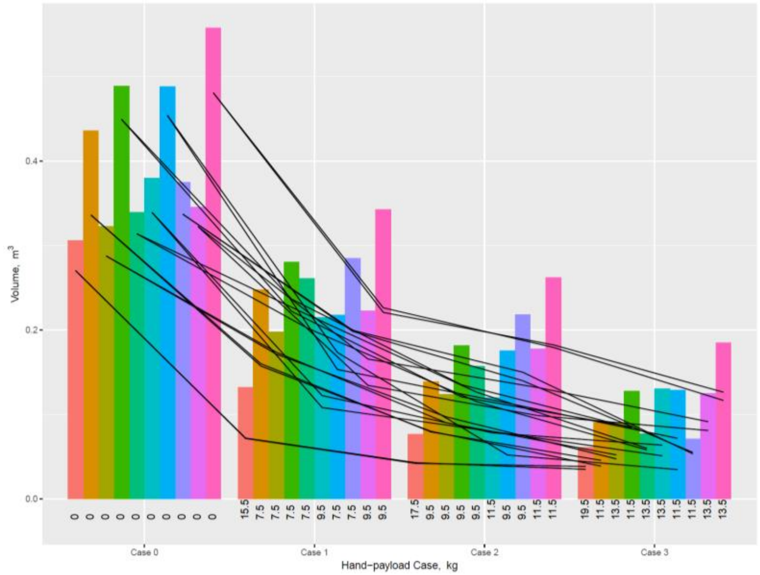




Intersection (exp w/ pred) Volume Vs Experimental Volume

JSF





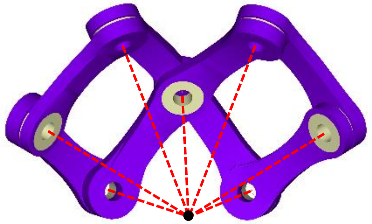
Discussion/Conclusion

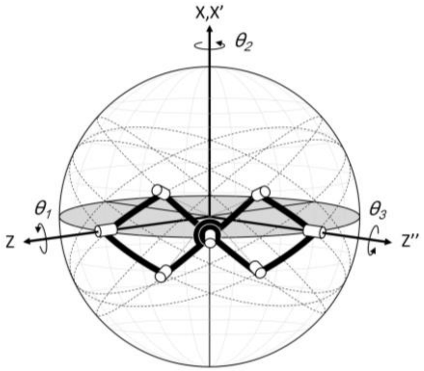
- Models length-mass-fat scaled are generally weak
- The simple one-step calibration method might not be enough
- More experimental data is required to validate this method
- This type of procedures are typically computationally expensive
- Reachable workspace can potentially be a validation tool

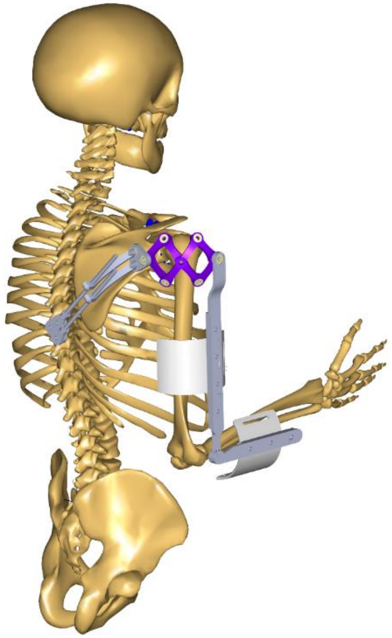
ON THE VALIDATION OF MUSCULOSKELETAL MODELS USING THE ANATOMICAL 3-D REACHABLE WORKSPACE

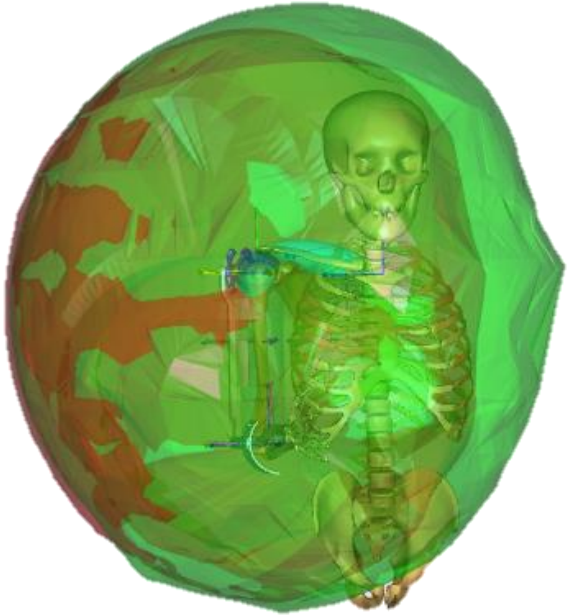
The CXD - Compact X-scissors Device

Compact
X-scissors
Device

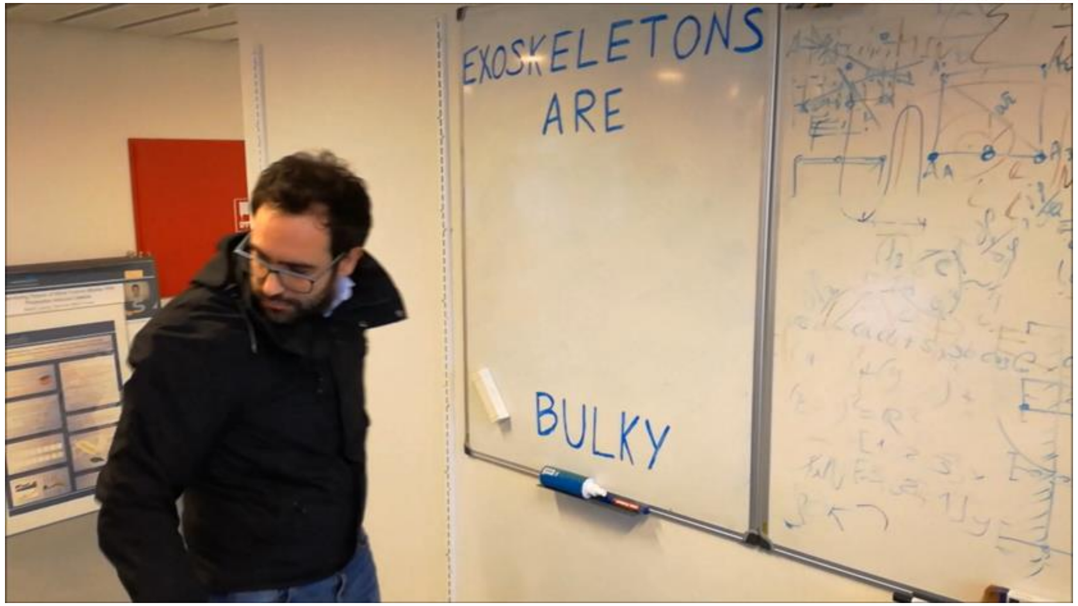






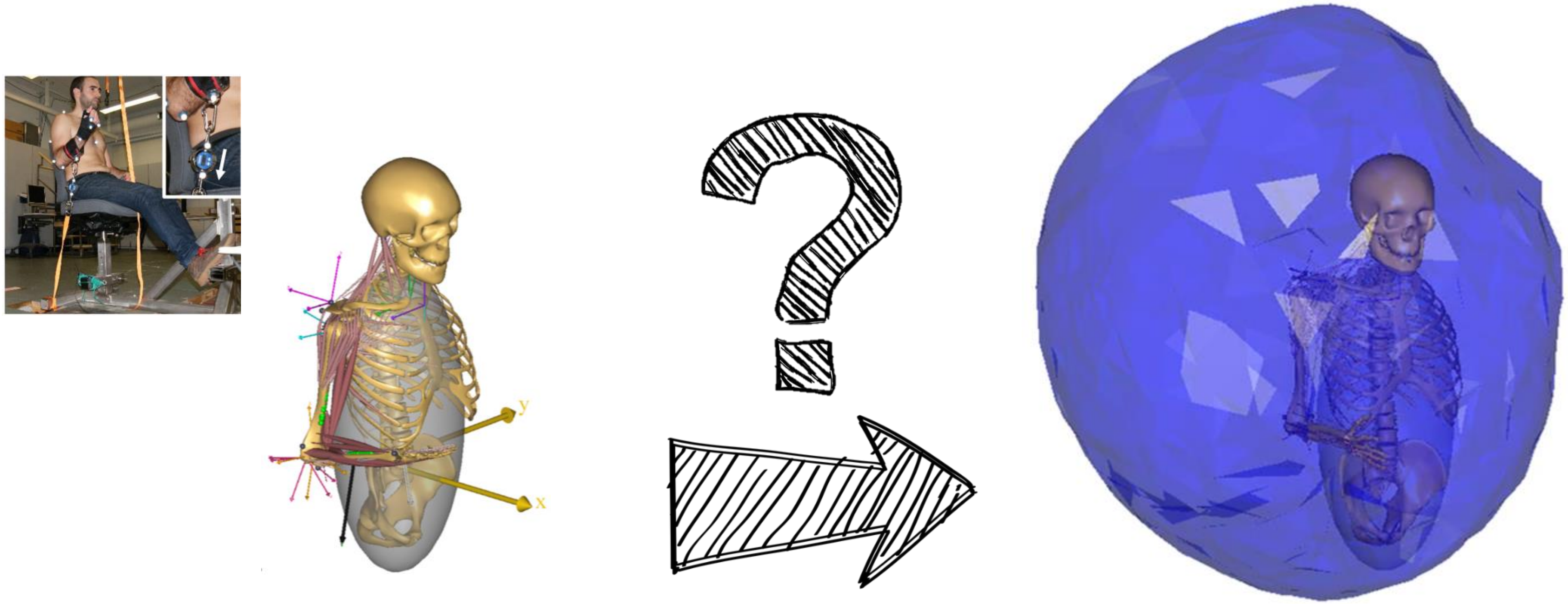


WearRAcon 18
SEE WHAT LEADS



https://youtu.be/67FZox9GxMc
https://youtu.be/Pw_esFdwGmo

ON THE VALIDATION OF MUSCULOSKELETAL MODELS USING THE ANATOMICAL 3-D REACHABLE WORKSPACE



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[1]Dept. Mechanical & Manufacturing Engineering, Aalborg University, Denmark

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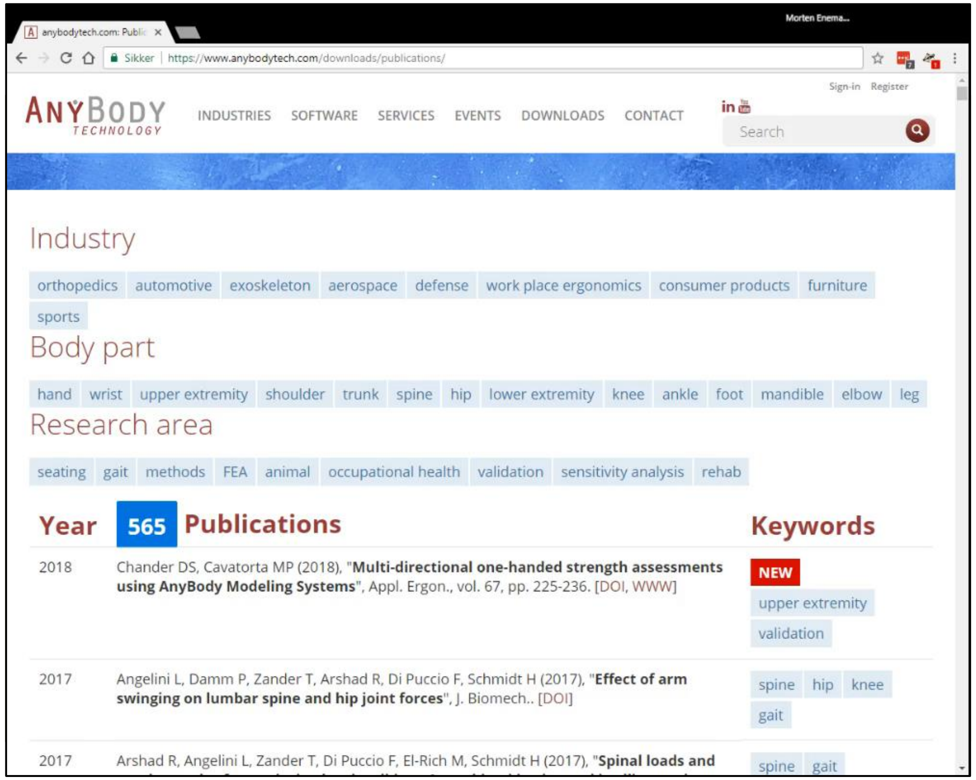
- Events, dates, publication list, ...



Events:

30 Apr- 4 May: Advanced PhD course on Musculoskeletal modeling.

Aalborg University, Denmark (Fully Booked)

7 May- 9 May: Qualisys European user group meeting.

Gothenberg, Sweden

8 Jul - 12 Jul: World Congress of Biomechanics

Booth + live session with Xsens (Outdoor MoCap)

Dublin, Ireland

Meet us? Send email to sales@anybodytech.com

Time for questions: