Is my simulation good enough?

Validation & Verification for Biomechanical Modeling and Simulation
Rules of good practice - Scaling

- Rely on anatomical landmarks and functional joint centers (FJC)
- Scaling is an iterative process. "preview static pose" option in the GUI.
- Check marker errors:
  - maximum marker errors for bony landmarks should be less than 2 cm.
  - RMS error should typically be less than 1 cm.
  - Pay close attention to errors in the bony landmark and FJC markers when assessing the quality of your scaling results.
- Visualize model and verify model fit.
- Adjust the virtual markers and marker weightings to improve your results (NOT anatomical and HJC)
Rules of good practise – IK/ID

- Weight "motion" segment markers (technical markers) more heavily than anatomical markers
- **Relative marker weightings** are more important than their absolute values
- **Verify the marker error**
  - Maximum marker error should generally be less than 2-4 cm, and RMS under 2 cm is achievable.
- Check with other 3D Mocap Software
  - Do not expect absolute agreement
    - Cfr offset of pelvis coordinate system and hip angle.
    - Cfr ankle angle kinematics due to subtalar joint.
Rules of good practise - RRA

- All forces need to be known!
- **Trunk data** needed!
  - Keep **optimal forces** for residuals low (increase control bounds if necessary)
  - Verify magnitude of **mass adjustments**
  - Floating or Sinking models? -> check overall **model mass**.
  - Verify magnitude of **residual forces**
  - Verify changes in the kinematics
Experimental Data
Inverse Kinematics
REA
Rules of good practise - RRA

- All forces need to be known!
- **Trunk data** needed!
  - Keep **optimal forces** for residuals low (increase control bounds if necessary)
  - Verify magnitude of **mass adjustments**
  - Floating or Sinking models? -> check overall model mass.
  - Verify magnitude of **residual forces**
  - Verify changes in the kinematics
  - Adjust **application point of forces on the pelvis to adjusted pelvis COM** (Actuator file)
- Lower weight on kinematics that track closely or have low confidence in measurement
- Make mass adjustments and run RRA again - repeat until residuals no longer change
Rules of good practise – CMC/SO

- Verify the changes in kinematics (CMC)
- Compare muscle activation to experimental EMG
- Verify the level of involvement of the reserve actuators
- Verify maxing out of muscle actuators.
  - Explosive movements: Double/triple maximal isometric force (?)
Rules of good practise

• Joint Reaction Forces
  – Compare to experimental data from instrumented implants.
  – Cave!: reserve actuators do not contribute to reaction forces.

• Induced acceleration analysis
  – Verify superposition
Is My Model Good Enough? Best Practices for Verification and Validation of Musculoskeletal Models and Simulations of Movement

Computational modeling and simulation of neuromusculoskeletal (NMS) systems enables researchers and clinicians to study the complex dynamics underlying human and animal movement. NMS models use equations derived from physical laws and biology to help solve challenging real-world problems, from designing prosthetics that maximize running speed to developing exoskeletal devices that enable walking after a stroke. NMS modeling and simulation has proliferated in the biomechanics research community over the past 25 years, but the lack of verification and validation standards remains a major barrier to wider adoption and impact. The goal of this paper is to establish practical guidelines for verification and validation of NMS models and simulations that researchers, clinicians, reviewers, and others can adopt to evaluate the accuracy and credibility of modeling studies. In particular, we review a general process for verification and validation applied to NMS models and simulations, including careful formulation of research questions and methods, traditional verification and validation steps, and documentation and sharing of results useful for use and testing by other researchers. Modeling the NMS system and simulating its motion involves methods to represent neural control, musculoskeletal geometry, muscle tendon dynamics, contact forces, and multibody dynamics. For each of these components, we review modeling choices and software verification guidelines; discuss variability, errors, uncertainty, and sensitivity relationships; and provide recommendations for verification and validation by comparing experimental data and testing robustness. We present a series of case studies to illustrate key principles. In closing, we discuss challenges the community must overcome to ensure that modeling and simulation are successfully used to solve the broad spectrum of problems that limit human mobility.