

Inverse Kinematics

OpenSim Workshop

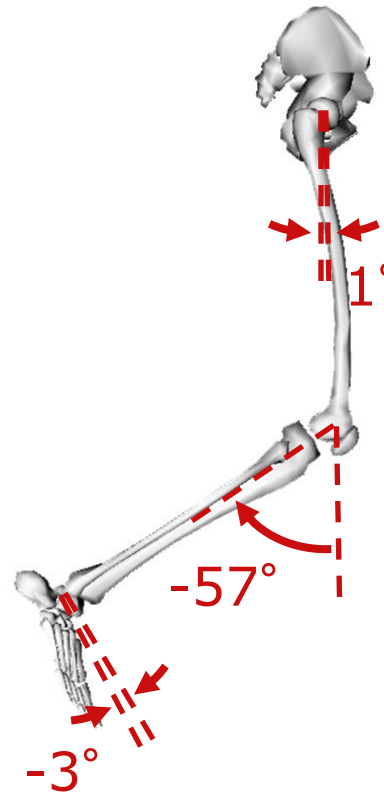
Key Concepts

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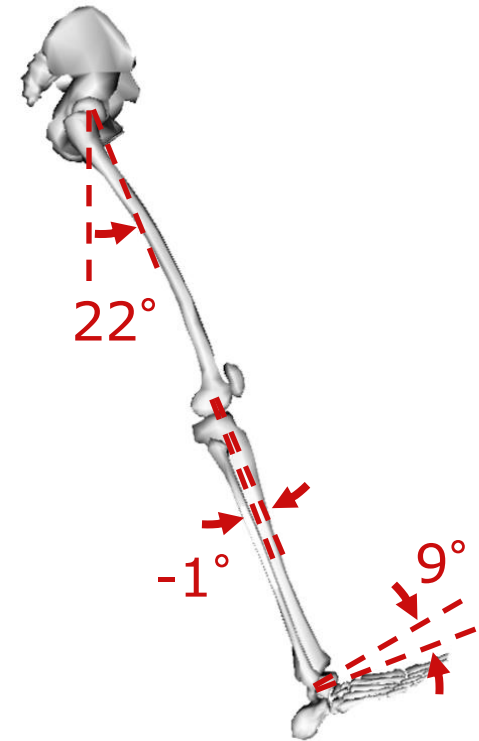
Model Pose and Coordinates

- 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

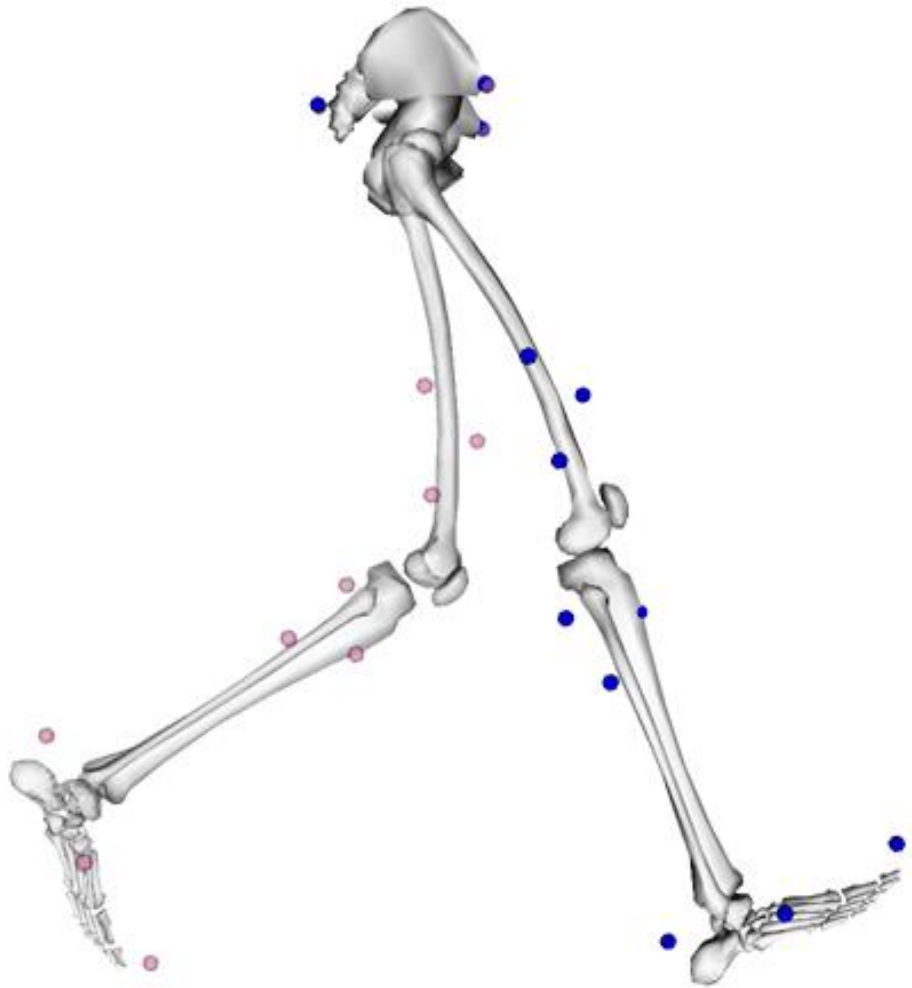
model pose #1



model pose #2

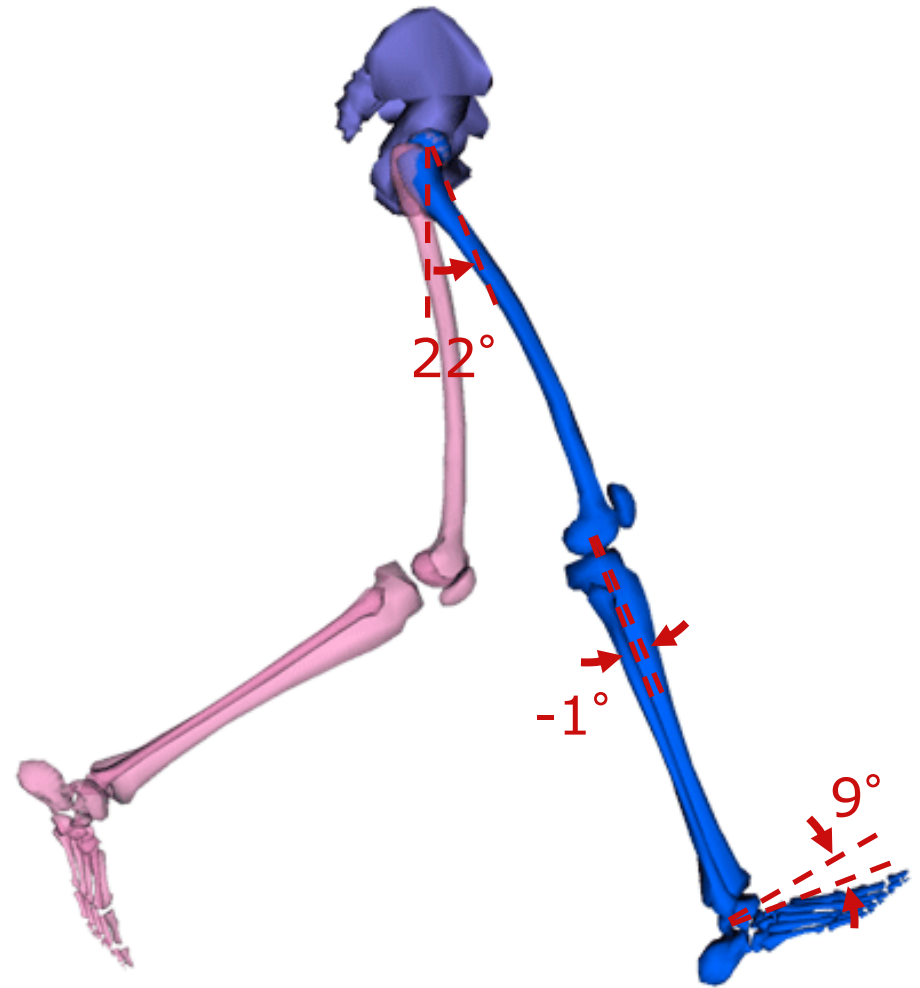


Marker Error



Marker Error

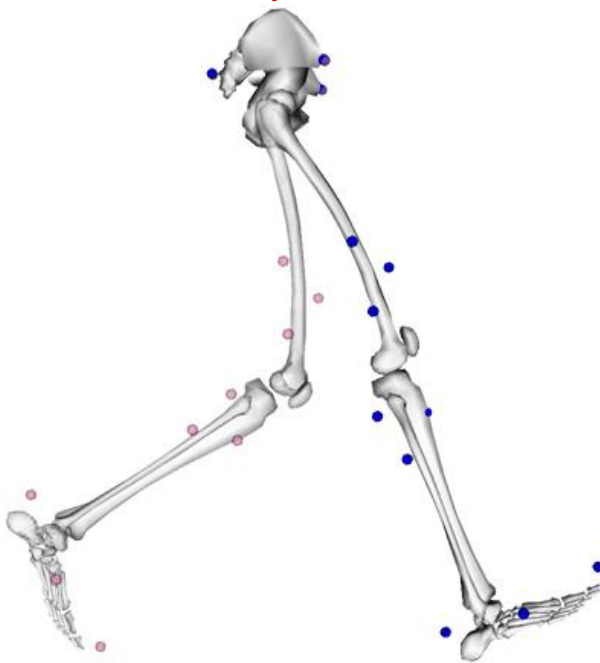
Coordinate Error



Coordinate Error

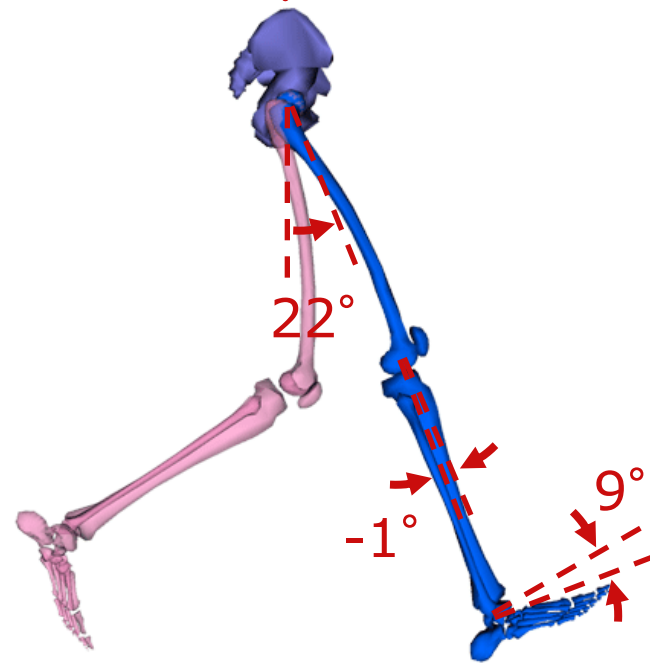
Weighted Least Squares Minimization

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



Marker Error

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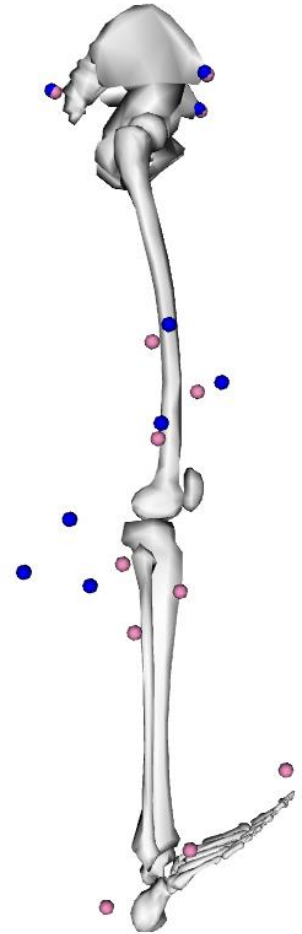


Coordinate Error

Exercise

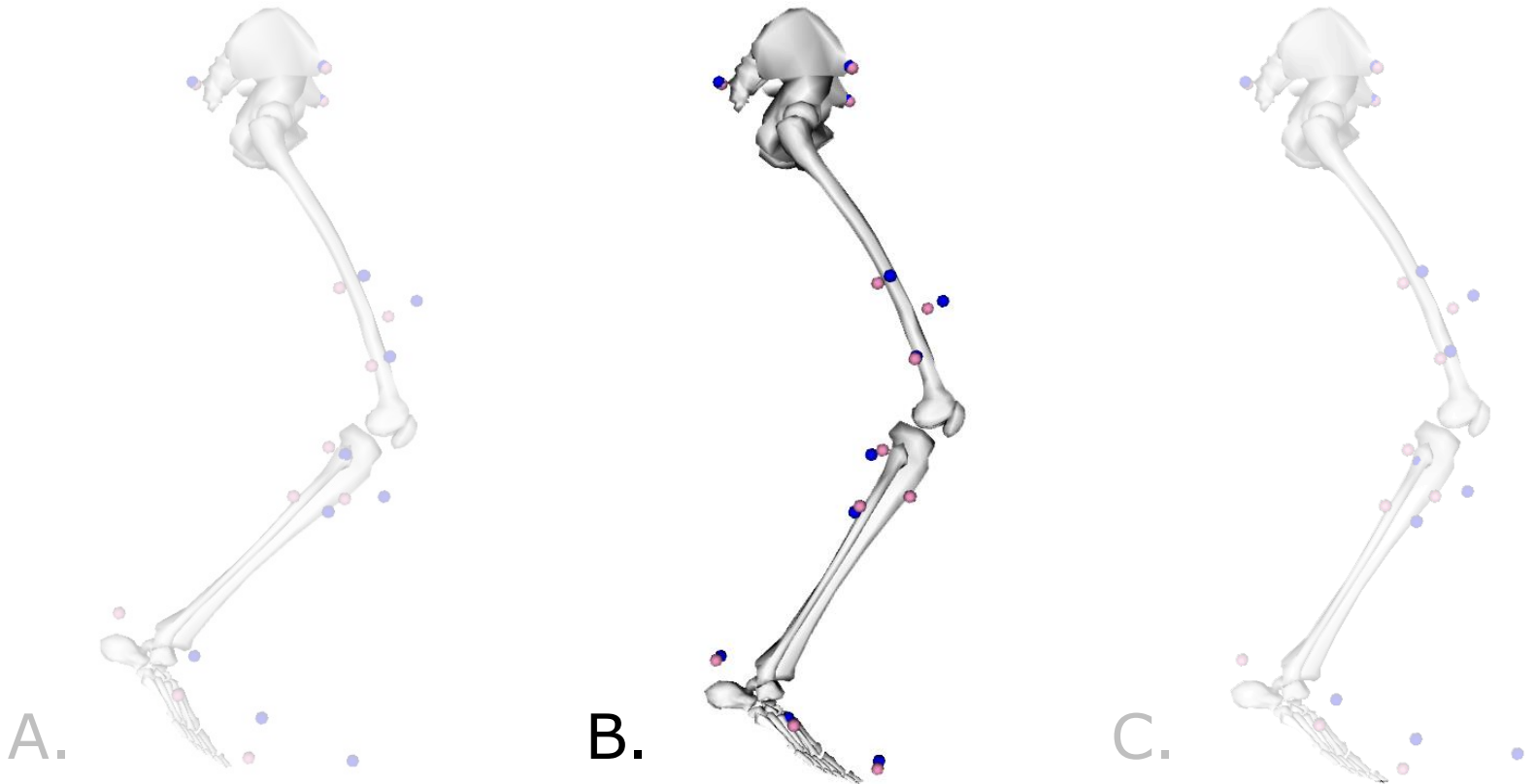
1. For the model shown on the right, which **coordinate(s)** need to be ***adjusted to*** create a model pose that ***“best matches”*** the **experimental markers** shown at the beginning of swing phase?

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



Exercise

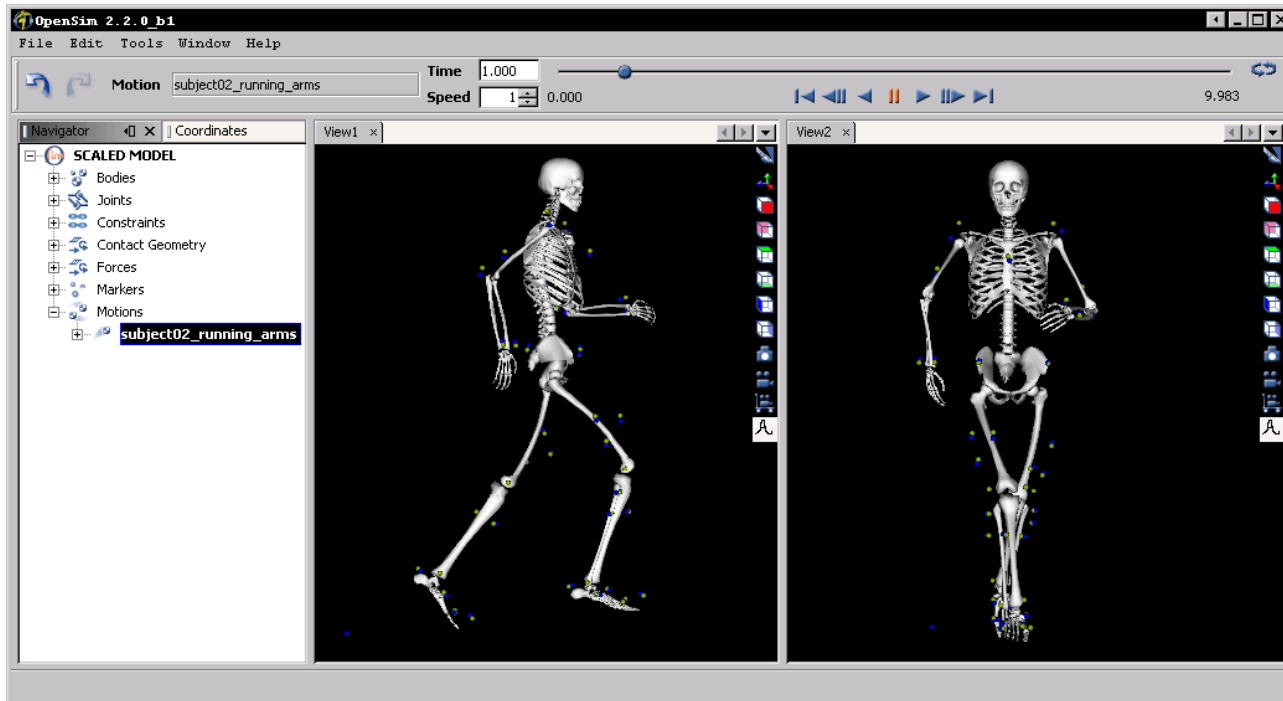
2. For the **model poses** and experimental markers shown below, which combination of pose and markers has the ***minimum*** marker errors?



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
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Inverse Kinematics (IK)



TIPS & TRICKS

Marker weights are relative

X-axis = forward

Check max and RMS marker errors in messages window

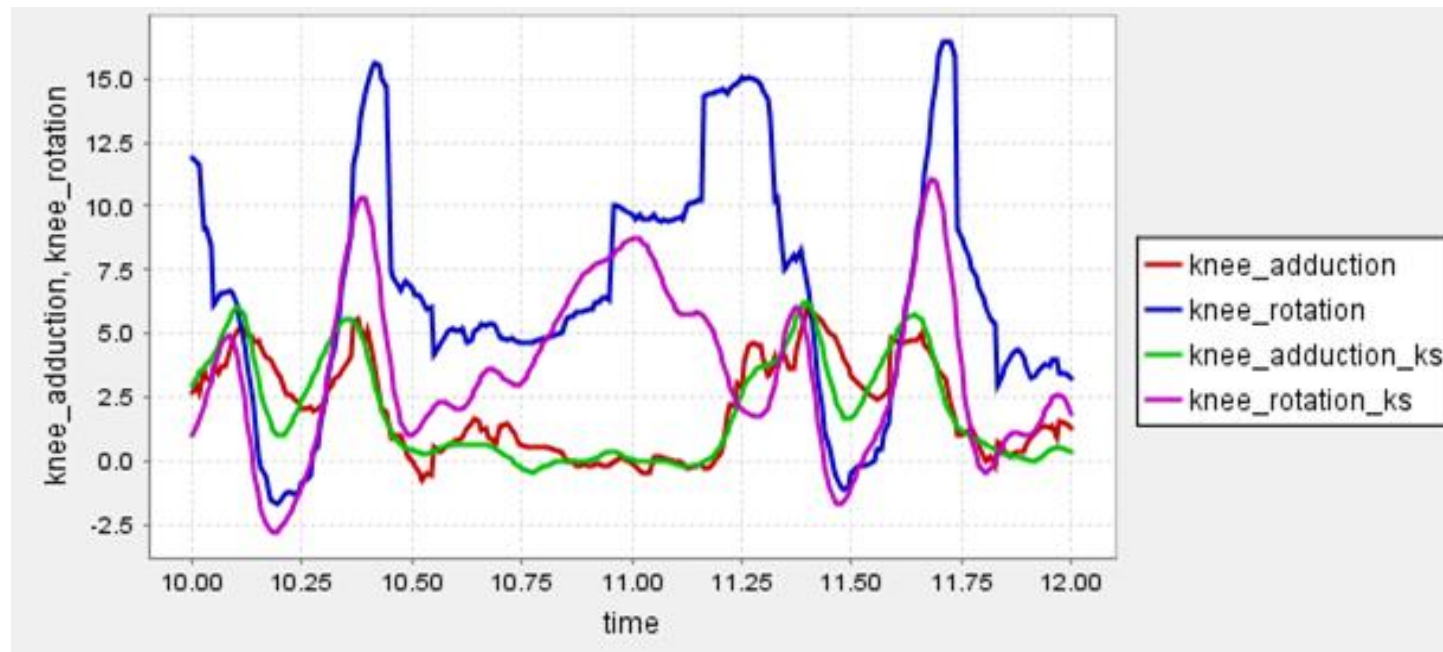
Weight “motion” marker triads on body segments higher than anatomical markers

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.
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