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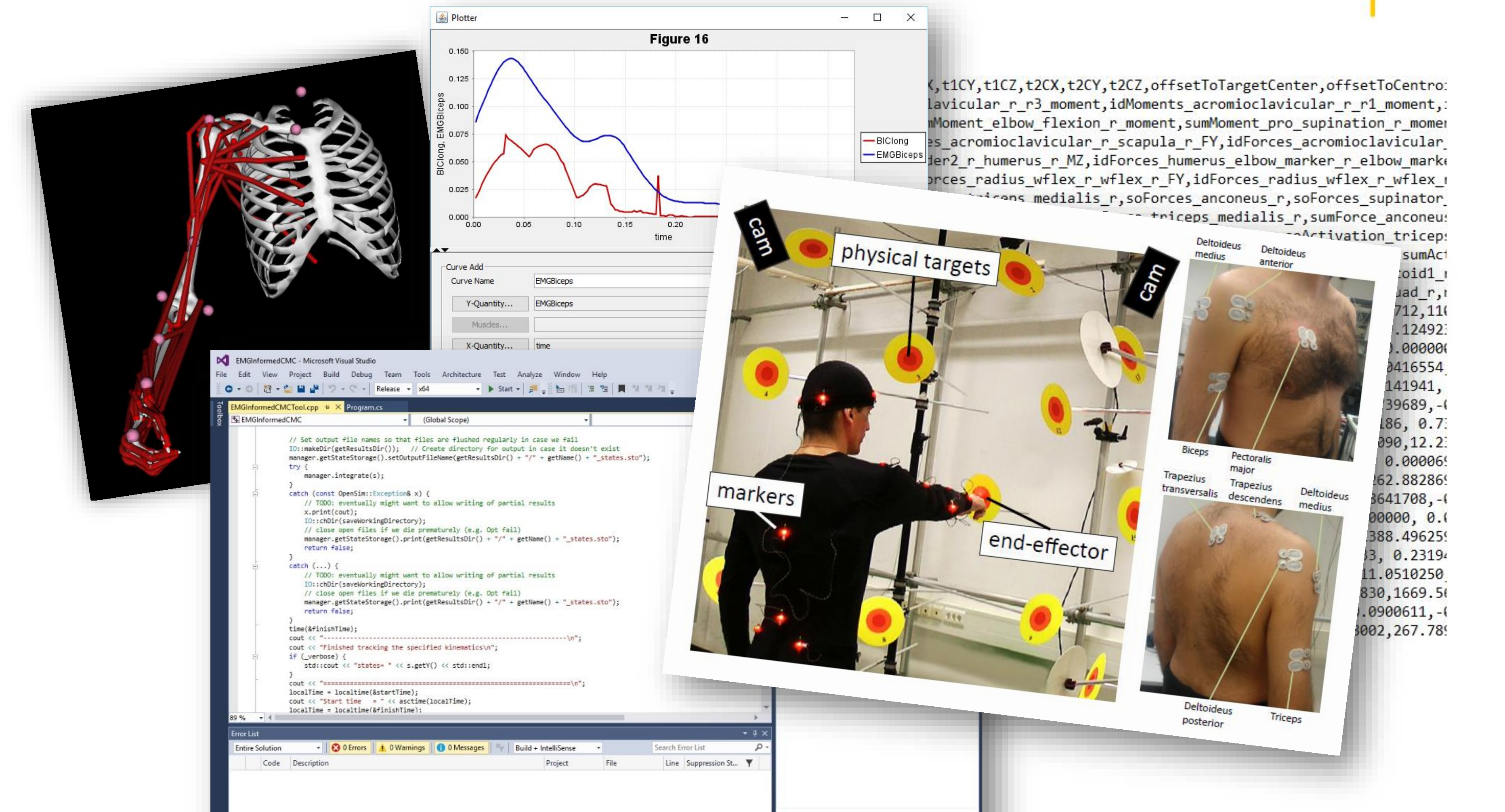

EMG Based Motion Capture [Project]

From Motion Capture to Musculoskeletal Simulation and (not quite) back

Felix Laufer

Recap: Why EMG Based Activation Estimation?

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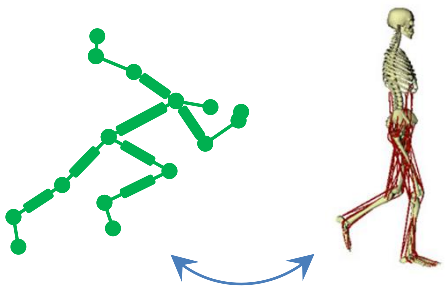


muscular redundancy

$$\sum_{i=1}^{N_m}(a_i)^2 \longrightarrow min$$

s.t. $\forall\, c_j := f^*{}_j - f_{j,\,exp} \approx 0$

classical stress minimization approach

What about …

- co-contraction
- fine motor tasks with higher muscle tension
- extreme (fast) movements
- (temporal / pathological) muscle fatigue **… ?**

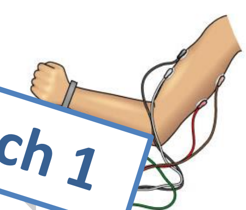
neurophysiological redundancy / activation patterns

$$\sum_{i=1}^{N_m}(a_i)^2 \longrightarrow min$$

s.t. $\forall\, c_j := f^*{}_j - f_{j,\,exp} \approx 0$

$\forall\, c_k := a_k - a_{k,\,exp} \approx 0$

Seminar: Approach 1



EMG informed minimization approach

Project*:* Is **surface EMG** data (sEMG) a **valid estimator** for computed muscle activation **in practice**?

$\forall\, c_k := a_k - a_{k,\,exp} \approx 0$ **?**

Project Setting & Motivation – MPI Study

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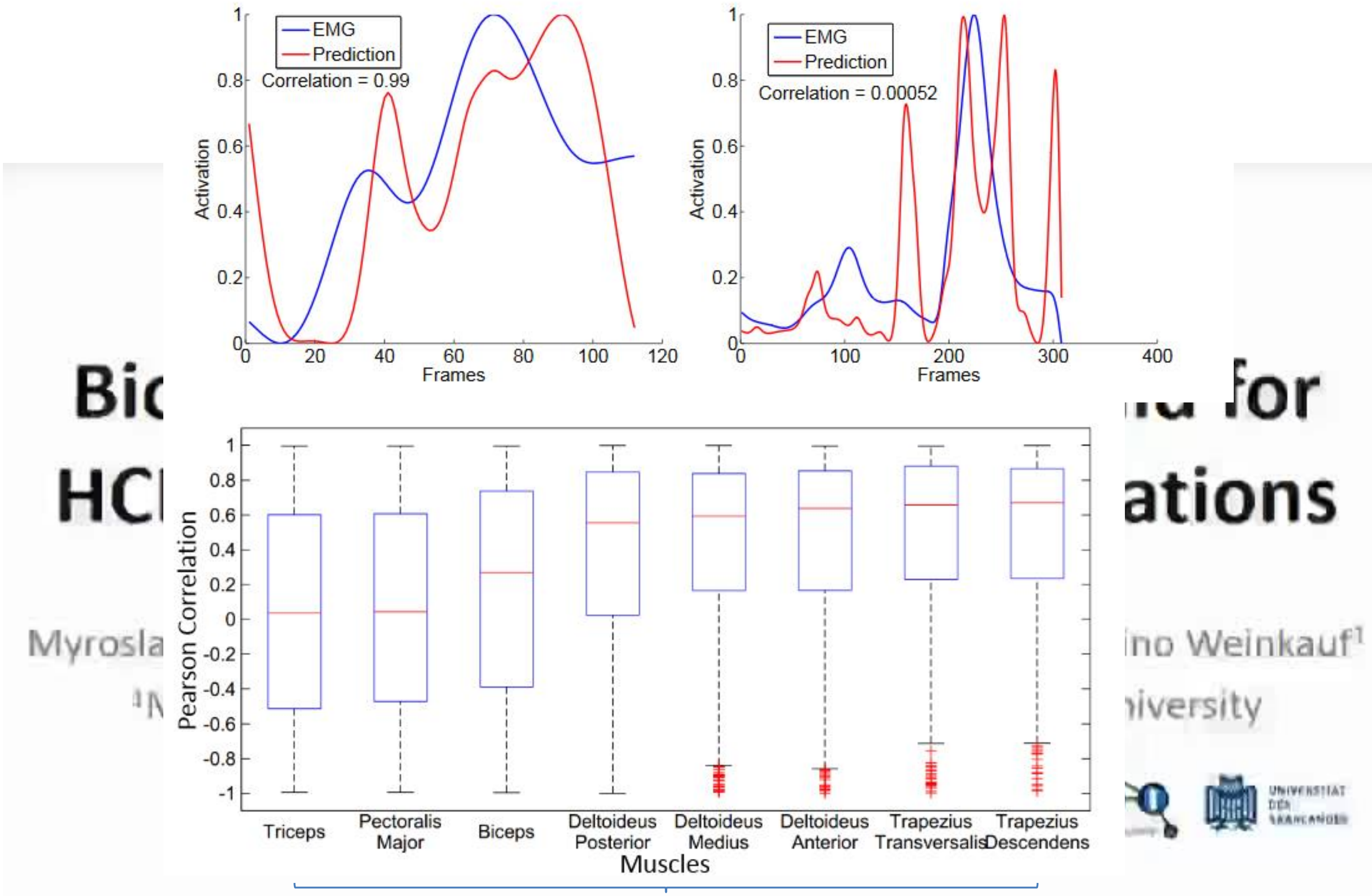

sEMG (8 muscles)

MPI study suggests that sEMG is a useful predictor for muscle activation
Goal := Verify that, reproduce results!

Project Plan – Overview

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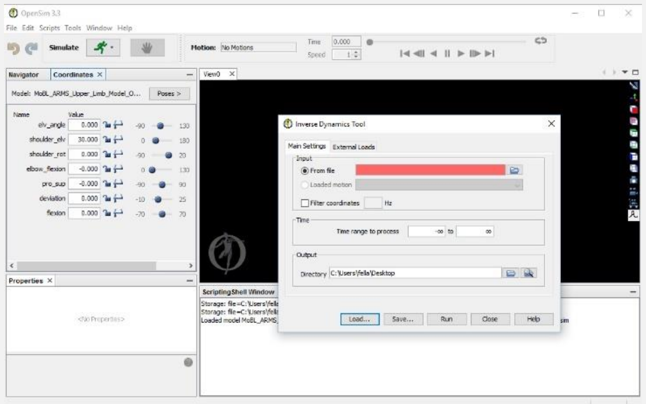
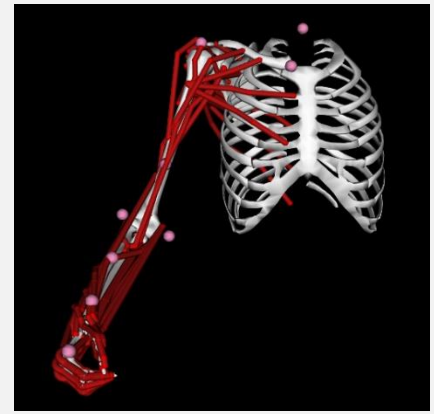
OpenSim



+

Arm model (musculosceletal)



Inverse **K**inematics
joint angles

⇨

Inverse **D**ynamics
forces, torques

⇨

Musculoskeletal **S**imulation
muscle activation and forces

MPI data

⇦ Q1? ⇨

- pointing movements (joint kinematics)
- sEMG measurements (8 muscles)
- computed muscle activations (classical minimization approach)

Project Plan – A Look at the Source Data

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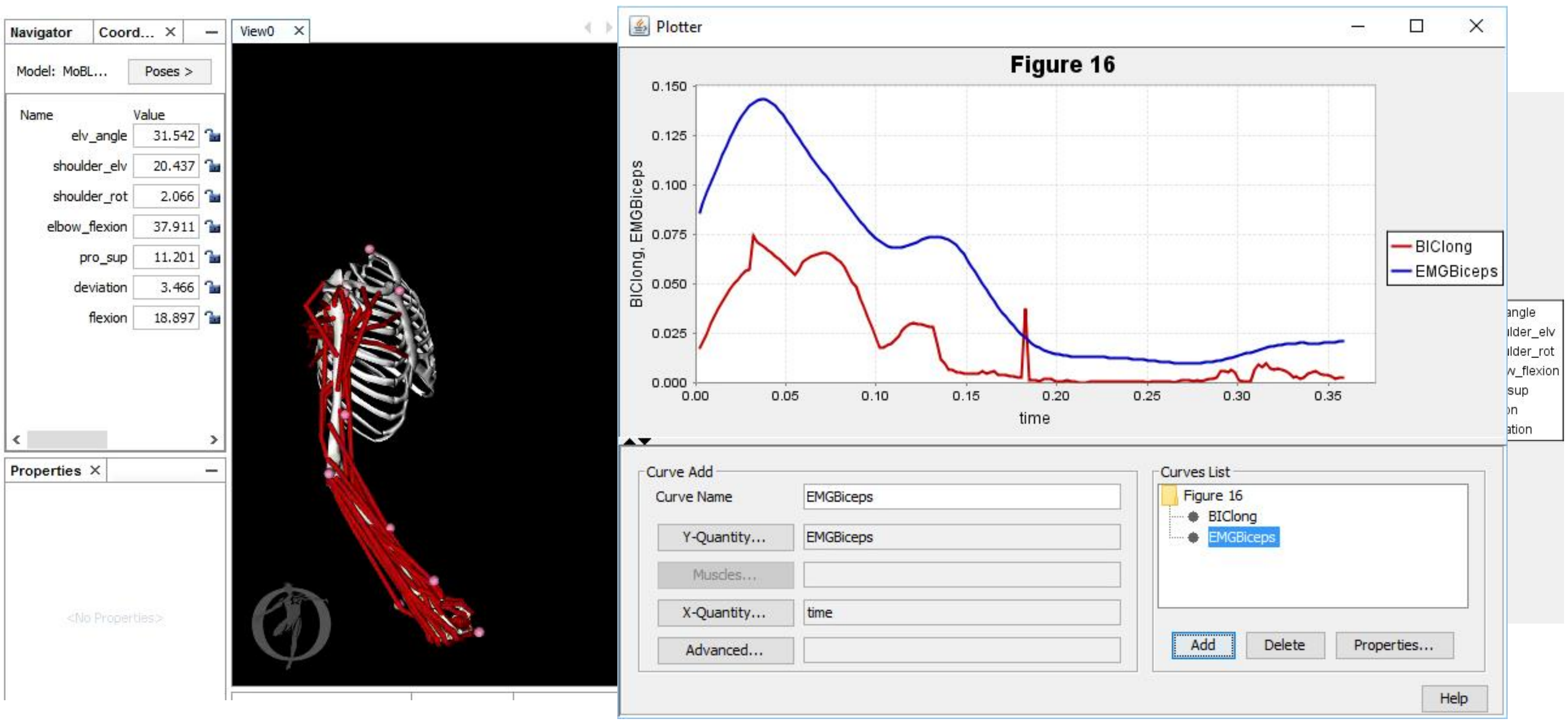
MPI data

- pointing movements (joint kinematics)
- sEMG measurements (8 muscles)
- computed muscle activations (classical minimization approach)



Actual Project – "Flowchart"

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MPI study used commercial full-body model (SIMM)

Choose open source full-body model

Conflicts with latest OpenSim version

Downgrade to earlier version

Different inverse dynamics algorithms

There are only antiquated free full-body models!

Choose a free partial arm model

Complex mapping between full-body model data vs. partial arm model requirements ... finally works!

Classical minimization algorithm doesn‘t converge!

Partial arm model has been updated!

New model release requires new data mapping

Classical minimization algorithm converges ... but ...

Intermediate inverse dynamics results (joint torques) are totally different from study results!

Trial and error phase, change any parameter randomly

Problem: Inconsistent Dynamics

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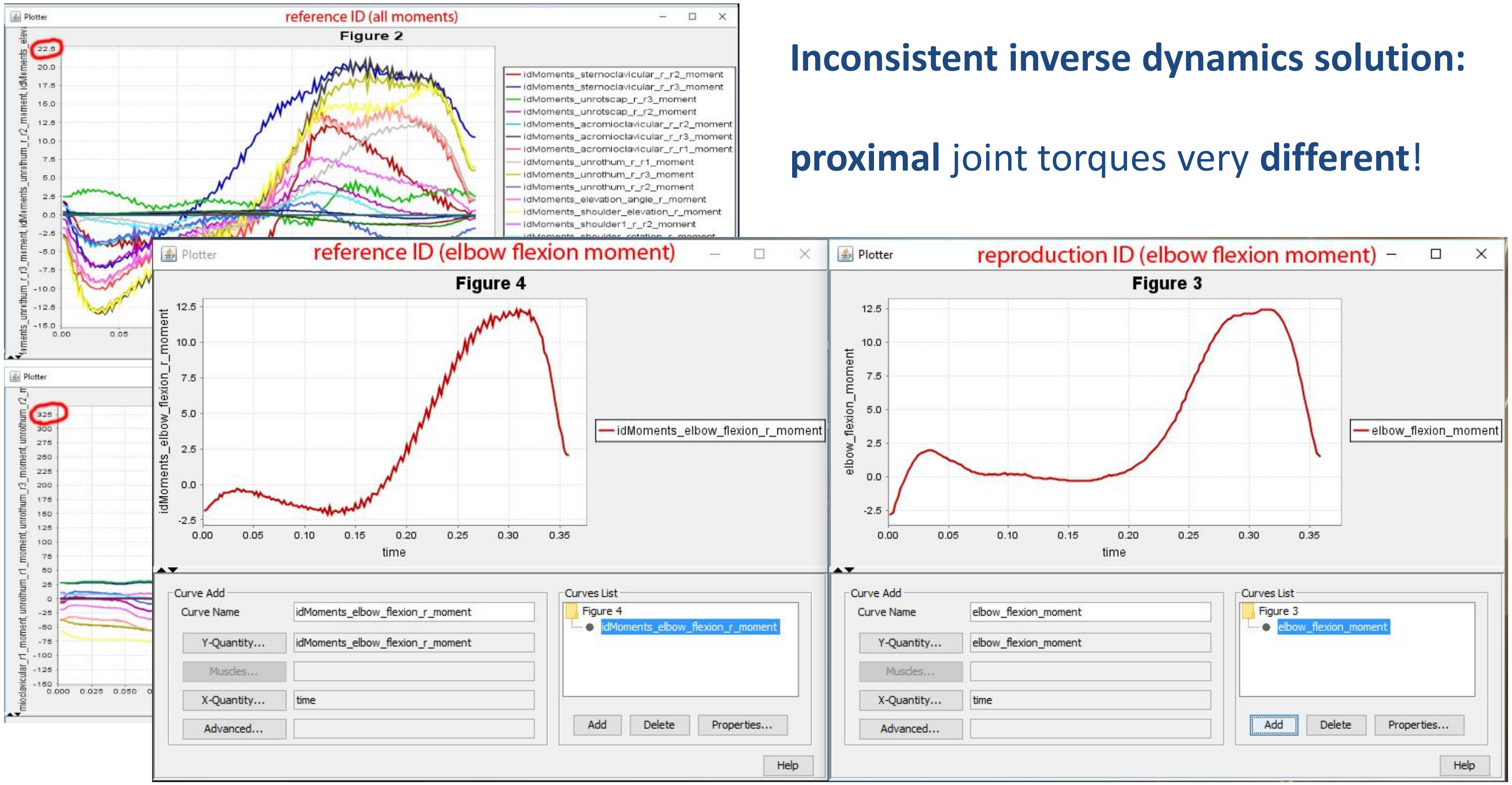

Inconsistent inverse dynamics solution:

proximal joint torques very **different**!

But: **distal** joint torques (e.g. **elbow**) quite **similar**!

Main Problem = Different Models

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Discussion with ...

Myroslav Bachynskyi (MPI study)

Kate Saul (partial arm model dev.)

OpenSim community (simtk.org)

"**Inertial properties** of the SIMM full-body model might be **[systematically] different** to the partial arm model." (M. Bachynskyi)

Subject specific scaling of inertial properties is **not possible.**
(No participant information (mass, scale factors) contained in MPI data)

Inverse Kinematics
joint angles

Inverse Dynamics
forces, torques

Musculoskeletal Simulation
muscle activation and forces

?

Workaround: Restrained Movements

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Alternative plan: Consider **only elbow** movement, **restrain** all **other joints**!
(1 free and 6 fixed DOFs)
➔ Compare only those computed activations vs. sEMG measurements related to elbow joint actuation: **biceps, triceps**

But ...

Restrained kinematics ➔ different dynamics (elbow torque cannot be considered in isolation)

different dynamics ➔ different computed muscle activations (stress minimization approach)

... and ...

elbow actuated by biceps, triceps, ~~*brachialis, pronator teres, anconeus*~~, ...

biceps / triceps actuate elbow, ~~wrist (supination) / shoulder (adduction)~~

muscular redundancy!

Thus ...

full movement sEMG measurements → valid for ...? → restrained elbow movement → yields ...? → similar computed muscle activations

still comparable ...?

How comparable (w.r.t. study) are results under these restraints / assumptions?

(Spurious) Results

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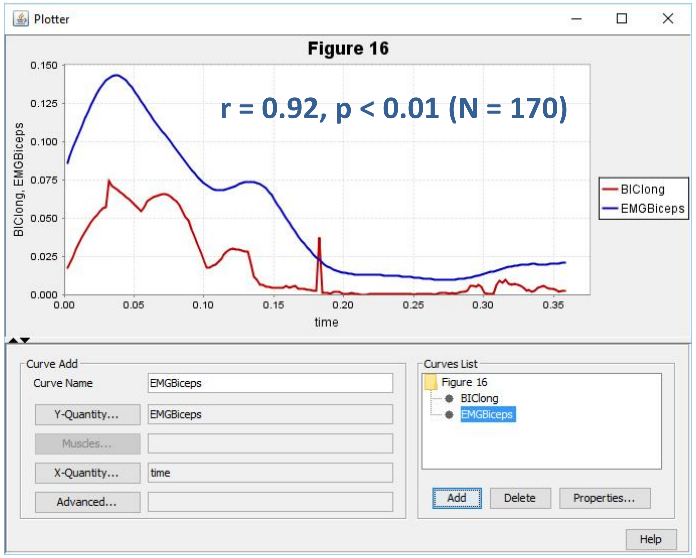
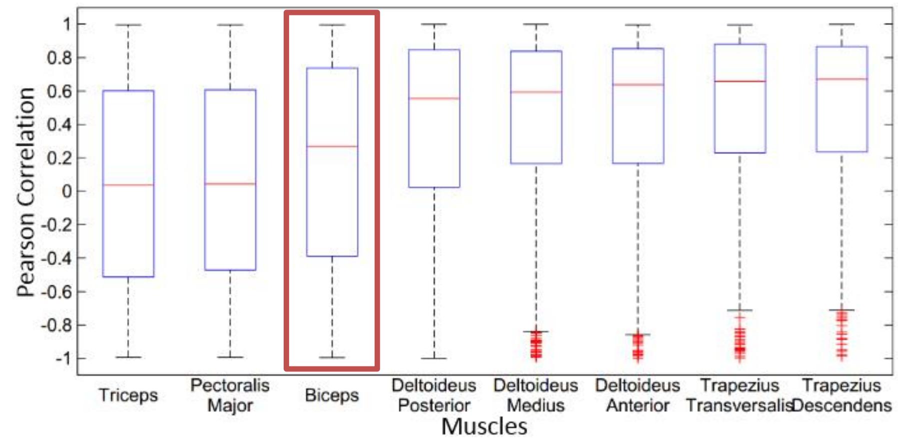
biceps correlation: computed vs. sEMG



MPI study: correlations boxplot

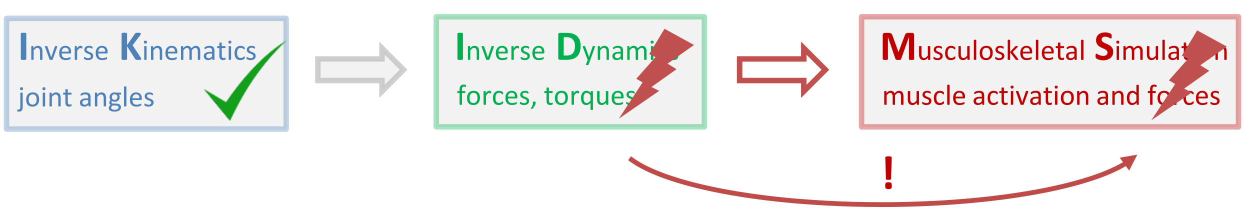


Authenticity of correlations "generated" with ...

- different model
  (inertia, internal forces, muscle properties, ...)
- restrained kinematics

But there are also "spurious" correlations contained in the actual study results!

Correlate totally unrelated muscles:
e.g. *pronator teres* vs. *deltoid* ➔ r = 0.74



Project Difficulties and Sources of Error

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marker placement & tracking
- real vs. virtual markers
- tracking accuracy
- repeatability

inverse kinematics
- drift of markers
- joint modelling
- numerical errors

inverse dynamics
- measure of external forces
- distribution of body mass
- numerical errors

Motion Capture – marker trajectories → **Inverse Kinematics** – joint angles → **Inverse Dynamics** – forces, torques → **Musculoskeletal Simulation** – muscle activation and forces

generalizability (subject ⇔ model)
- individual neural drive and activation strategies
- MTU params highly dependent on subject

model scaling
- marker points
- distribution of body mass
- …

(neuro)muscular redundancy
- **muscular** := several muscles for one joint or muscles spanning multiple joints
- **neurophysiological** := task-dependent activation strategies or multiple neurons innverating the same muscle
- **co-contraction**

MTU modelling
- tendon slack length, optimal fiber length and maximum isometric force
- …

EMG ⇔ muscle activation ⇔ muscle forces
- mapping poorly understood,
- no reliable models

Motion Simulation – marker trajectories ← **Forward Kinematics** – joint angles ← **Forward Dynamics** – forces, torques ← **Musculoskeletal Modelling** – muscle activation and forces

EMG extraction and processing
- surface EMG only (no deeper MTUs)
- characterizing frequency bandwidths
- ➔ generalizability?

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Theory  **Seminar**

vs. **vs.**

Practice  **Project**

Questions?

Thanks for your attention!

From Motion Capture to Musculoskeletal Simulation and (not quite) back

Assuming that sEMG is a valid estimator ...

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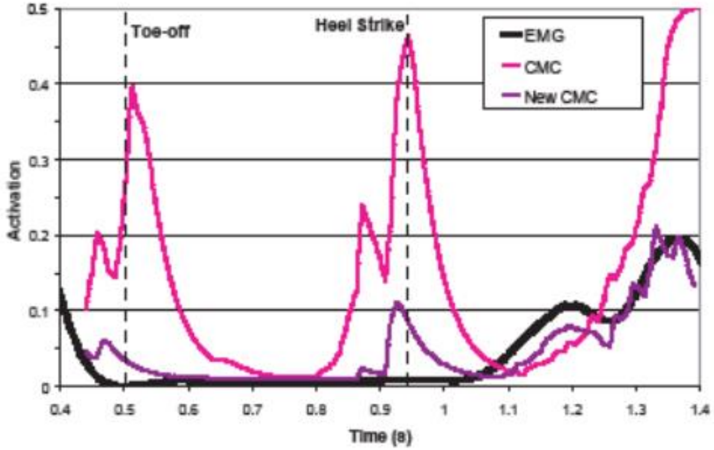

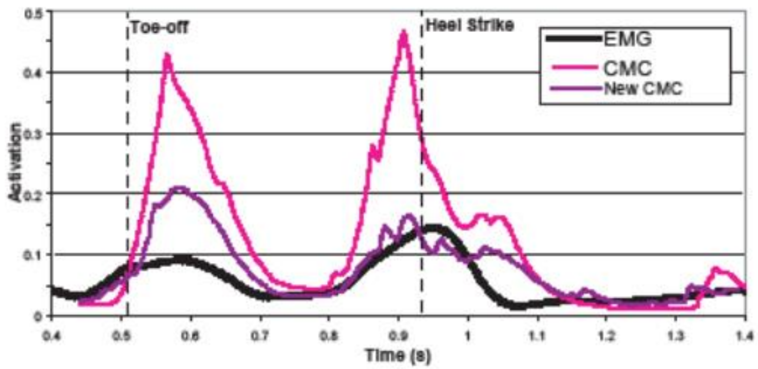

$$+\sum_{k=1}^{N_{c_k}} \omega_k (a_k - a_{k,\,emg})^2 \longrightarrow min$$

$$\sum_{k=1}^{N_{c_k}} \omega_k \, Corr\left(a_k, a_{k,\,emg}\right) \longrightarrow max$$

$$-\sum_{k=1}^{N_{c_k}} \omega_k \, Corr\left(a_k, a_{k,\,emg}\right) \longrightarrow min$$