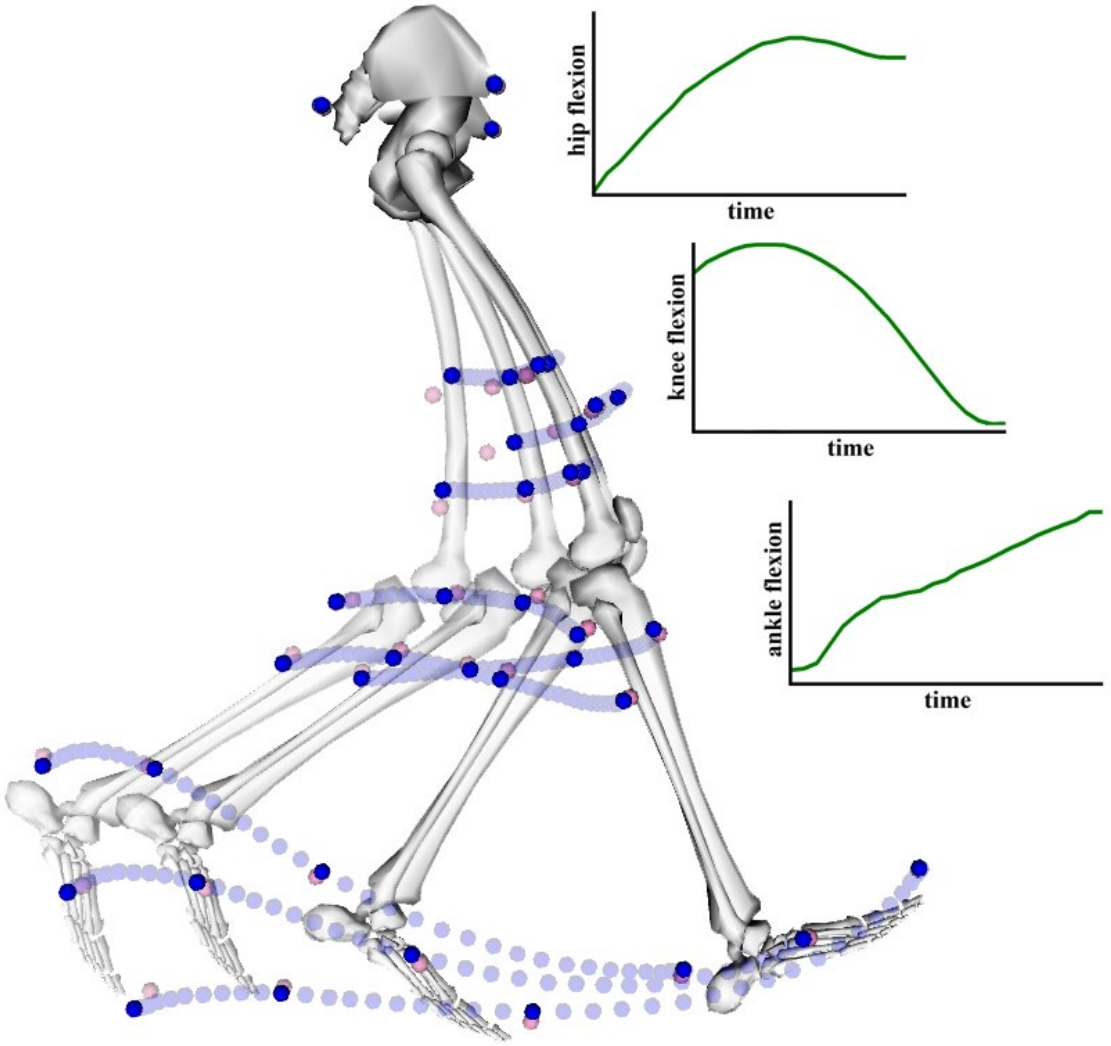
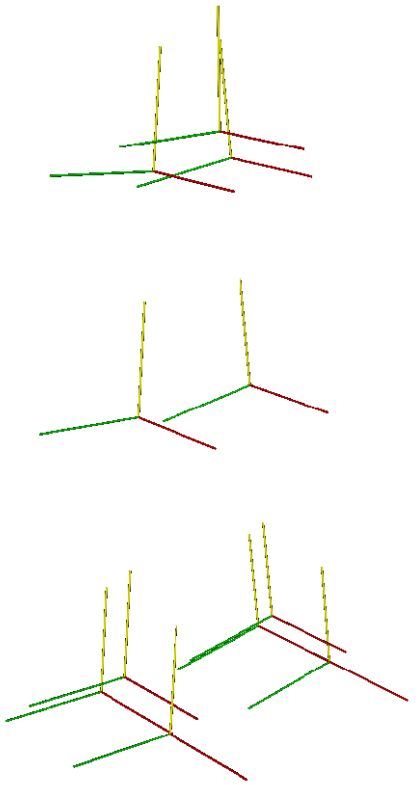


Inverse Kinematics

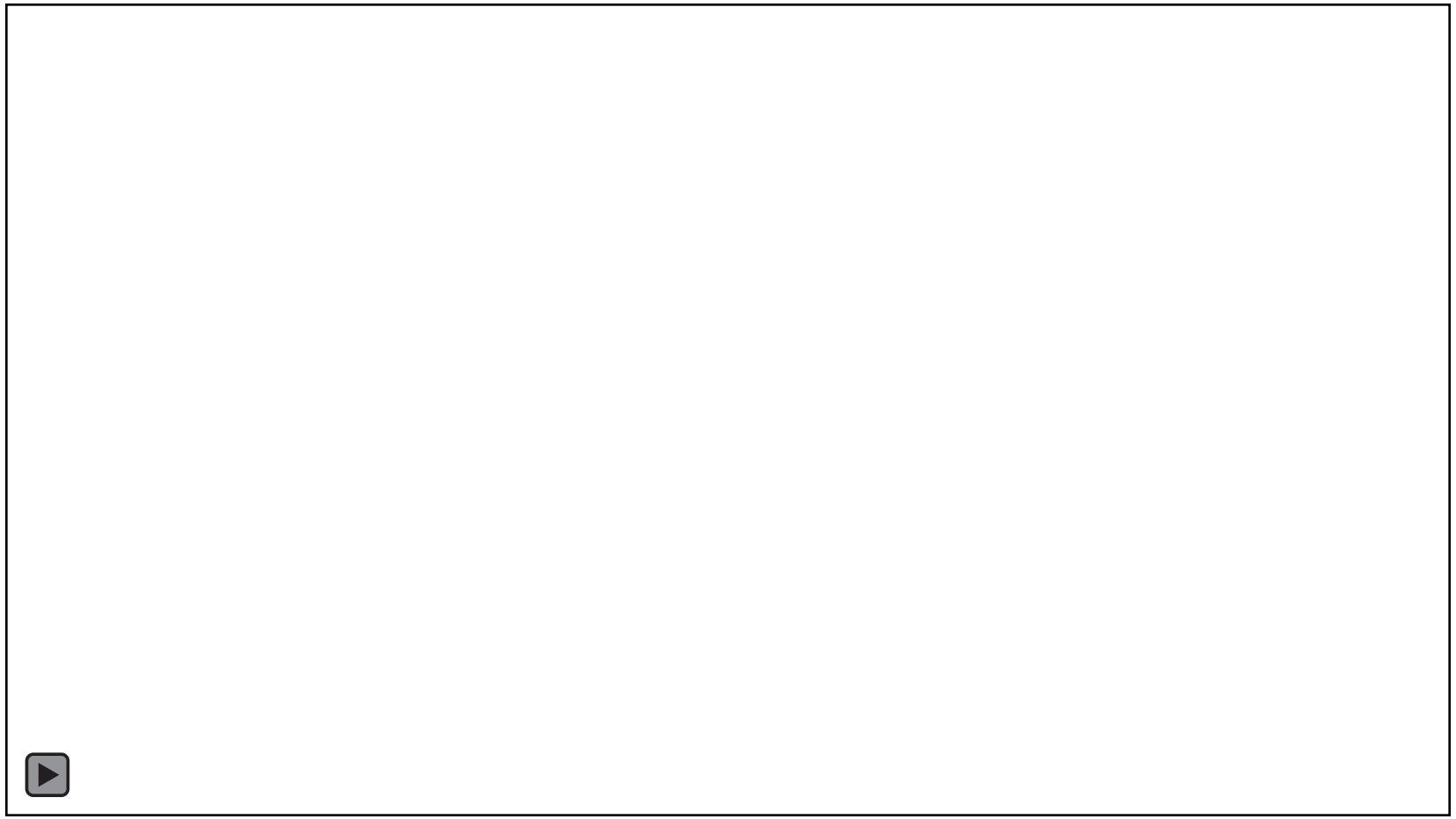
OpenSim Workshop

Modeling without Constraints

- Adjacent bodies are independent
- Bodies can rotate and translate with respect to adjacent bodies
- If three markers per segment, model markers and experimental markers match perfectly by definition
- No fixed joint centers



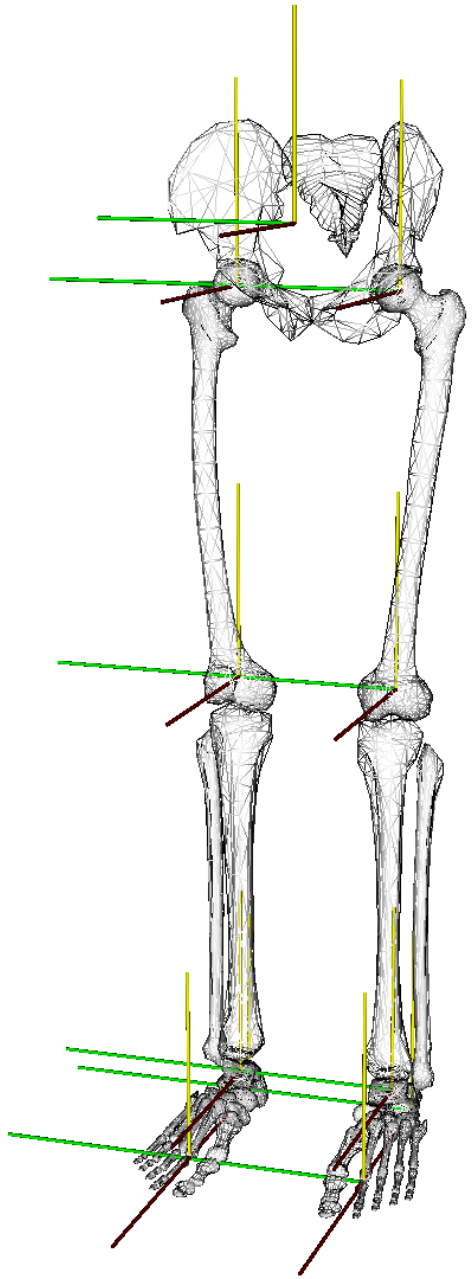
Kinematics without Constraints



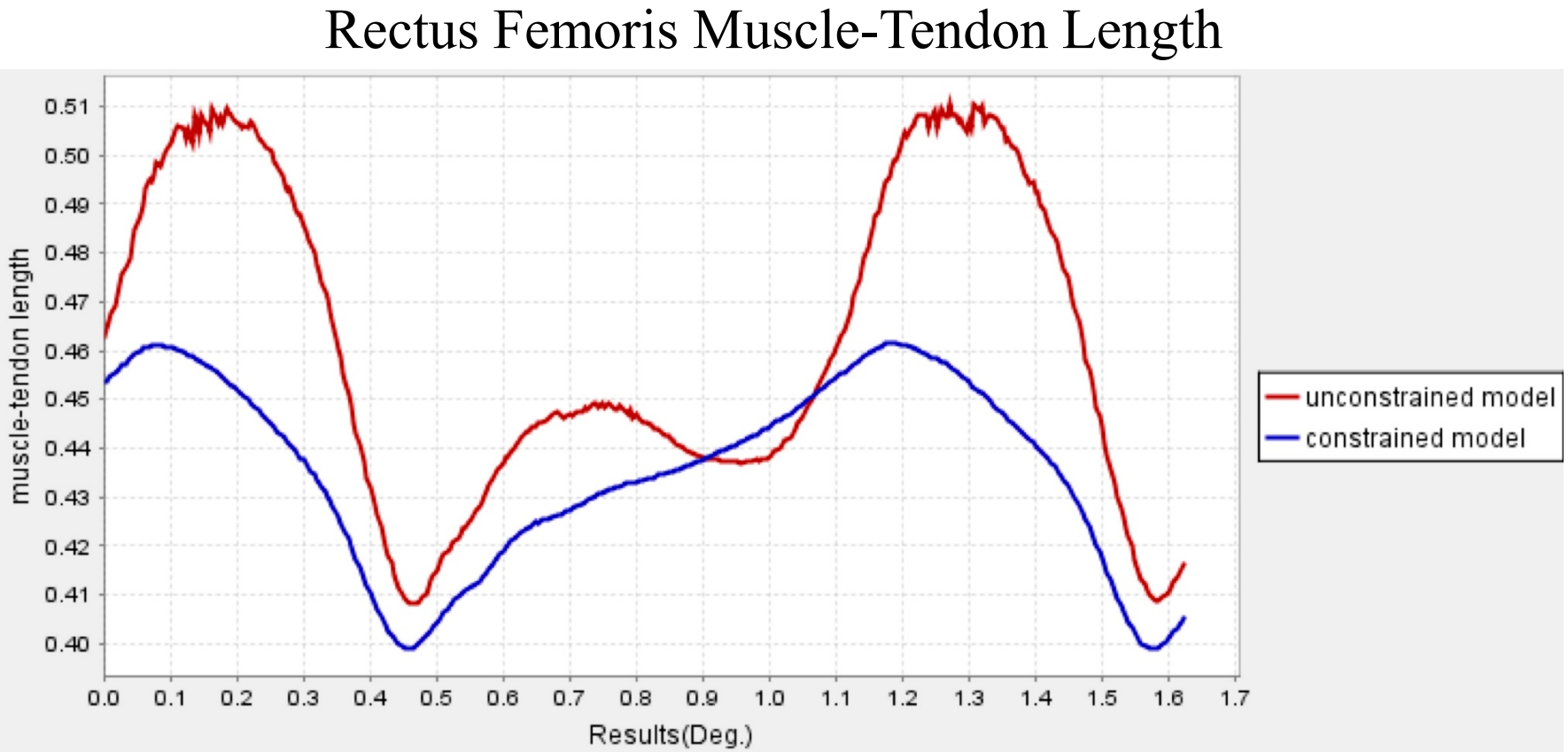
Femur penetrates and dislocates from pelvis

Modeling Constraints

- Body lengths maintained
- Joints don’t dislocate or interpenetrate



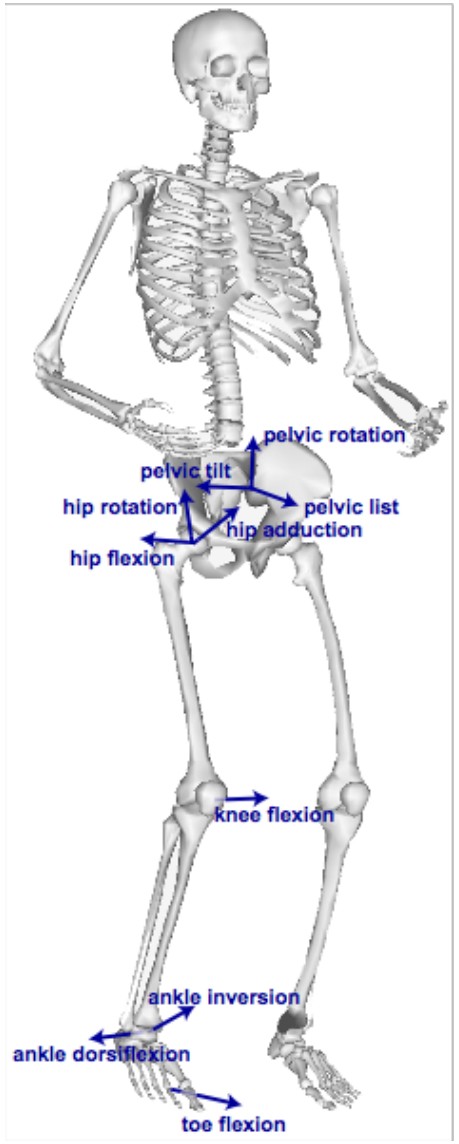
Kinematics without Constraints



Constrained model has more realistic muscle-tendon lengths

Modelling with OpenSim

- OpenSim models include rigid bodies and joint constraints
- Marker-based methods for kinematics results in small marker errors, but allow unphysiological motion between bodies
- Inverse Kinematics poses the model to minimize marker errors, but limits motion of the bodies
- Models with constraints are more accurate (Lu and O'Connor, 1999)

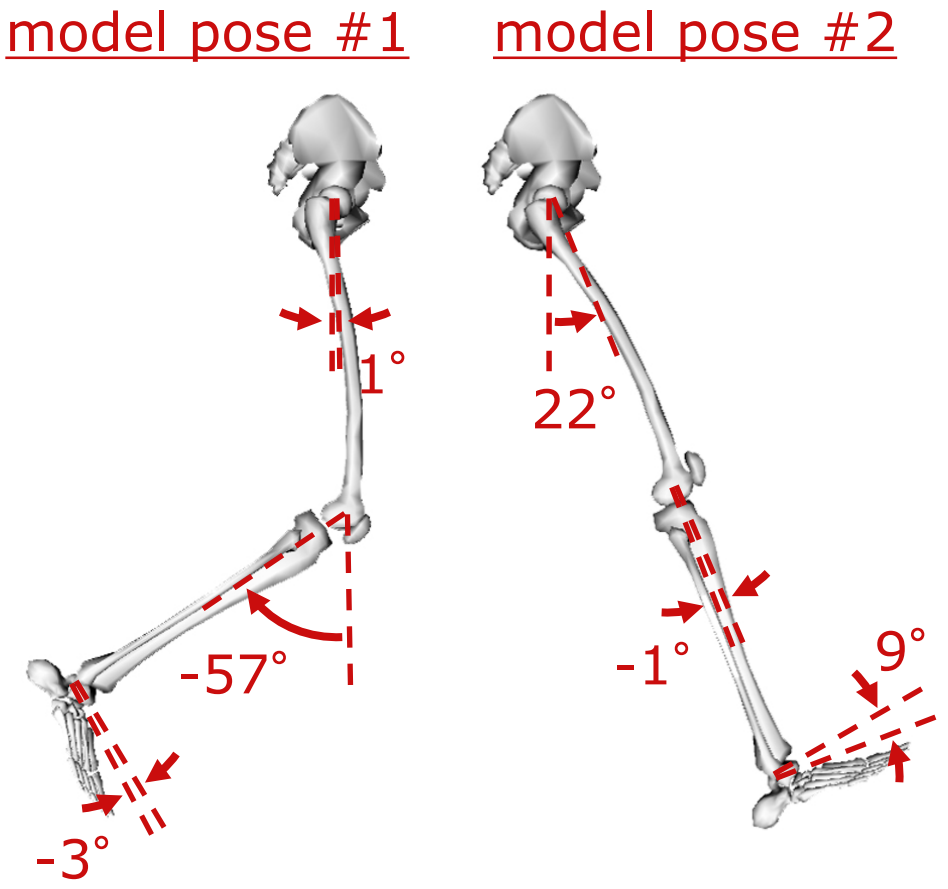


Key Concepts

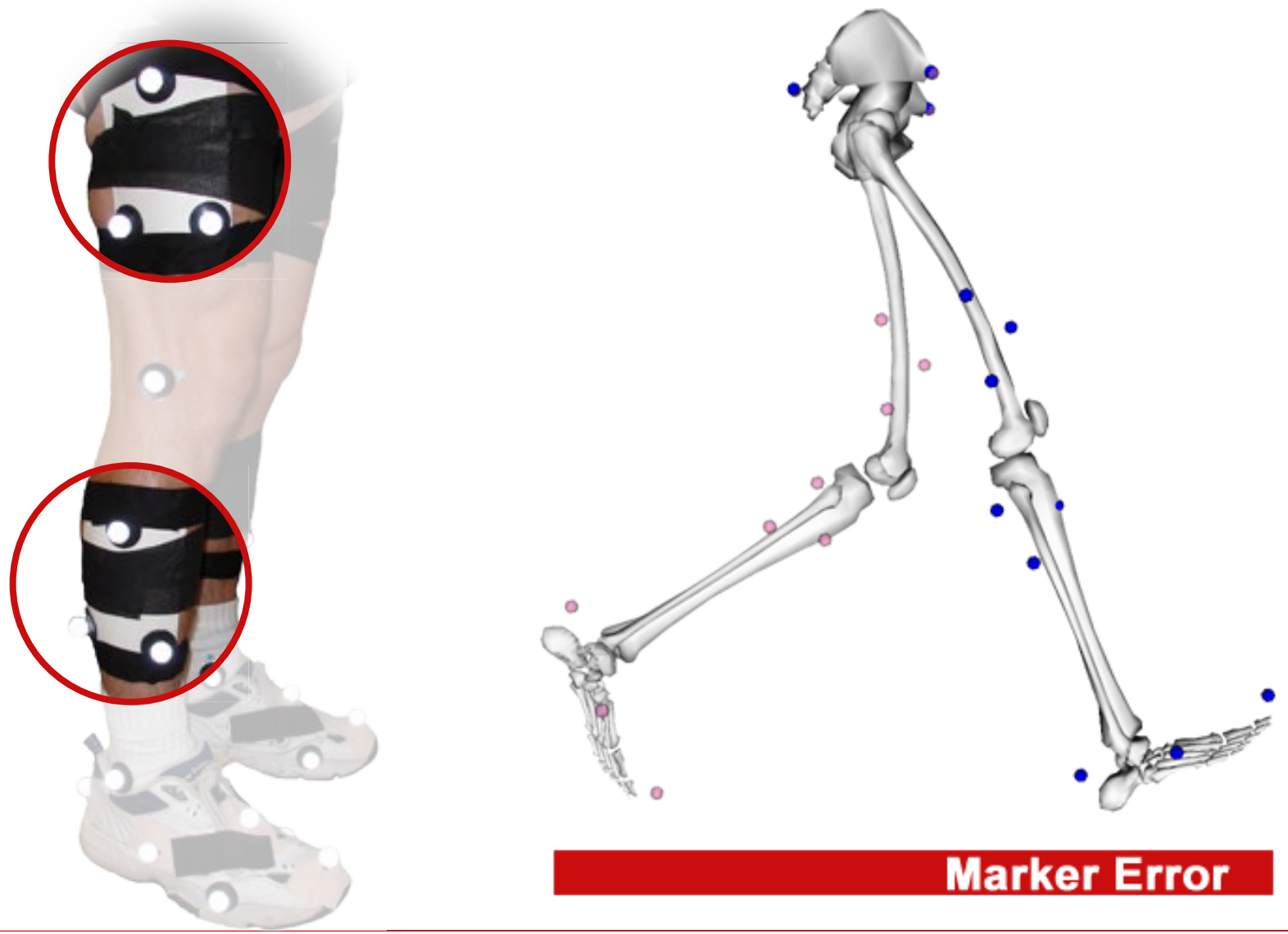
- Model pose and coordinates
- Marker error
- Coordinate error
- Weighted least squares minimization

Model Pose and Coordinates

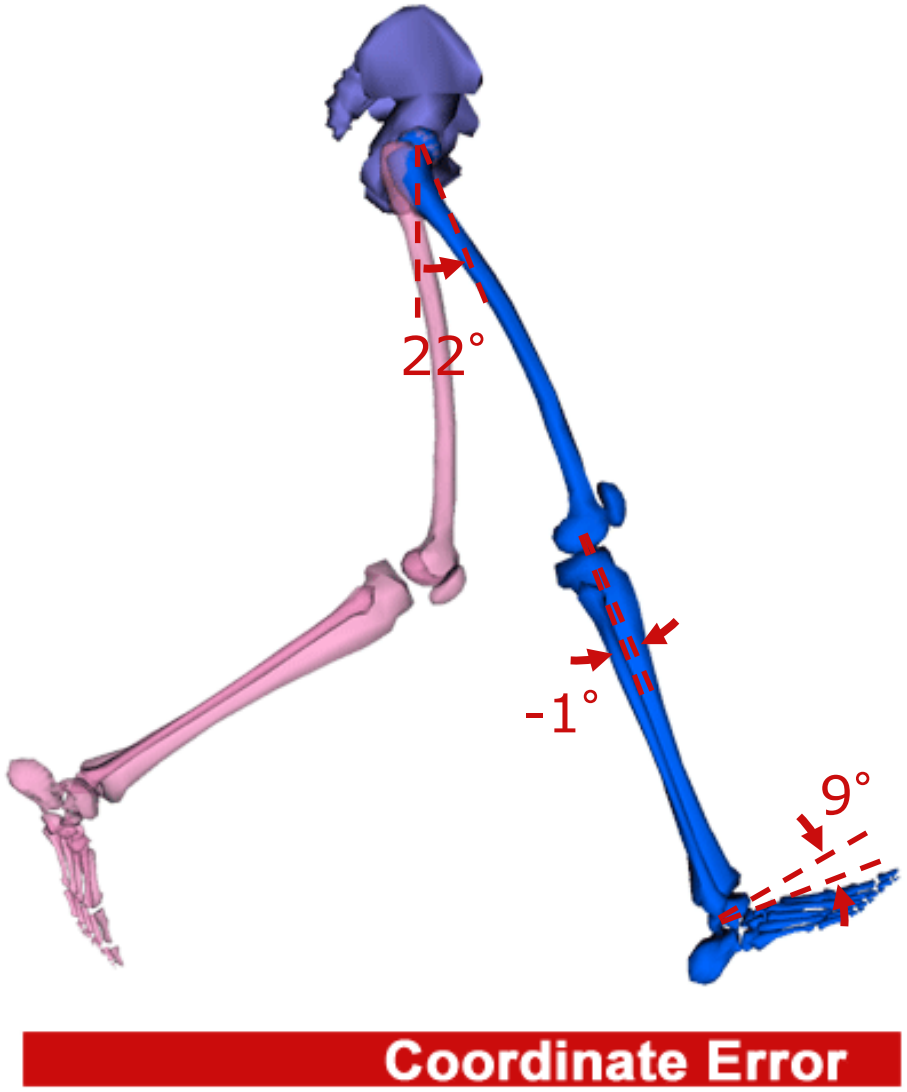
- Model Pose
  - Orientations and locations of body segments in the model
  - Defined by set of model coordinates
- Coordinate
  - Joint angle or distance specifying relative orientation or location of two body segments



Marker Error

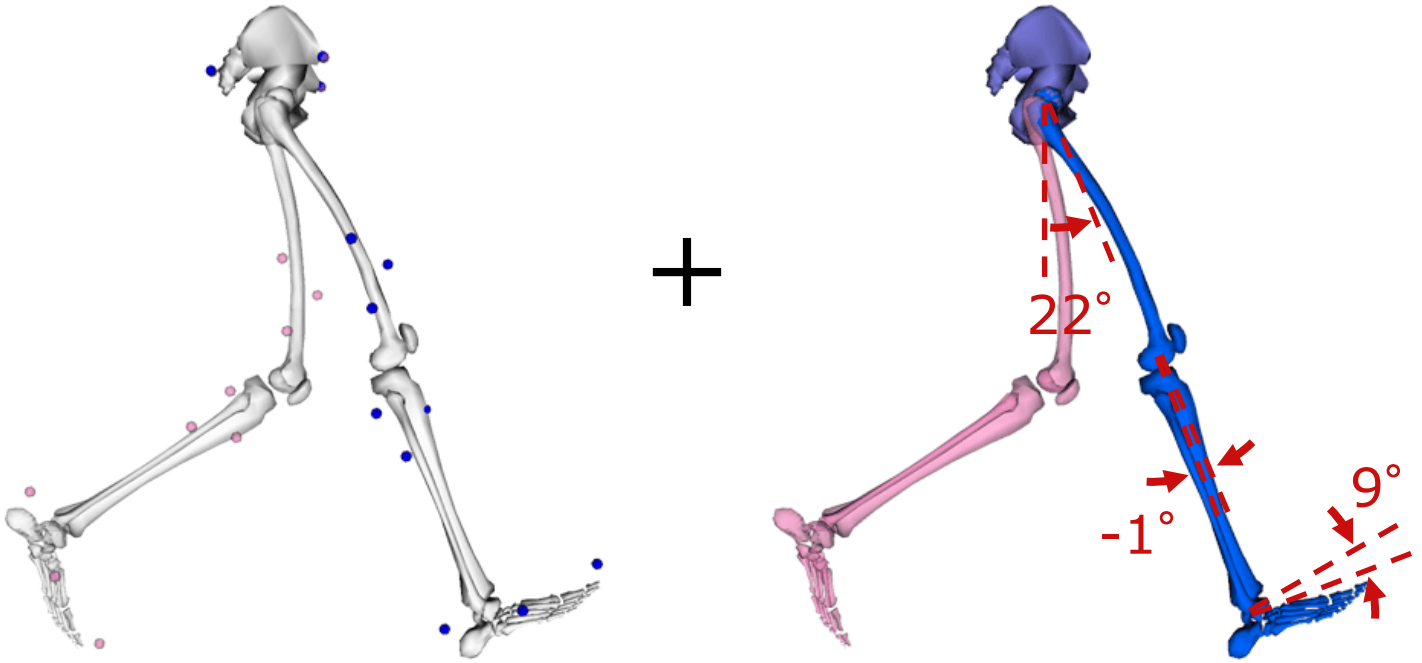


Coordinate Error



Weighted Least Squares Minimization

$$\min_{q}\left[\sum_{m=1}^{\#\text{ markers}} w_m \left\| x_m^{\exp} - x_m(q) \right\|^2 + \sum_{c=1}^{\#\text{ coordinates}} \omega_c \left(q_c^{\exp} - q_c \right)^2 \right]$$

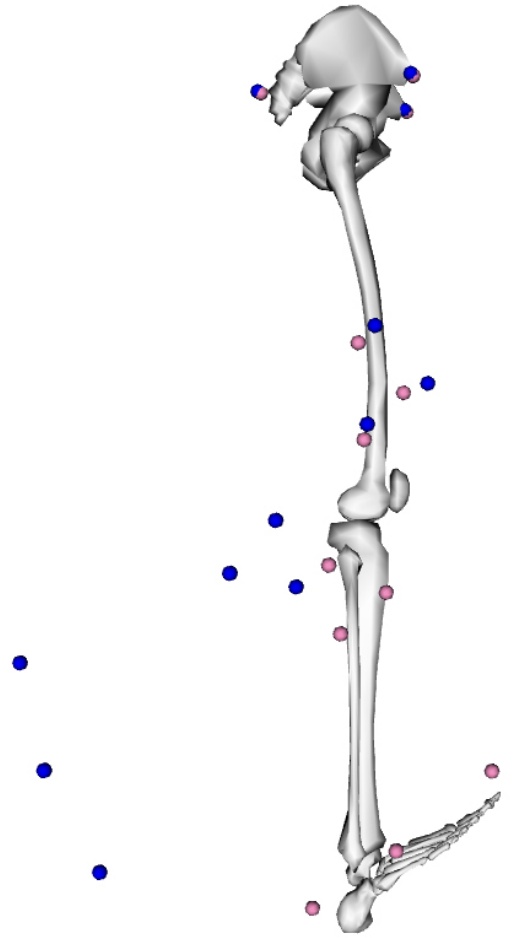


Marker Error

Coordinate Error

Exercise

1. For the model shown on the right, which **coordinate(s)** need to be ***adjusted to*** create a model pose that ***"best matches"*** the **experimental markers** shown at the beginning of swing phase?

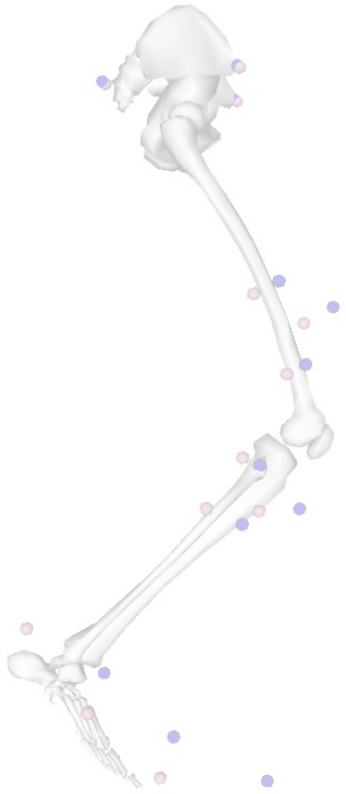


A. Hip
B. Knee
C. Ankle
D. Hip and ankle
E. Knee and ankle

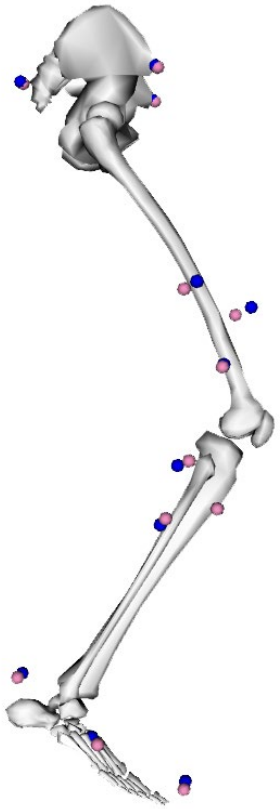
Exercise

2. For the **model poses** and experimental markers shown below, which combination of pose and markers has the ***minimum*** **marker errors**?

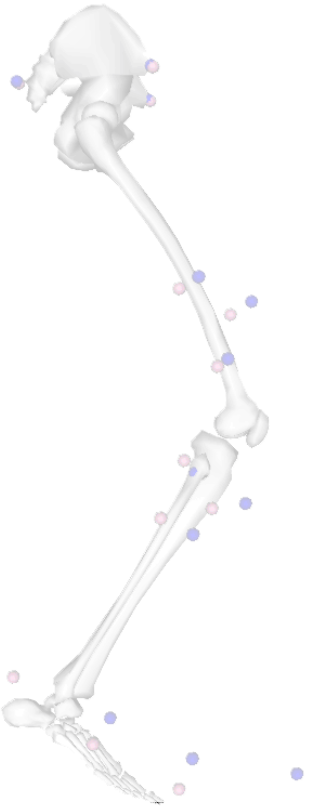
A.



B.



C.



Exercise

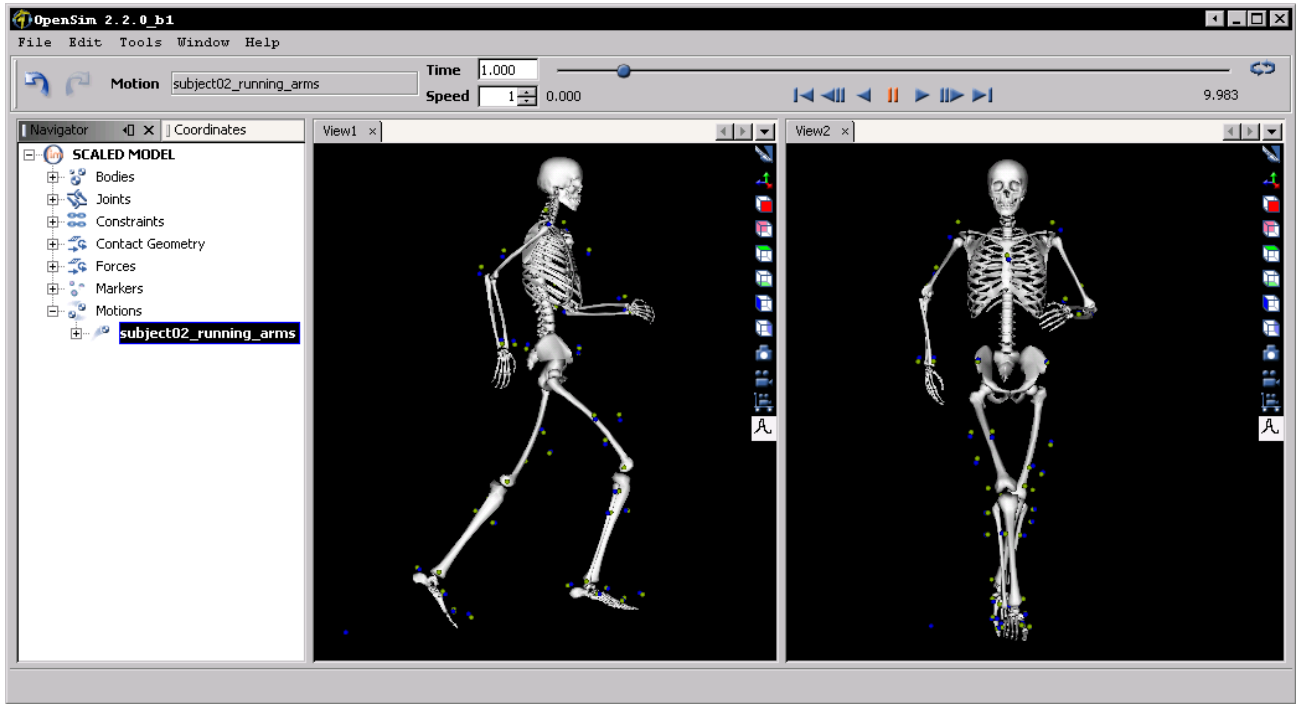
3. In theory, experimental **markers on the thigh and shank** could have ***more skin movement artifacts*** compared with the **foot markers**; which of the following scenarios would be ***most appropriate*** for the **weighted least squares minimization** solved by the Inverse Kinematics Tool?

   A. Decrease tracking weights on thigh markers
   B. Decrease tracking weights on shank markers
   C. Increase tracking weights on foot markers
   D. All of the above

Inverse Kinematics (IK) – Tips and tricks

- Highest weightings to markers that you trust the most
- Inverse kinematics benefits from redundant markers
- During evaluation, compare kinematics to the literature and review marker errors
- Good kinematics come from good data and a well-scaled model

Inverse Kinematics (IK)



TIPS & TRICKS

Marker weights are relative

X-axis = forward

Check max and RMS marker errors in messages window

Max marker error should be < 2 cm with RMS error <1 cm

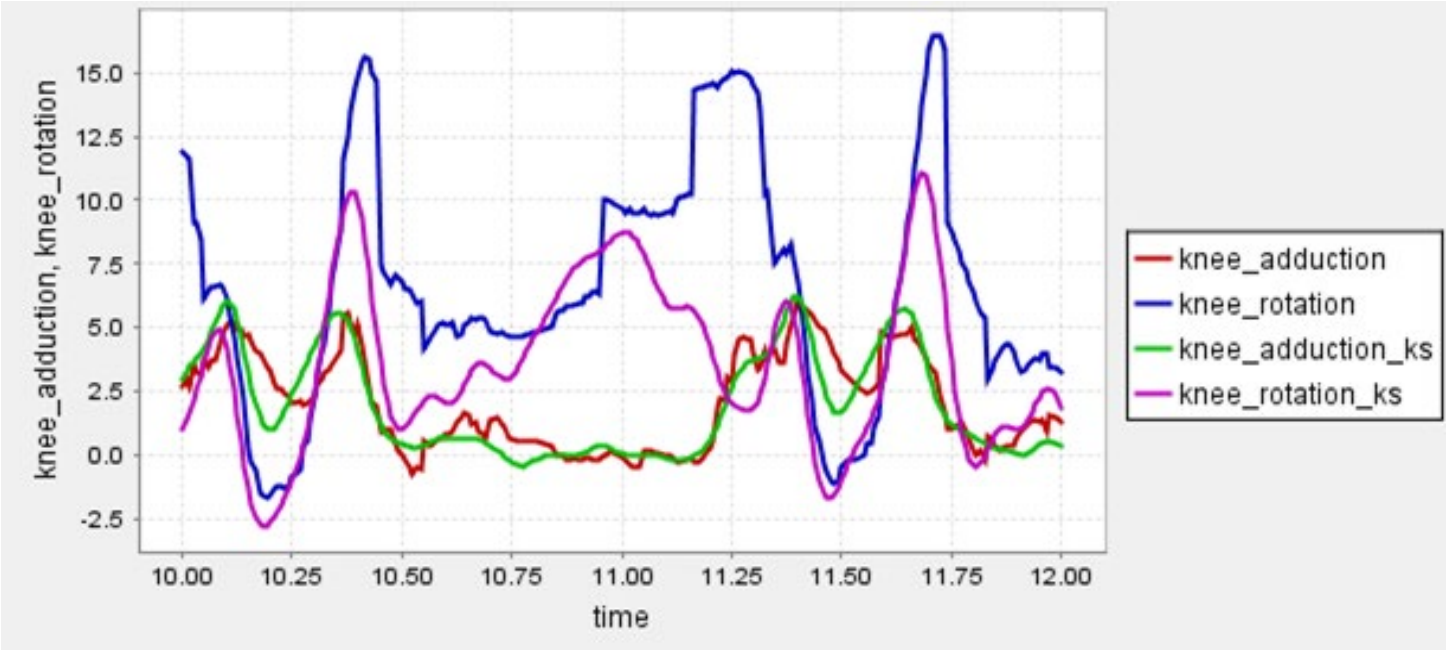
Kalman Smoothing for Inverse Kinematics (KS)

- Kalman smoothing (KS) takes a priori knowledge about smoothness of motion into account. (No discontinuities in positions, velocities, accelerations, ...)

- Positions, velocities, and accelerations simultaneously estimated based on:
  1. Measurement model: correspondence between measured and model marker positions (cfr IK Tool).
  2. Process model: smoothness of the motion by assuming that n-th derivative of generalized coordinates is constant.

- Uncertainty is modeled by:
  1. Measurement uncertainty (How uncertain are we about the measured marker positions?)
  2. Process uncertainty (How uncertain are we about the assumption that (n+1)-th derivative of generalized coordinates is zero?)

Kalman Smoothing for Inverse Kinematics (KS)



TIPS & TRICKS
https://simtk.org/home/kalmanforik
Command line: ks –S ks_setup.xml
Same input and setup files as IK Tool
Marker weights are absolute (inverse of expected measurement error in cm)!

Demo

- C:\OpenSim 3.3\Models\Gait2392_Simbody

- Inverse Kinematics - GUI

- Kalman Smoothing for Inverse Kinematics – command line
  available on https://simtk.org/home/kalmanforik
  subject01_Setup_KS = subject01_Setup_IK
  except marker weights 10 → 2

- Evaluating your Results:
  - Total RMS (< 2 cm) and maximum marker errors (2-4 cm).
    Change weightings, redo marker placement or scaling.
  - If using coordinates from a motion capture system, make sure that the joint/coordinate definitions match.
  - Compare your results to similar data reported in the literature.