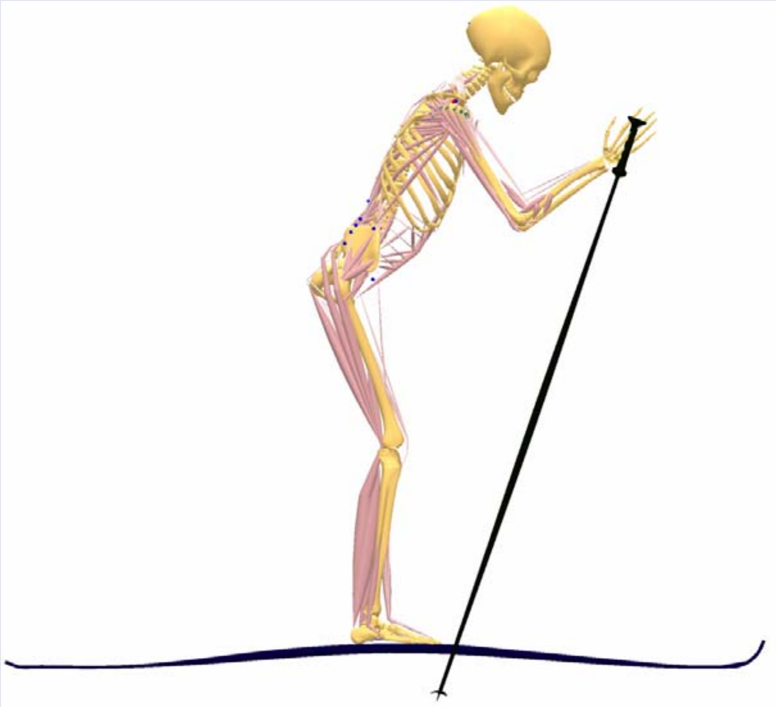
Cross-country skiing biomechanics using measurement driven full-body simulations

Joakim Holmberg



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(Presenter)

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(Panelist)

Arne Kiis
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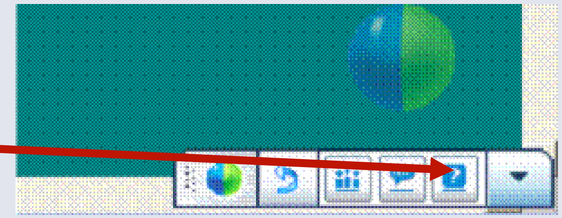

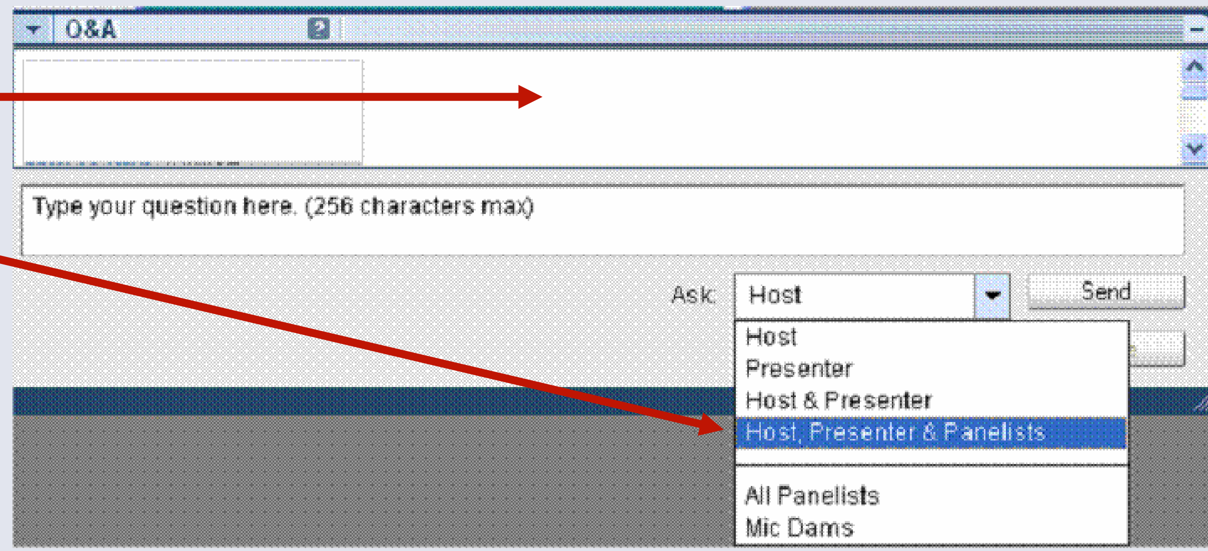

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Outline

- Cross-country Skiing Biomechanics
    - Short introduction
    - Examples of Use
    - Simulation Model
- Static Optimization for Fast Full-body Motions
- Conclusions

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Cross-country Skiing Biomechanics

- <u>Short introduction</u>
  - Cross-country skiing comes natural in Östersund, Sweden.
    - Skiable snow almost half the year
    - Great deal of local interest
    - Last week we hosted the world championships in Biathlon
  - Traditionally, cross-country skiing biomechanics has been just experimental testing
    - Simulations should add further insight
  - Focusing on simulation models and the application
  - Main goal: to explore the possibilities for computational musculoskeletal biomechanics in cross-country skiing

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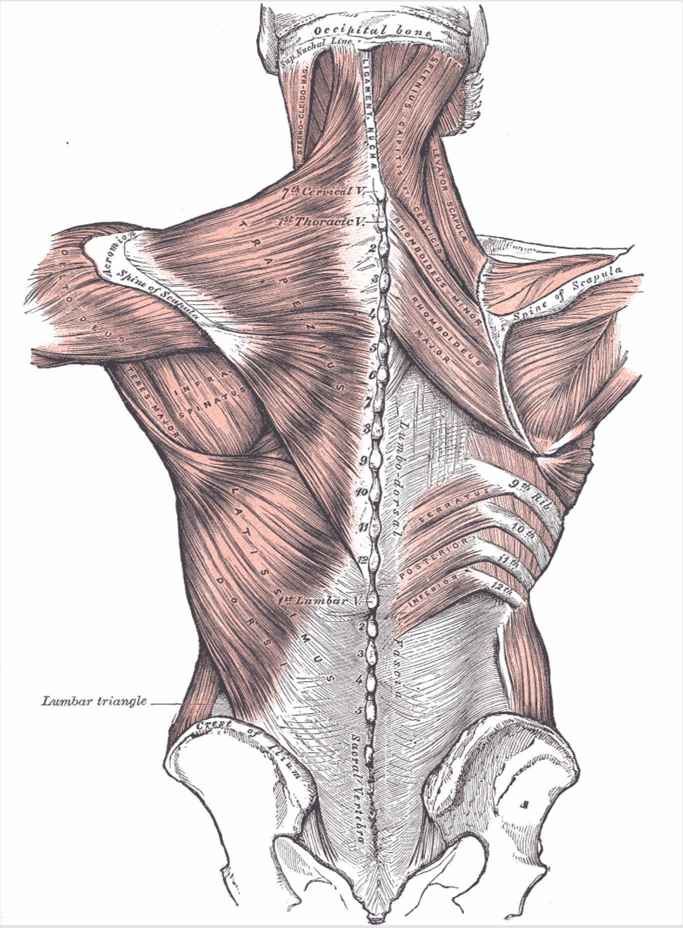
Cross-country Skiing Biomechanics

- <u>Examples of Use</u>
  - Finding antagonist muscle pairs
    - Problem: “rounded shoulder” – muscular imbalance – strong *pectoralis major*
      - May hinder backswing of upper arm in 4th gear skate technique
    - AnyBody solution technique: change passive resistance of *pectoralis major* by changing the resting length
    - Simulation result: antagonists increase their work – train them
      - *Rhomboideus*
      - *Trapezius* (scapular part)
      - *Infraspinatus*
      - *Latissimus dorsi* (extending part)



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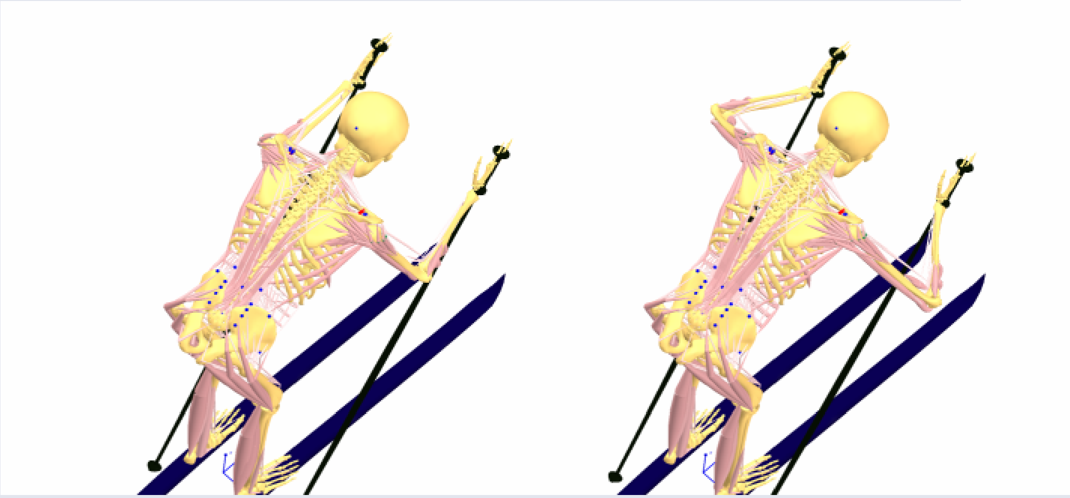
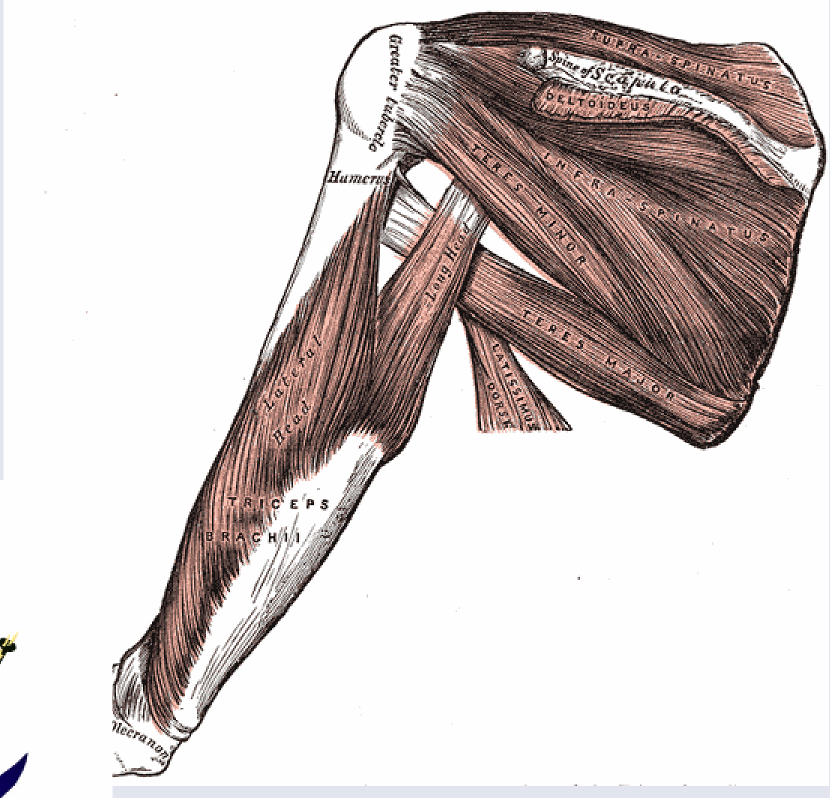
Cross-country Skiing Biomechanics

- <u>Examples of Use</u>
  - "What if?" questions
    - Does the load distribution between muscles (*teres major* and *latissimus dorsi*) change depending on double-poling style?
    - Results: with greater arm abduction, *teres major* carries more of the load





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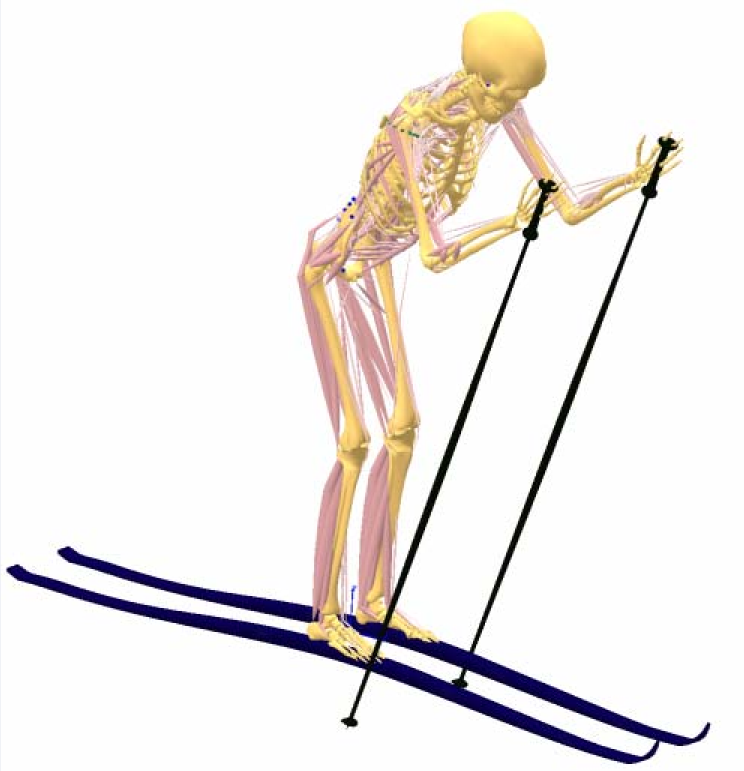
Cross-country Skiing Biomechanics

- Simulation model – basic info
  - For an animation, see
    http://www.anybodytech.com/fileadmin/downloads/AnySkierDPHolmbergMiUn.mpg
  - Measurement driven
  - Based on AnyBody 3.0 & Model Repository 6.1
  - 464 muscles
  - 64 rigid bodies
  - Simulation model = body model and boundary conditions



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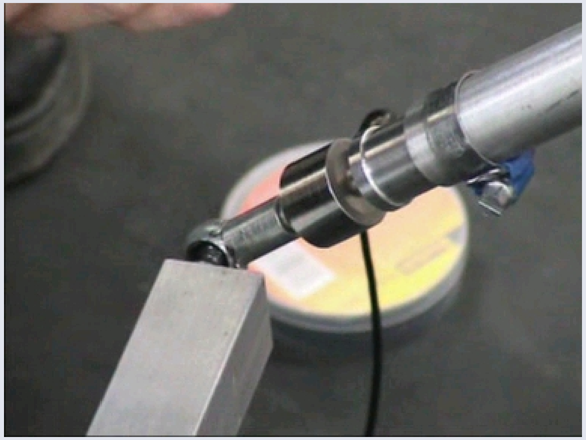
Cross-country Skiing Biomechanics

- Simulation model – boundary conditions
  - Boundary conditions = motion and external forces (& drivers)
  - Experiment using double-poling ergometer
    - 2D video
    - Load cells at pole tips



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Cross-country Skiing Biomechanics

- Simulation model – boundary conditions
  - Smooth but high forces, “Non-smooth” motion
  - Problems:
    - boundary conditions don’t “fit” together
    - high accelerations
  - Solution:
    - Bézier interpolation spline on all boundary conditions
  - Results:
    - Motion & forces altered, but simulation model works
  - Conclusion:
    - Loss of accuracy
    - Use similar measuring frequency

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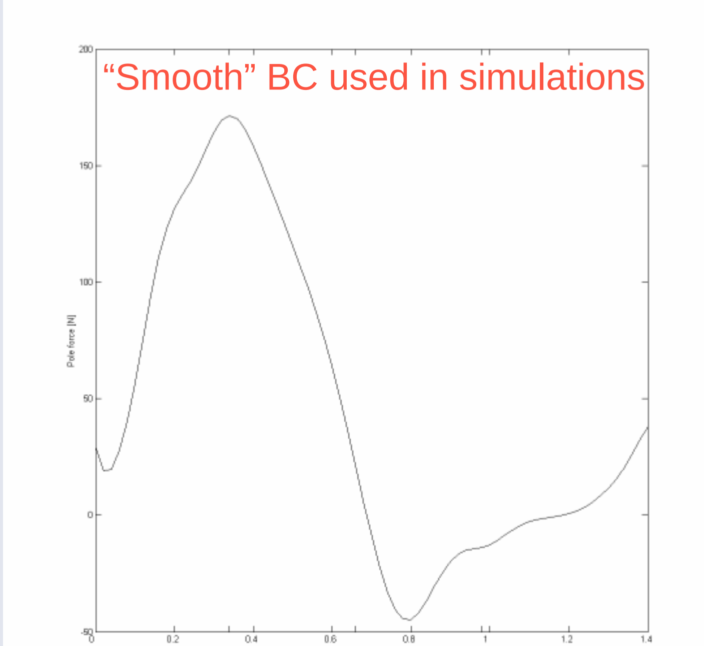
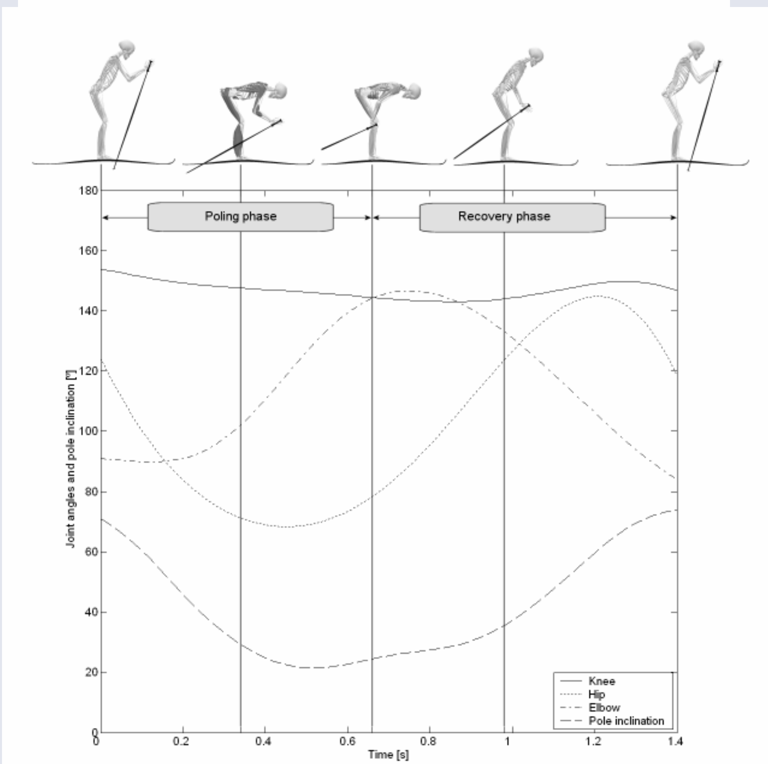
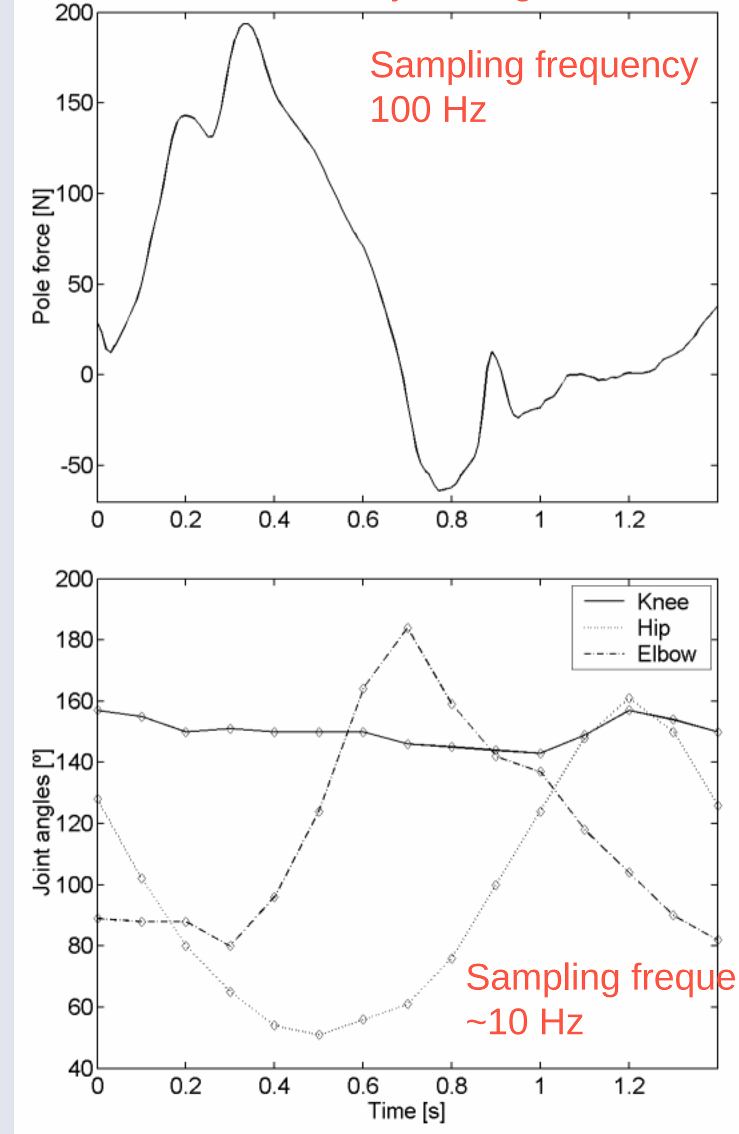
“Smooth” BC used in simulations





Measured raw BC with the “non-smooth” joint angles



Sampling frequency 100 Hz

Sampling frequency ~10 Hz

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Questions, it is ok to ask

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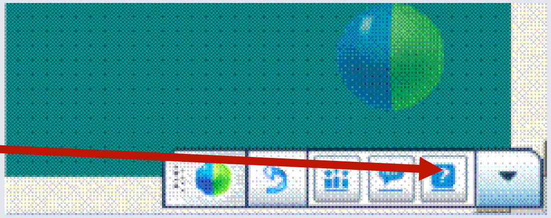

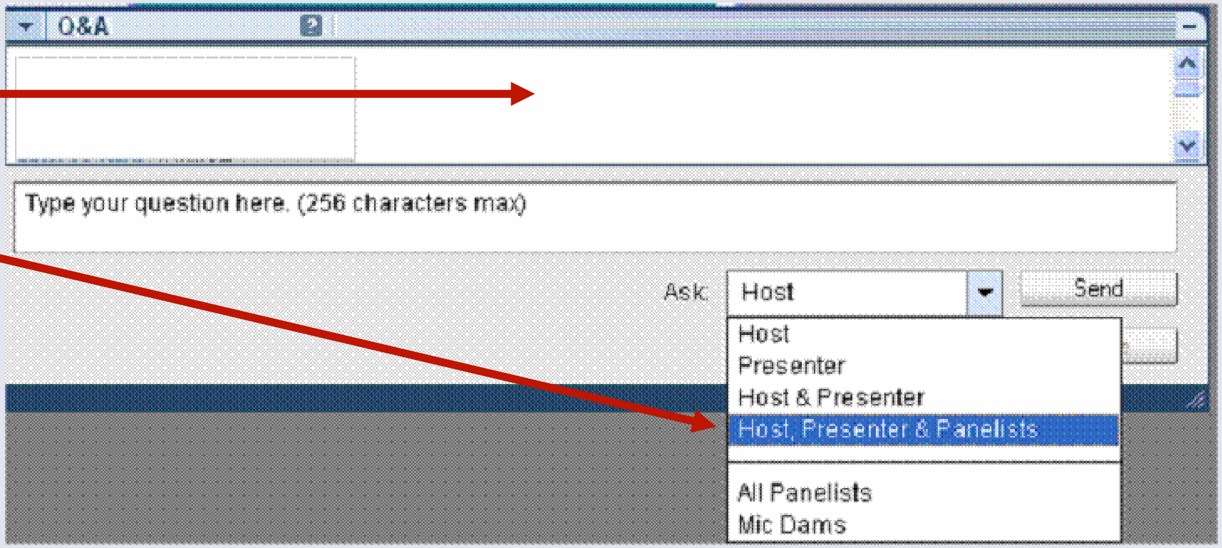

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Cross-country Skiing Biomechanics

- Simulation model – drivers
  - 2D motion & 2D data – 3D body model, how to do?
  - Create a 2D dummy without inertia properties but “limb lengths” matching the subject (2D version)
  - Apply motion to the 2D dummy
  - Let the 2D dummy “guide” the 3D body model

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Cross-country Skiing Biomechanics

- <u>Simulation model – drivers</u>
  - Guiding the 3D body model
    - 2D dummy only moves in the sagittal plane
    - Body model are constrained to "follow" 2D dummy in a parasagittal plane at certain joint centers (using *AnyKinEq*)
    - The lower body is a closed chain – save the constrained DOF to the upper body
  - Spine of 3D body model is driven directly

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Cross-country Skiing Biomechanics

- Simulation model – body model
  - Simple muscle model (constant force)
  - Full-body model – why legs?
  - Cross-country skiing is a full-body movement, even double-poling
  - The legs do considerable work, see animation
    http://www.anybodytech.com/fileadmin/downloads/AnySkierDPHolmbergMiUn.mpg

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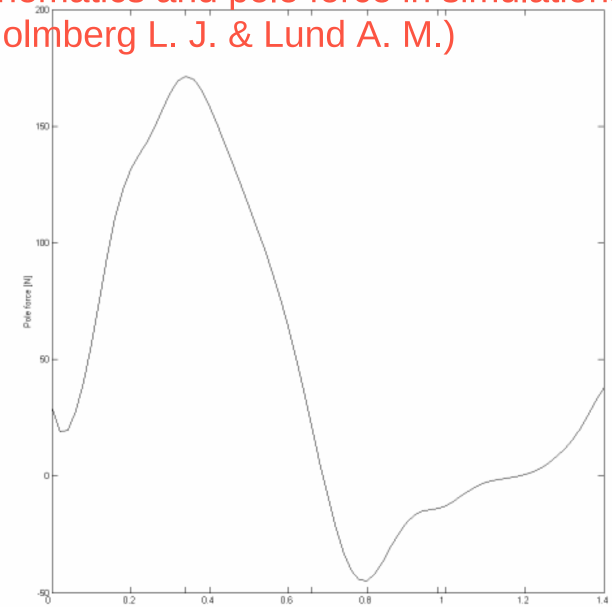
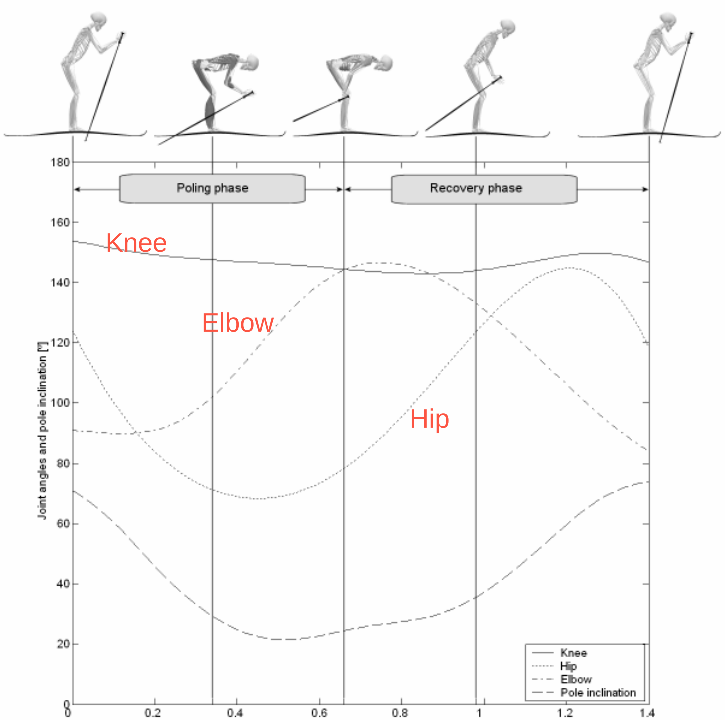
Cross-country Skiing Biomechanics

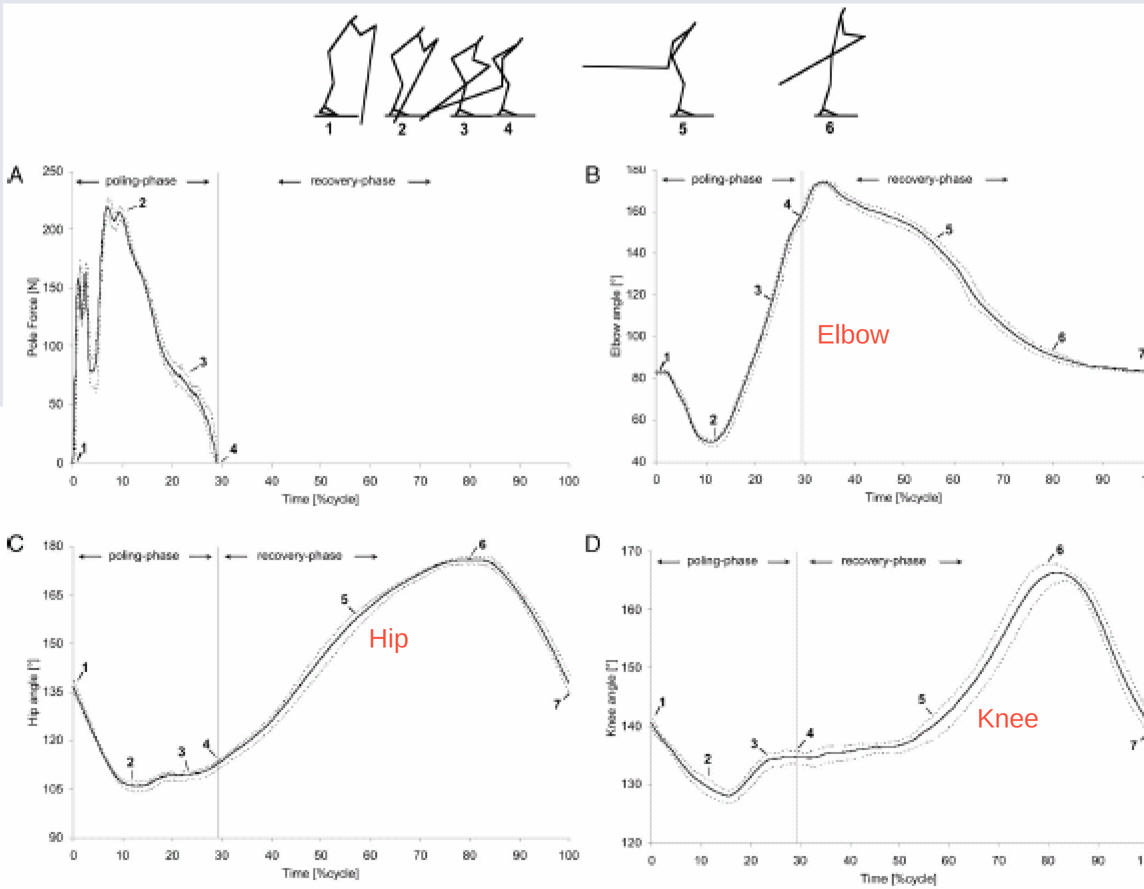
- Simulation model – results
  - Simulation model is reasonably stable and can handle realistic loads (for skiing)
  - Muscle activation compared with literature
    - Agrees fairly well when considering the slightly different motion and pole force found in literature

Kinematics and pole force in simulations (Holmberg L. J. & Lund A. M.)





Kinematics and pole force from literature (Holmberg H. –C., et al.)



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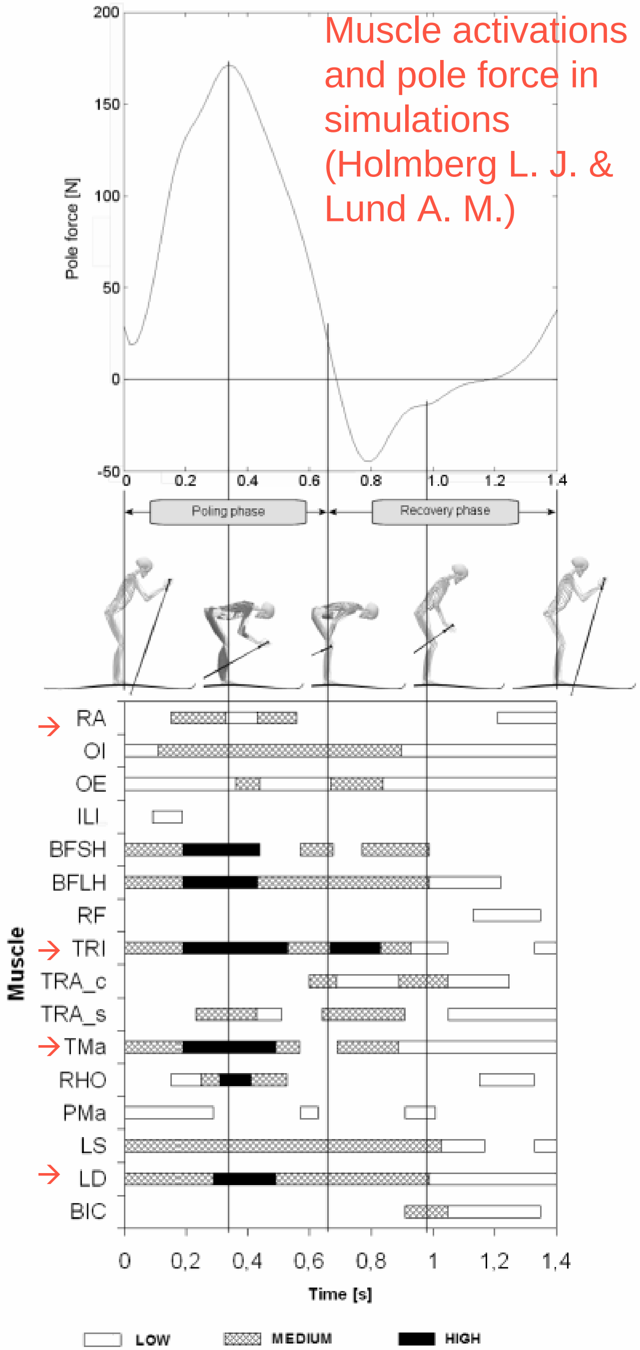
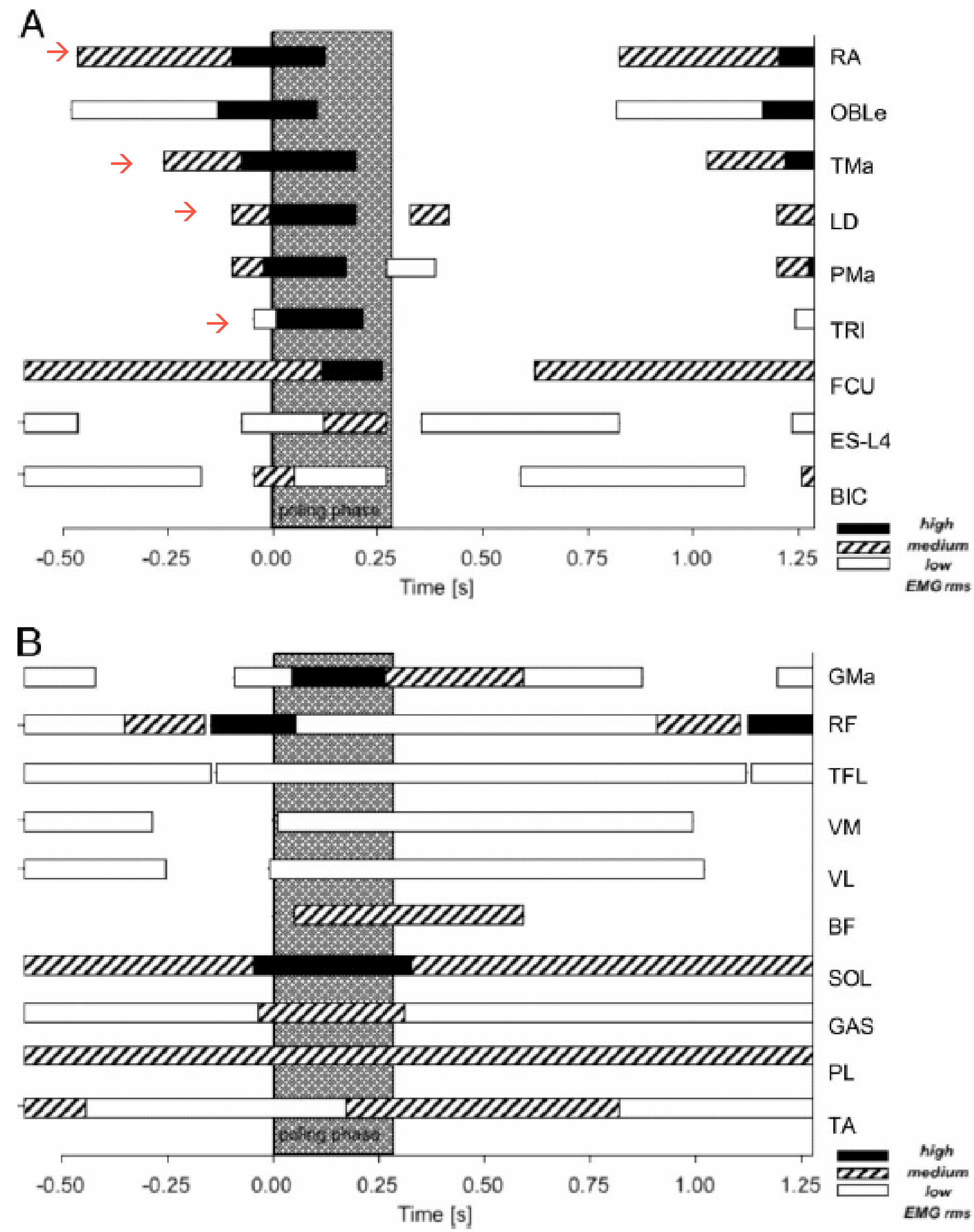
Muscle activations and pole force in simulations (Holmberg L. J. & Lund A. M.)





EMG results from literature (Holmberg H. –C., et al.)

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Static Optimization for Fast Full-body Motions

- No activation dynamics
  - Therefore, it is common to restrict the method to slow and skilled motions
  - What is a slow and skilled motion?
    - Gait is a commonly used example
    - No standards
  - Cross-country skiing is a fast and powerful full-body motion, but seems to work

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Static Optimization for Fast Full-body Motions

- No activation dynamics
  - Signal speed, brain (CNS) -> muscle -> muscle contraction
    - Even methods that claim to include activation dynamics usually don’t include the first step. Of importance? Also, there are probably more steps than the ones above.
  - Also, most important: what is good agreement (with reality)?
  - Do you seek the muscle forces or the muscle group activation sequences for a specific motion?
    - Then static optimization may be good enough …

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Conclusions

•Cross-country skiing biomechanics using musculoskeletal simulations can add knowledge that would be hard to achieve with traditional experimental methods alone

•2D motion and 2D data can drive a 3D body model by using a 2D dummy

•Fast full-body motions like cross-country skiing does <u>not</u> seem to be <u>too fast</u> for static optimization

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Thank You!

Photo by Kalle Börjes

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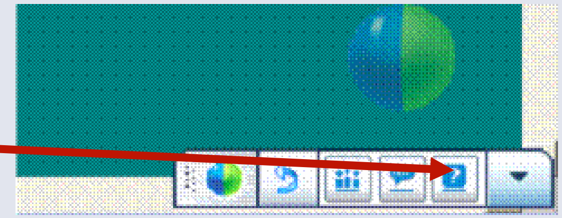

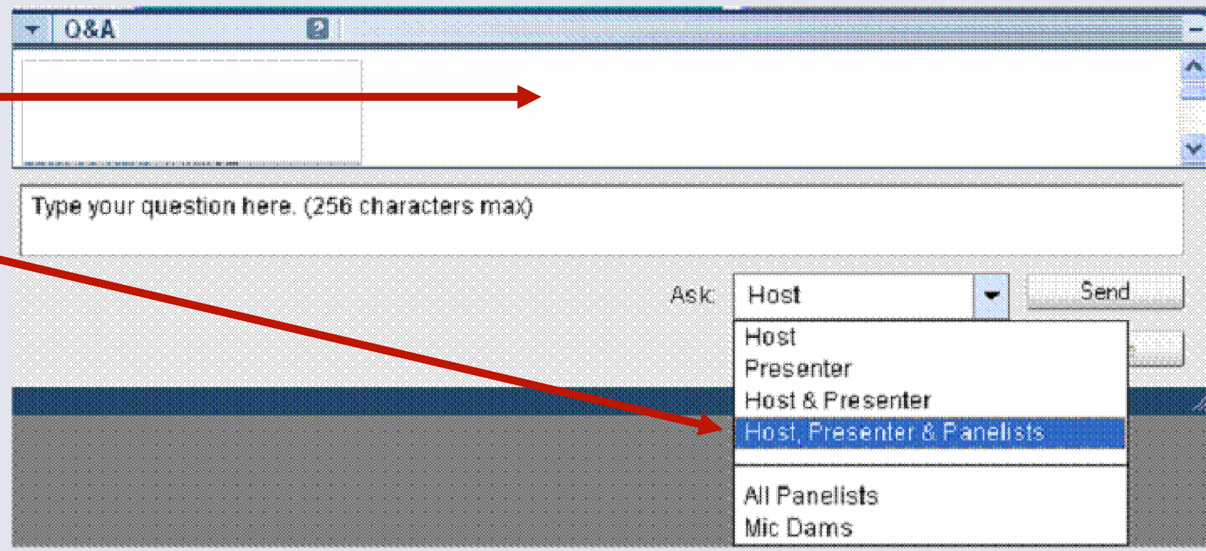

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