Validation of musculoskeletal models

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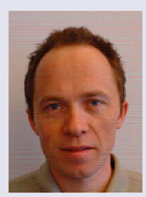
Presenters

Mark de Zee
(Presenter)

Arne Kiis
(Host)

John Rasmussen
(Panelist)



Søren T. Christensen
(Panelist)

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Q&A Panel

- Søren T. Christensen & John Rasmussen.
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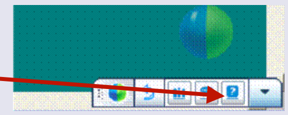
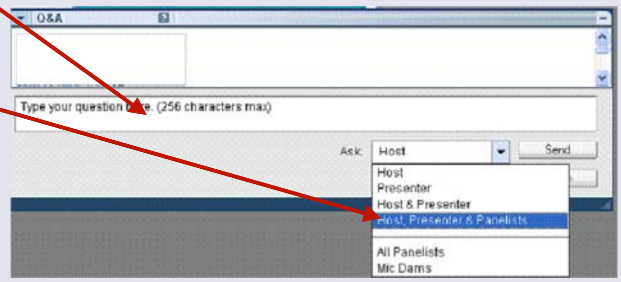
- Send the question to ”Host, Presenter & Panelists”
- Notice the answer displays next to the question in the Q&A box. You may have to scroll up to see it.





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The presenter: Mark de Zee

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Agenda

- Some definitions
- Three general ways of validating a model
- Examples
- Concluding remarks

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Definition of a model

- Model: A model is an attempt to represent reality
- Two purposes:
  - To increase knowledge and insight about reality
  - To estimate or predict variable of interest

Biomechanics of the Musculo-skeletal System – Second Edition

Benno M. Nigg & Walter Herzog

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Modeling and simulation

- Modeling:
  - Computer modeling refers to the setting up of mathematical equations to describe the system of interest, the gathering of appropriate input data, and the incorporation of these equations and data into a computer program.
- Simulation
  - Computer simulation is restricted to mean the use of a **validated** computer model to carry out "experiments", under carefully controlled conditions, on the real-world system that has been modeled.

Christopher Vaughan (2002, WCB Calgary)

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Validation

- To validate a model can be defined as to provide evidence that the model is strong and powerful for the task it has been designed

Three ways of validating

- Direct measurements (2 examples)
  - One is able to measure directly the variable of interest
- Indirect measurements (2 examples)
  - Impossible to measure directly the variable of interest
- Trend measurements (1 example)
  - Focus on the prediction of trends

Biomechanics of the Musculo-skeletal System – Second Edition
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Example: Direct measurement

– Hip contact forces and gait patterns from routine activities.
Bergmann G, Deuretzbacher G, Heller M, Graichen F, Rohlmann A, Strauss J, Duda GN. J Biomech. 2001 Jul;34(7):859-871.

– Musculo-skeletal loading conditions at the hip during walking and stair climbing.
Heller MO, Bergmann G, Deuretzbacher G, Durselen L, Pohl M, Claes L, Haas NP, Duda GN. J Biomech. 2001 Jul;34(7):883-893.

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Measurement in vivo of hip contact forces

J Biomech. 2001 Jul;34(7):859-871

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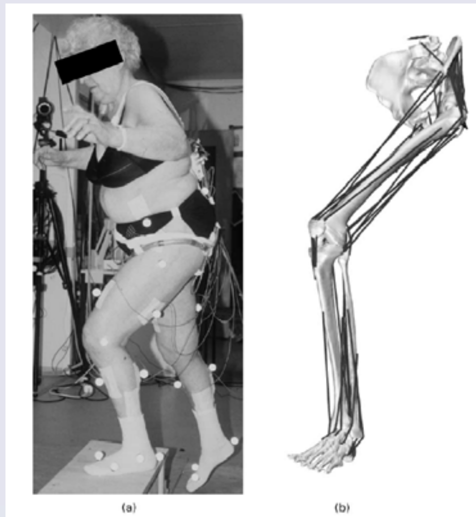
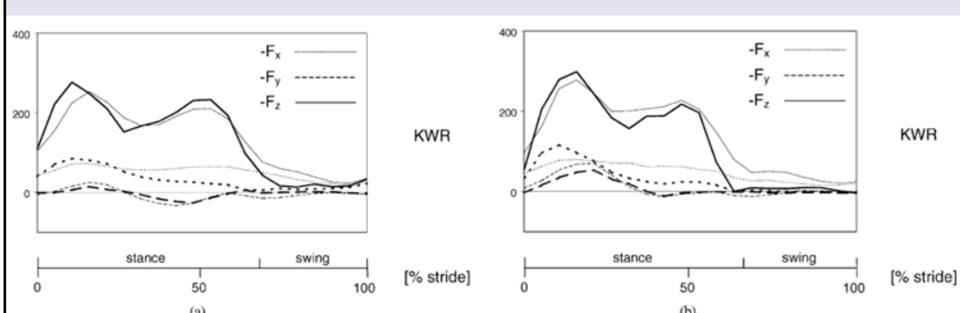
Modelling

J Biomech. 2001 Jul;34(7):883-893



Results



Walking

Stair climbing

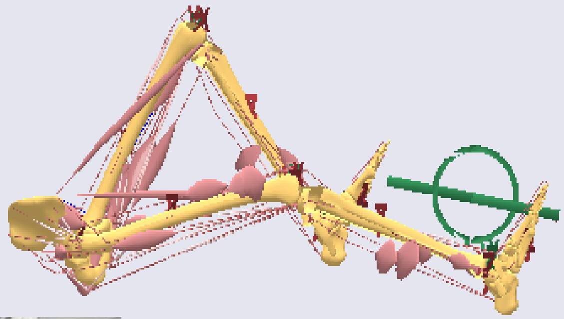
Thin: measured

Thick: calculated

J Biomech. 2001 Jul;34(7):883-893

Example 2: Direct measurement

Recumbent cycling



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Kenneth Meijer

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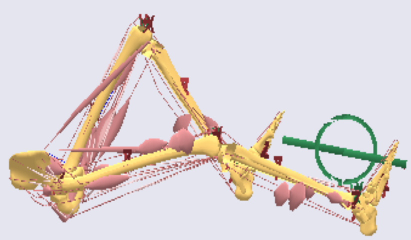
Example 2: Direct measurement

Input in model:

- Kinematics
- Crank torque (not the pedalforces!!), based on the measured tangential pedal forces



Model output:

- Tangential pedal forces
- Radial pedal forces
- Muscle forces and activations

Measured variables:

- Tangential pedal forces
- Radial pedal forces
- Surface EMG measurements

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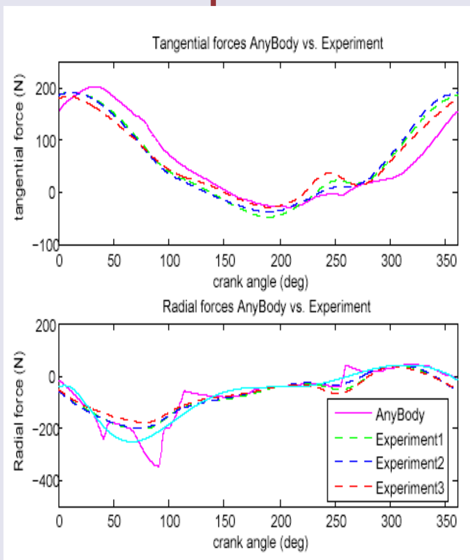
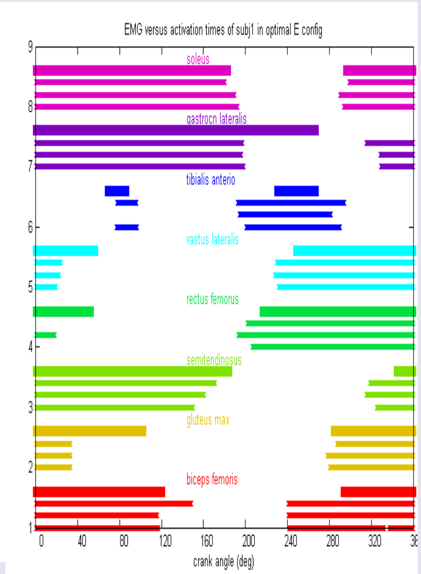
Example 2: Direct measurement





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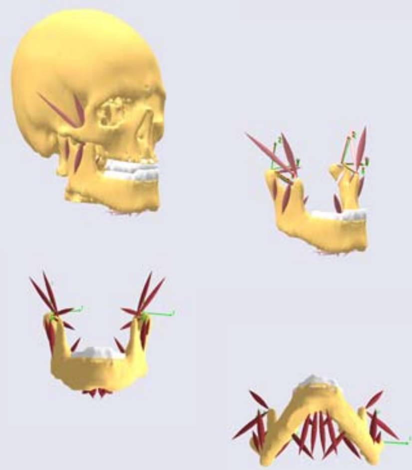
Indirect measurements

- Based on CT scan of ”normal” face of a 30 year old male
- 24 Hill-type muscles (Koolstra and Van Eijden, *J. Biomech.* 38: 2431-2439, 2005)
- Mandible modelled with 4 DoF



de Zee et al., *J. Biomech*, in press.

http://dx.doi.org/10.1016/j.jbiomech.2006.06.024

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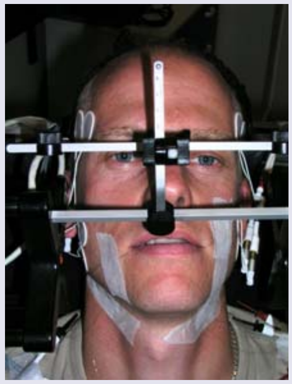
Measurements



- Bite force measured with force transducer
- Magnetic jaw tracker: 3D position of the central incisors
- Surface EMG: masseter and temporalis
- Wire electrodes: Medial and lateral pterygoid

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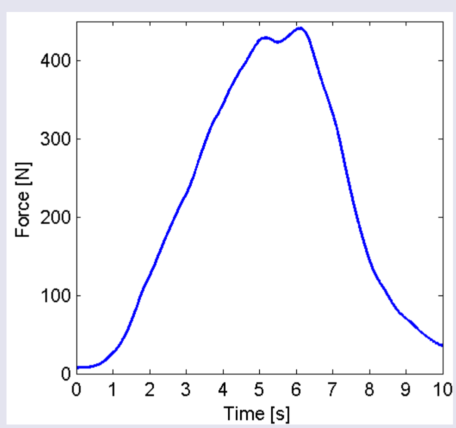
Validation: Unilateral clenching left first premolars (1)



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Bite force input in the model

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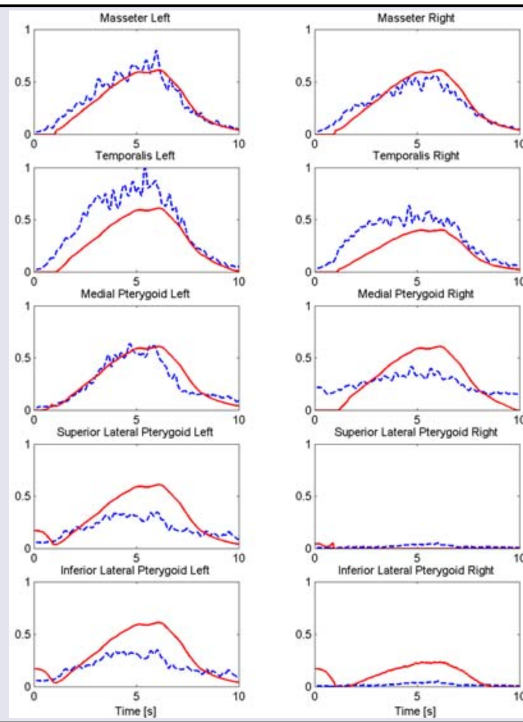
Validation: Unilateral clenching left first premolars (2)



EMG

Simulation

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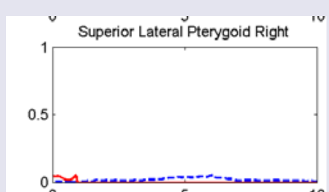
Quantification

Table 2
Correlation coefficients between the normalized EMG envelopes and the estimated muscle activities for each muscle and task

Muscles	Task 1	Task 2	Task 3	Task 4	Task 5	Mean
Masseter left	0.851	0.754	0.890	0.955	0.946	0.879
Masseter right	0.868	0.446	0.876	0.956	0.928	0.815
Anterior temporalis left	0.848	0.557	0.848	0.932	0.798	0.797
Anterior temporalis right	0.920	0.754	0.911	0.884	0.918	0.877
Medial pterygoid left	0.599	0.255	0.952	0.933	0.938	0.735
Medial pterygoid right	−0.379	−0.085	0.672	0.888	0.824	0.384
Superior lateral pterygoid left	0.540	−0.134	0.685	0.854	−0.352	0.319
Superior lateral pterygoid right	0.770	0.396	−0.113	−0.332	−0.096	0.125
Inferior lateral pterygoid left	0.516	−0.259	0.706	0.854	0.780	0.519
Inferior lateral pterygoid right	0.768	0.414	−0.116	0.765	−0.096	0.347
Mean	0.630	0.310	0.631	0.769	0.559	0.580



Only a number does not tell you the whole story

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Indirect measurement: Arm cranking

Michael Voigt, Jonas Haahr, Tine Madsen
Center for Sensory-Motor Interaction
Dept. Health Science and technology
Aalborg University

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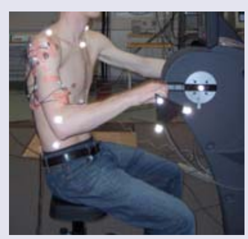
Arm cranking



- In rehabilitation it would be useful to be able to give well defined movement instructions to administer specific exercise for weakened muscles or to avoid loading of pain full muscles.
- How does the muscle recruitment change with different arm positions?

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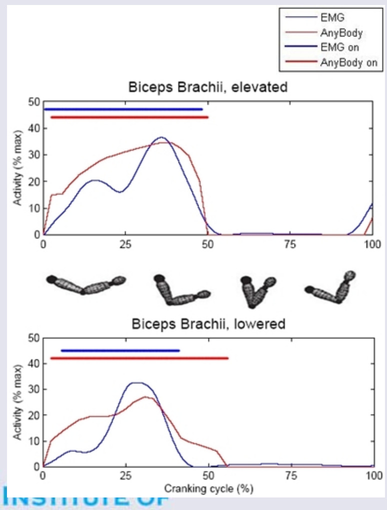
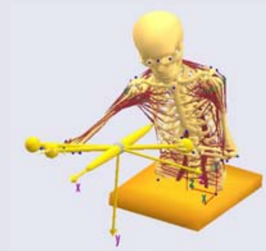
Arm cranking model – 'Validation' by EMG





Success ratio:
the fraction of time points during the simulated movement where the predicted state (either on or off) matched the EMG measured on or off states

Especially useful for cyclic movements

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Success ratios – arm cranking

Elbow position — Subject #

ELEVATED	02	03	04	Mean
Ant. Deltoid	0.88	0.52	0.69	0.70
Med. Deltoid	0.89	1.00	0.77	0.89
Post. Deltoid	1.00	0.99	0.89	0.96
Biceps	0.92	0.78	0.94	0.88
Triceps	0.75	0.61	0.34	0.57
Brachioradialis	0.84	0.83	0.74	0.80
Mean	0.88	0.78	0.73	

LOWERED	02	03	04	Mean
Ant. Deltoid	0.58	0.90	0.31	0.60
Med. Deltoid	0.22	0.52	0.22	0.32
Post. Deltoid	0.03	0.00	0.39	0.14
Biceps	0.82	0.72	0.73	0.76
Triceps	0.92	0.97	0.43	0.77
Brachioradialis	0.53	0.82	0.69	0.68
Mean	0.52	0.66	0.46	

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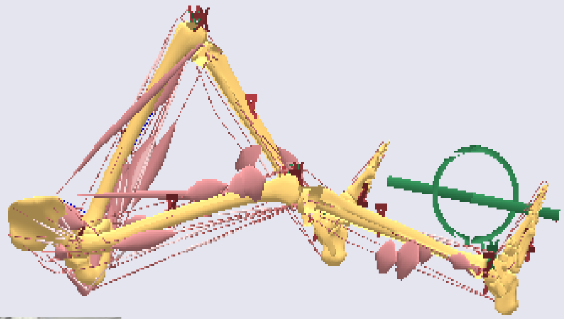
Example: Trend measurements

Recumbent cycling



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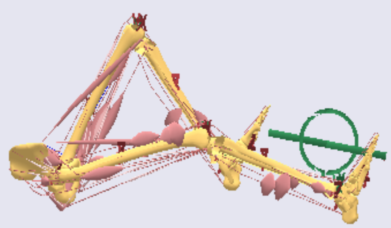
Example: Trend measurements

Recumbent cycling



The aim of this study was to find an optimal recumbent position in combination with an optimal cadence.

Trend measurements are good for comparing different designs/configurations

Oxygen consumption was measured and estimated for three different configurations.

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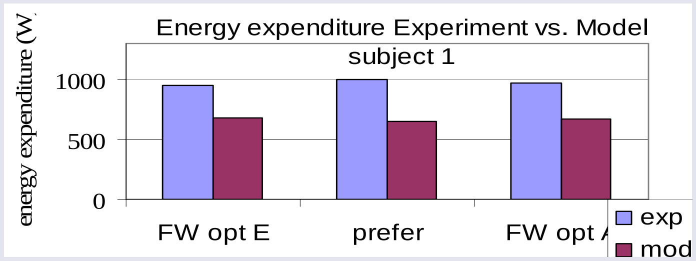
Example: Trend measurements



In this case trends found in simulation, could not be confirmed experimentally.

• In a model you can change one parameter, which is very difficult to do experimentally

• The measurement of oxygen might not precise enough

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Experimental challenges

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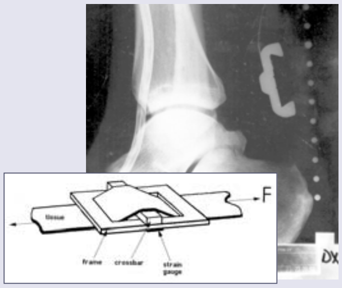
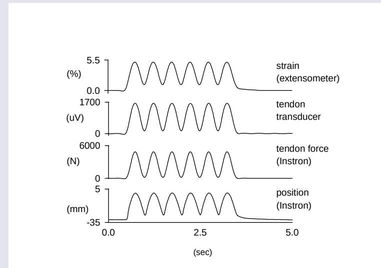
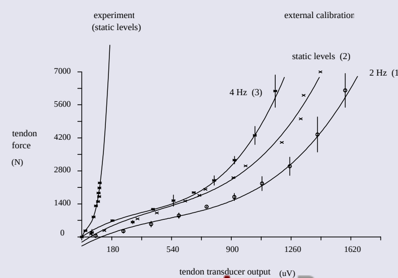
Tendon forces in vivo

Buckle transducer in situ



In vitro dynamic test

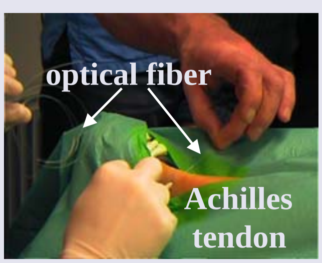




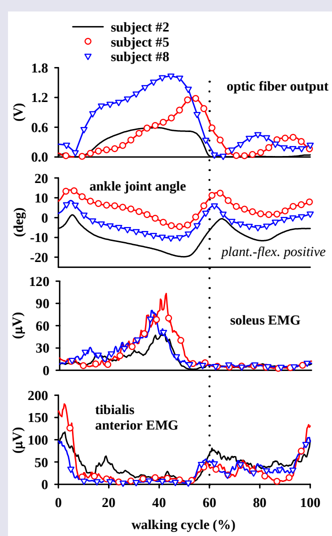
In vivo calibration

(Voigt, Ph.D Thesis (1994) University of Copenhagen)

Tendon forces in vivo



(N = 8)



Some remarks

- A combination of quantitative and qualitative methods is desirable
- How accurate are the experimental methods?
- Paradox: the reason for developing models is often because it is very difficult or even impossible to obtain experimental data
- Trend measurements should be made more important

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Concluding remark

"Whatever arguments can be made regarding validity, we suggest that such models are perhaps best considered as working hypotheses. Under these circumstances, a model's use of plausible input information, and its demonstration of any trends, associations and consequences which support such observations as are available, simply strengthens or weakens the case for the hypothesis/model as a conceptual framework."

Langenbach and Hannam, *Archives of Oral Biology* 44 (1999), 557-573.

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