BIP OpenSim

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Required Software

- OpenSim (version 4.4 preferable)
- Mokka
- Windows OS (tutorial works for Mac with minor adjustments)

Useful tutorials:

- https://simtk-confluence.stanford.edu:8443/display/OpenSim/Tutorial+1+-+Intro+to+Musculoskeletal+Modeling
- https://simtk-confluence.stanford.edu:8443/display/OpenSim/Workshops+and+Events
- https://simtk-confluence.stanford.edu:8443/display/OpenSim/ESMAC+Workshop+September+2022
- https://simtk-confluence.stanford.edu:8443/display/OpenSim/Overview+of+OpenSim+Workflows#OverviewofOpenSimWorkflows-SimulationPipelines(Workflows)

Useful tools:

- VSCode or other IDE

Check the cheat_sheet.pdf for detailed information on terminology used throughout

- Bodies
- Actuators
- Probes
- Markers

Day 1

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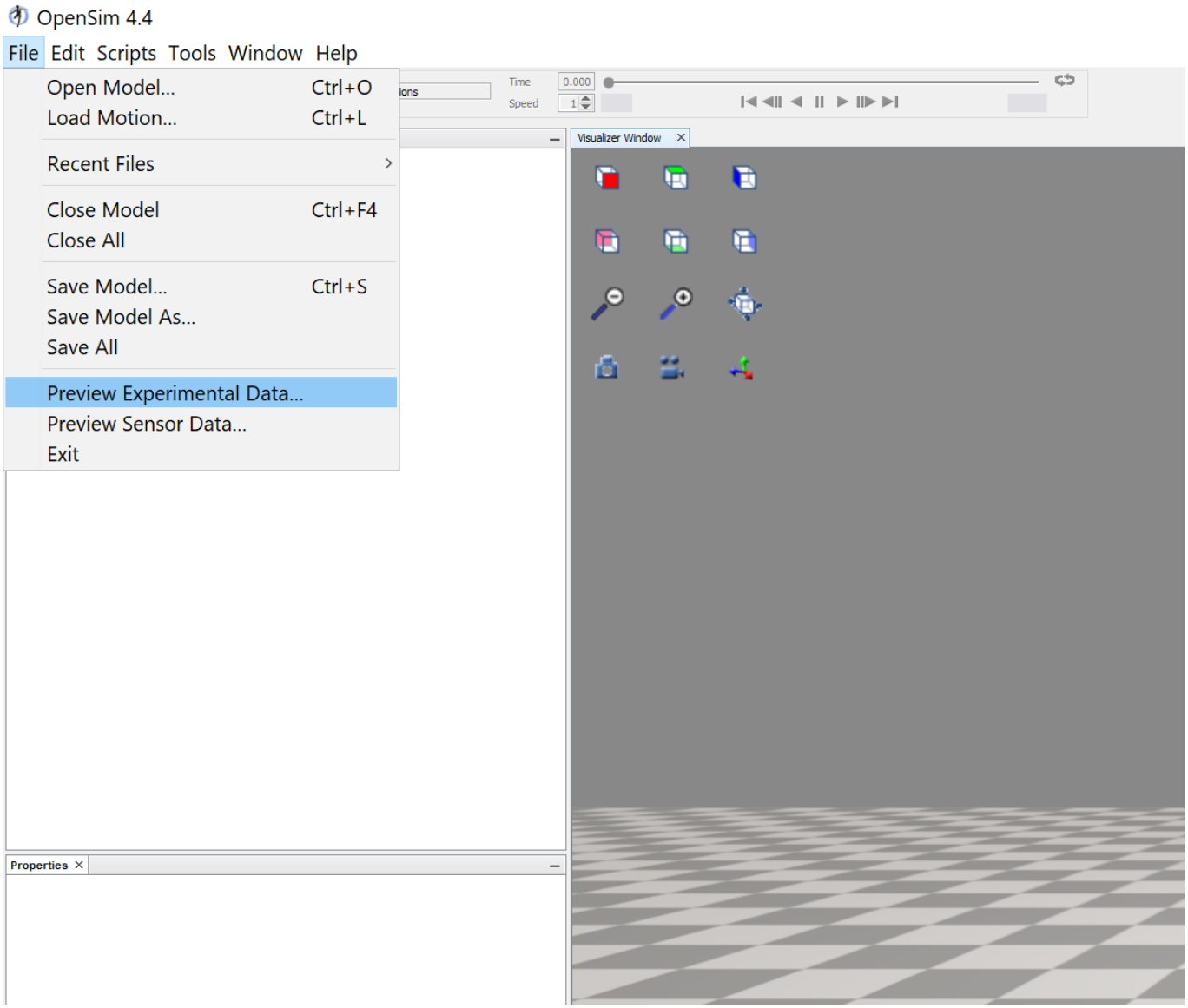
1. Intro - 3h (start at 14h00)

1.1 Quick examples based on presentations (20 min - 14h30)

https://www.sciencedirect.com/science/article/abs/pii/S0278591920305068
https://www.sciencedirect.com/science/article/abs/pii/S0021929009003169
https://www.sciencedirect.com/science/article/abs/pii/S0966636223010044

1.2 What is an MSK Skeletal Model? Open your first model (30 min - 15h00)

- Open the folder "Hello_world_of_simulations"
- Open OpenSim
- Load model "gait2392_simbody.osim"
- Let's go through the different components step by step
- Explore the different commands and tools
- Use the tool "Preview Experimetnal Data" to view marker and grf
    - subject01_walk1.trc
    - subject01_walk1.trc



Questions:

- What are the components of a model?
- How can a model be edited? (GUI, text editor, scripting)
- How many bodies does this model have?
- How many muscles does this model have in each leg?
- What is the maximum isometric force of rect_fem_r?
- How many dof hip and knee joint have?
- How heavy is the tibia segment?
- Load experimental markers. Why are the markers doing a moon walk?
- Load experimental GRF. Why are the forces not below the feet markers? Make them alignned

1.3 Getting to know the files and plotting tool (30 min)

- Open the files in their respective software:
  - Use Mokka for .c3d files
  - Use excel for .trc, .mot, .sto
  - Use NotePad++ for .xml
  - Use OpenSim for .osim
- For those who cannot, we will provide assistance during a break

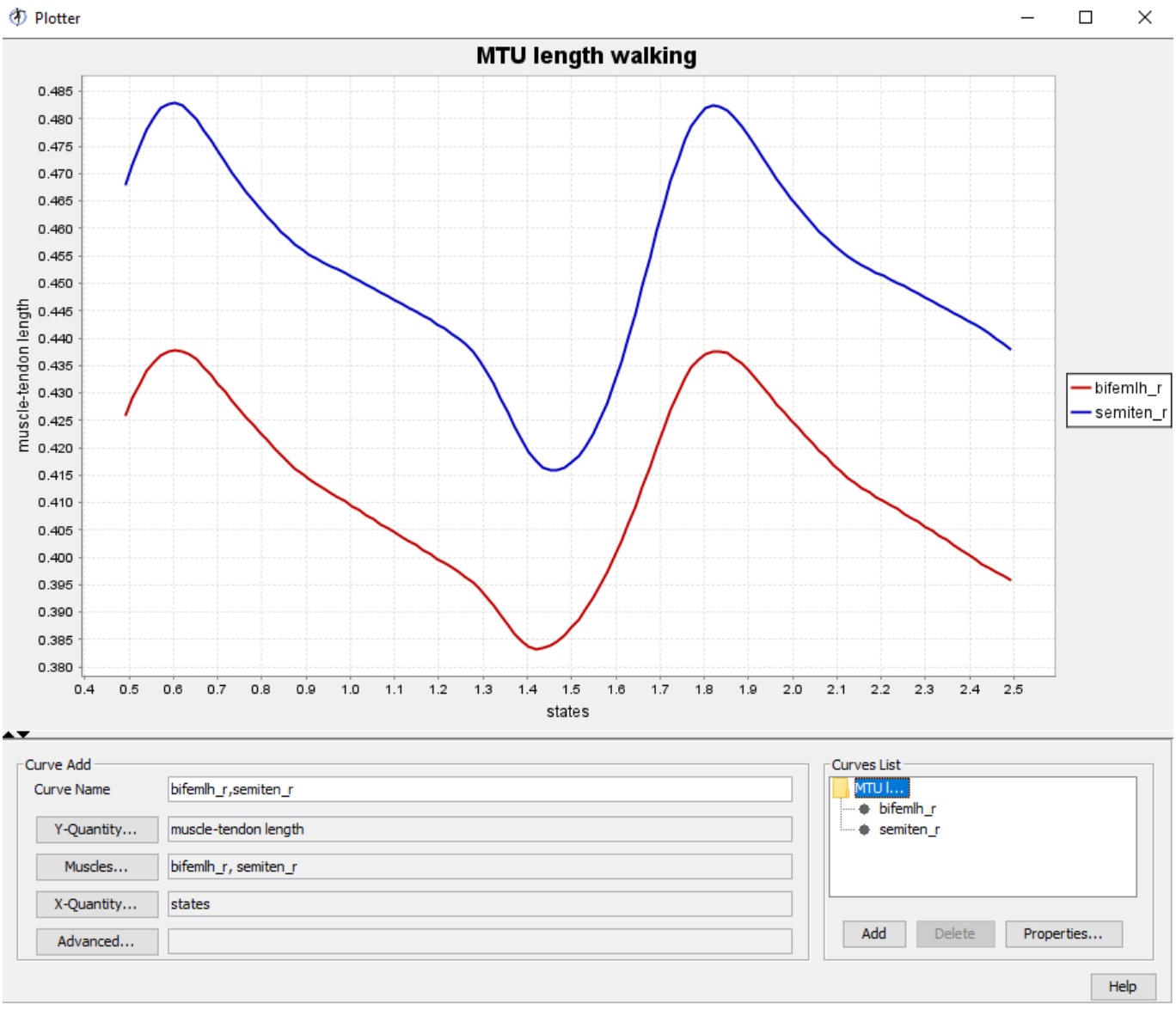
Questions:

- What is the maximum moment arm of psoas during hip_flexion_r?
- Why are moment arms negative?
- Plot the mtu length of the psoas_r during hip_flexion_r. Explain the figure.
- Plot mtu length of lat_gas_r and bflh_r during hip flexion. Why are they so different?
- Plot active, passive, and total-fiber force.

---------- 10 min Break ----------

1.4 Run all the steps of the simulation Gait2392 (60 min)

- Run scale tool (subject01_Setup_Scale.xml)
- Inverse kinematics tool (subject01_Setup_Scale.xml)
- Inverse dynamics tool (subject01_Setup_Scale.xml)
- Static optimization (subject01_Setup_Scale.xml)
- Analyze tool (subject01_Setup_Analyze.xml)
- Plot simulation results for each step (load the results files first)



Questions

- What are the range of marker errors during the inverse kinematics step?
- What are the peak hip, knee, and ankle angles?
- what are the peak sagittal joint moments hip, knee, and ankle?
- What are the lat_gas and rect_fem peak forces and activation?
- What are the mtu lengths for bflh_r and soleus_r.
- What are the maximum reserves moments hip_flexion_r, hip_adduction_r, hip_rotation_r, knee_angle_r, ankle_angle_r
- What is the peak vertical component of hip contact loads, relative to participants body weight?

Summary and questions

Day 2

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2. The importance of scalling and marker registration (3h)

2.0 Add markers to the model

2.1 Scaling, Inverse kinematics (1h)

- Theory https://simtk-confluence.stanford.edu:8443/display/OpenSim/How+Scaling+Works https://simtk-confluence.stanford.edu:8443/display/OpenSim/How+Inverse+Kinematics+Works
- Load the model
- Open the setup file
- Attempt scaling with incorrect settings
- Show how to adjust and apply proper scaling settings
- Scale the same model with two different sets of weights (1000 vs 500 vs 1 for anatomical landmarks)
    1. Load C:\Git\BIP_OpenSim_Hungarian_USports\ExampleData\Sprinting\009\ (make sure model is called Rajagopal_with_deep_hip_muscles)
    2. Change the weights and save new setup file
    3. Run Scale tool
    4. Overlay experimental markers (right click "subject01 -> Motions -> static pose")
    5. Load subject01_Setup_IK.xml and run IK tool
    6. Assess marker errors
    7. Repeat with different weights

Note: Right click the models to show/hide, change offset,...

2.1.1 Questions

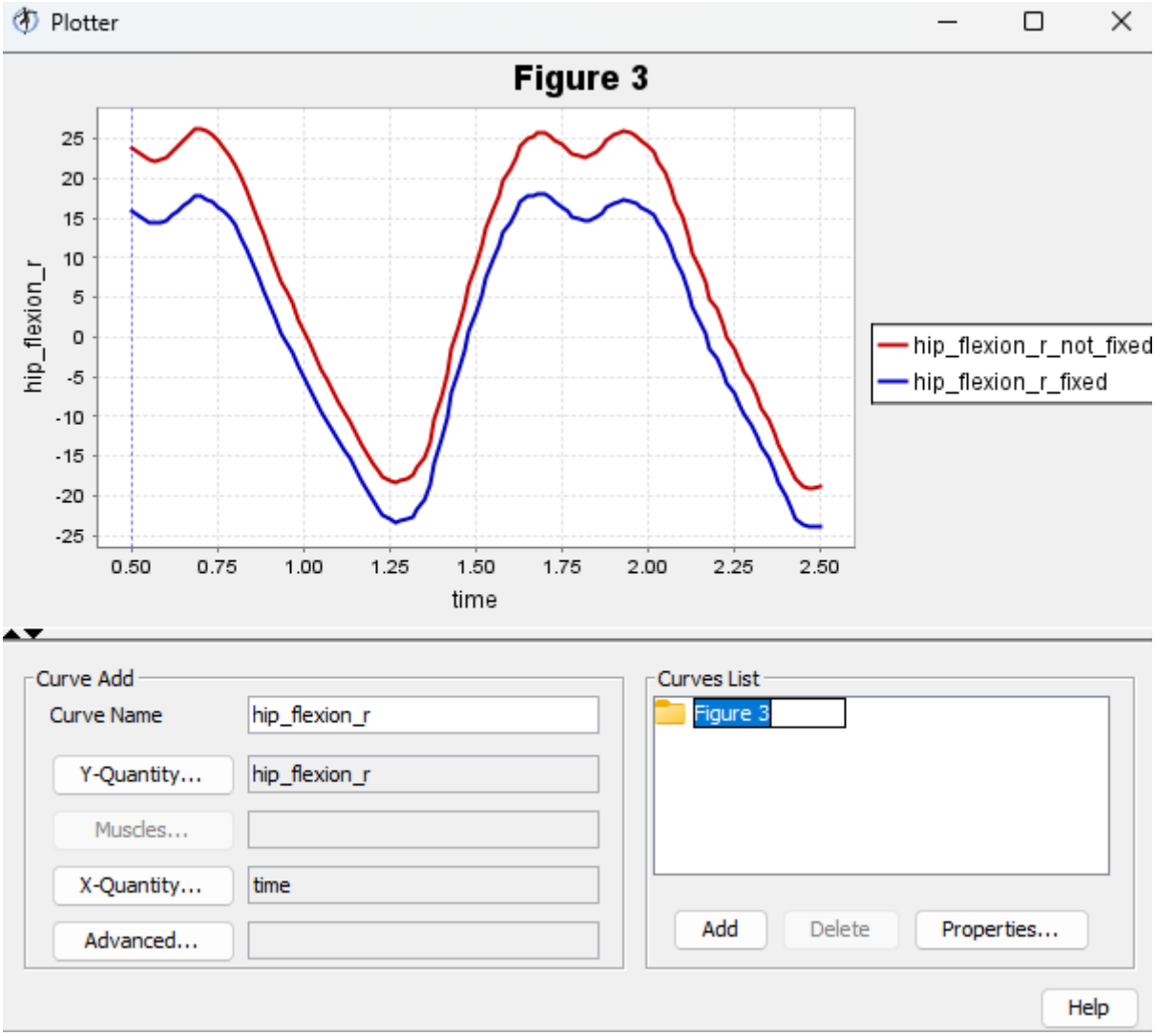
- How do marker weights change scale factors?
- What are, approximately, total, RMS, and maximum marker errors?
- Plot hip, knee, and ankle angles
- What is the peak hip flexion angle during sprinting?
- What is the peak knee flexion angle during sprinting?
- What is the peak ankle plantarflexion angle during sprinting?
- How can you increase the trust on your results?

2.2 Register markers (30 min)

- Create a new model with all the markers set to not "fixed" (Tip: use the replace function in the tex editor)
- Save model
- Load the new model and run scale
- Run inverse kinematics

2.2.1 Questions

- What happened to the marker errors during scalling?
- Compare hip, knee, and ankle angles between the two models.
- Describe what happened to each joint angle.



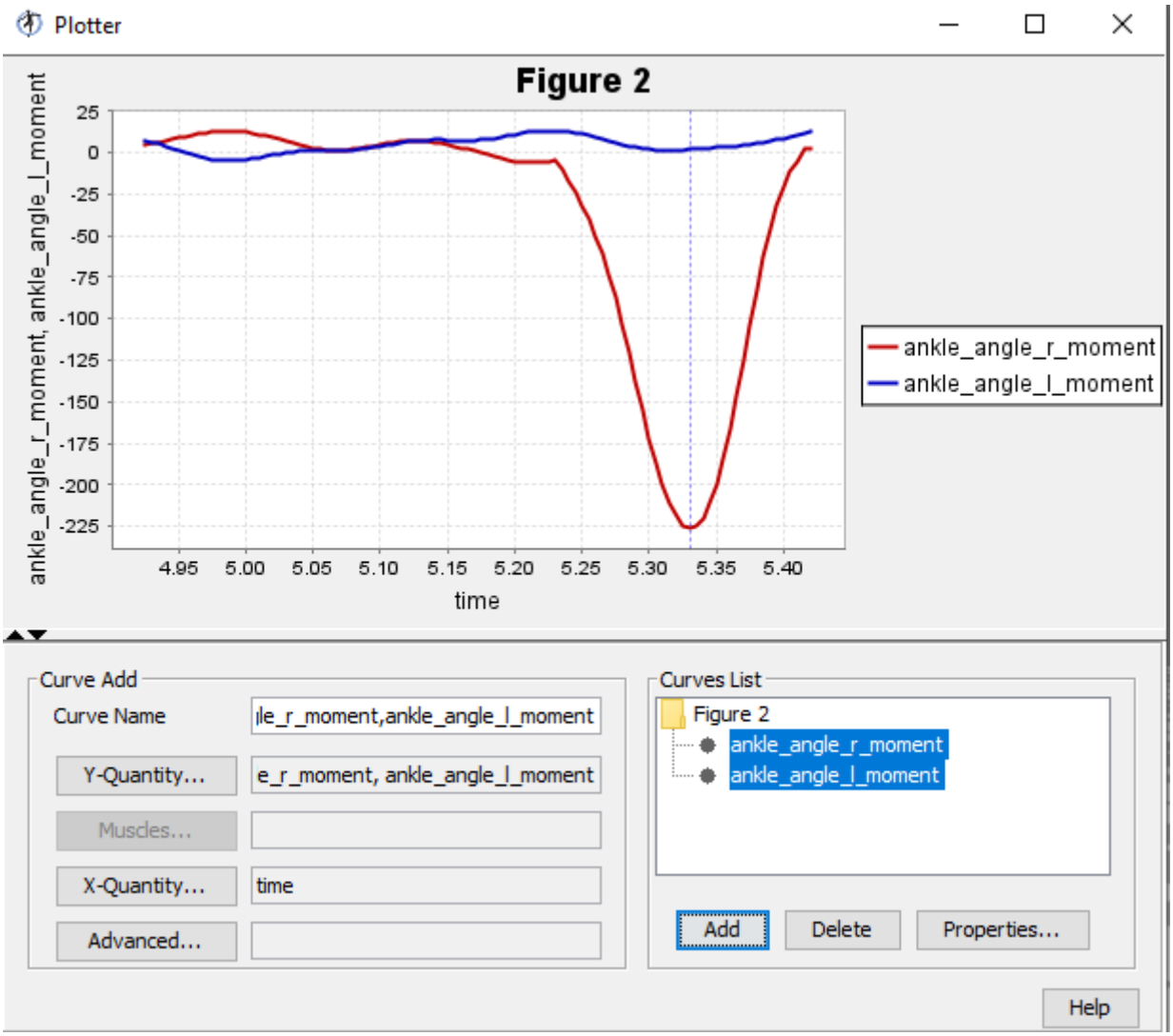
---------- 10 min Break ----------

2.3 Visualize GRF and set up .xml file (10 min)

- Associate motion data "subject01_walk1_grf.mot"
- Check if the force vecotrs are syncronized with motion (if there is a delay or offset, restart opensim)
- run inverse dynamics tool
- plot right and left ankle moments

2.3.1 Questions

- What are the peak plantar flexion moment?
- Why is the left ankle moment so much smaller compared with right?



2.4 Apply GRF to correct bodies (30 min)

- Load the setup_ID.xml
- Change the point of application of the forces
- run inverse dynamics tool

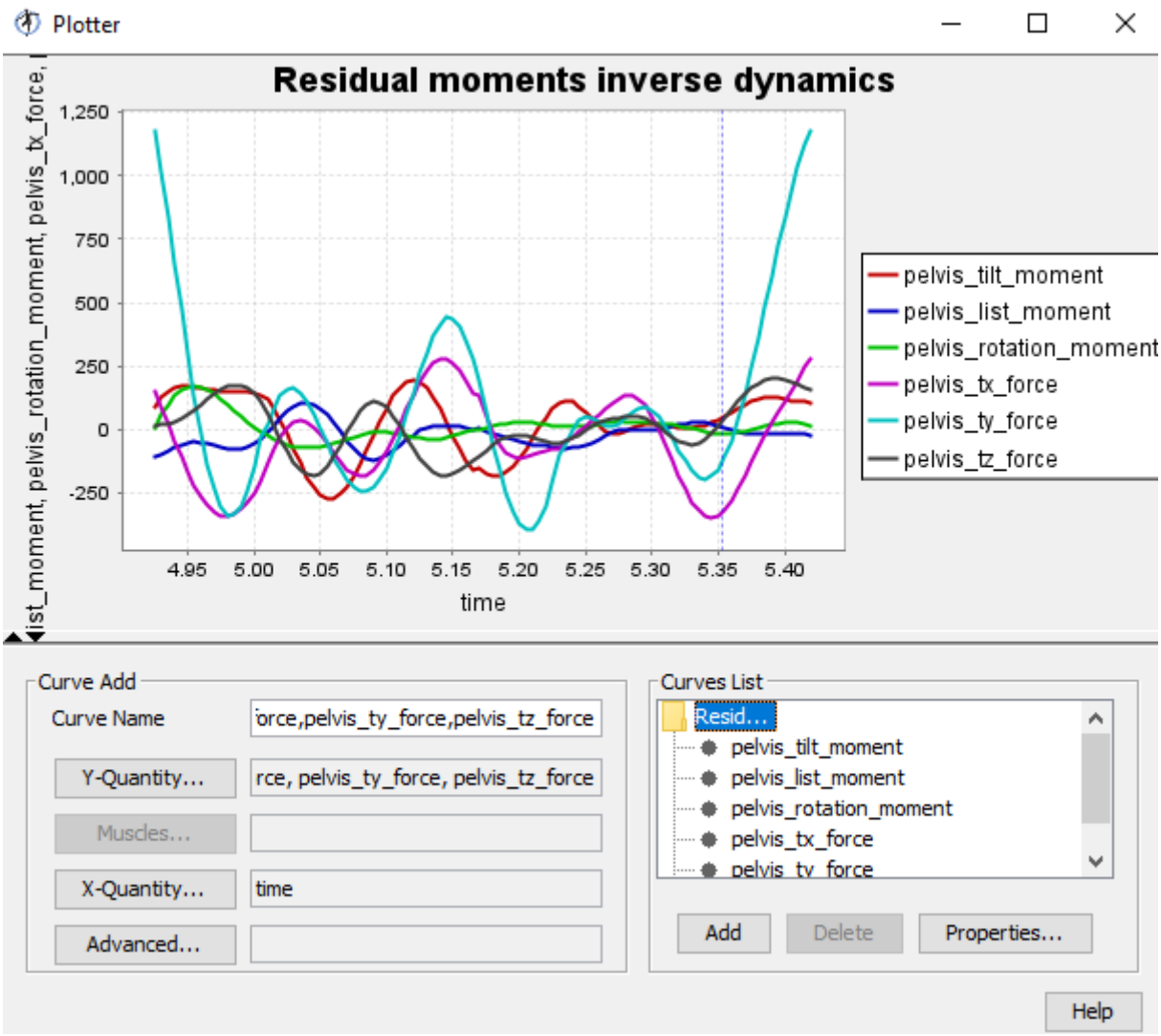
2.4.1 Questions

- Compare hip, knee, and ankle moments
- How did moments change during stance?
- How did moments change during swing?

Alt text

2.5 Residual reduction analysis (45 min)

- Theory about RRA https://simtk-confluence.stanford.edu:8443/display/OpenSim/How+RRA+Works
- Load .\Run_baseline\setup_RRA.xml and run RRATool
- Plot results for pelvis moments from .\Run_baseline\inverse_dynamics.sto
- Plot results for pelvis moments from .\Run_baseline\RRA_Actuation_force.sto



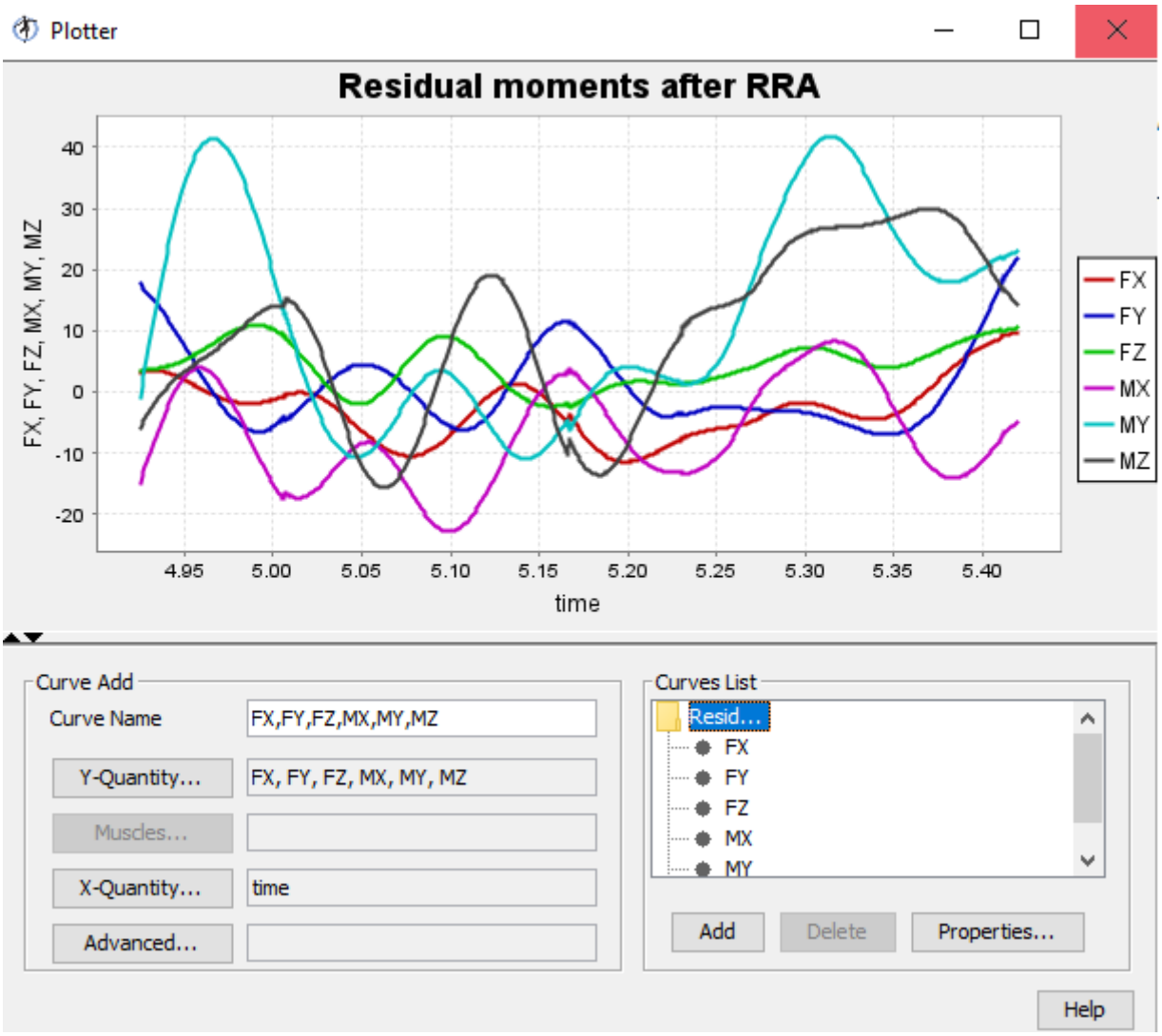
Evaluating your Results:

1. RMS difference in joint angle during the movement should be less than 2-5° (or less than 2 cm for translations).
2. Peak residual forces should typically be less than 10-20 N. Average residuals should typically be less than 5-10 N.
    a. The size of residuals will depend on the type of motion being studied. For example, residuals for high-speed activities like sprinting will typically be larger than walking.
    b. Residuals will also be larger if there are external forces that you have not accounted for, such as a subject walking with a handrail.
3. Compare the residual moments from RRA to the moments from Inverse Dynamics. You should see a 30-50% reduction in peak residual moments.
4. Compare the joint torques/forces to established literature (if available). Try to find data with multiple subjects. Your results should be within one standard deviation of the literature.

The table below shows an example of threshold values used to evaluate RRA results for full-body simulations of walking and running.

Thresholds:	GOOD	OKAY	BAD
MAX Residual Force (N)	0-10 N	10-25N	> 25 N
RMS Residual Force (N)	0-5 N	5-10 N	> 10 N
MAX Residual Moment (Nm)	0-50 Nm	50-75 Nm	>75 Nm
RMS Residual Moment (Nm)	0-30 Nm	30-50 Nm	>50 Nm
MAX pErr (trans, cm)	0-2 cm	2-5 cm	>5 cm
RMS pErr (trans, cm)	0-2 cm	2-4 cm	>4 cm
MAX pErr (rot, deg)	0-2 deg	2-5 deg	> 5 deg
RMS pErr (rot, deg)	0-2 deg	2-5 deg	> 5 deg

Note: the presnet residuals are recomendations for walking, during running residuals are expected to be higher.



2.4.1 Questions

- What changes in the trunk segment properties?
- What changed more hip flexion or trunk extension angles?
- How did the residual moments change after RRA?
- Are the residual moments acceptable?

Day 3

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3. Muscle and joint contact forces (3h)

Theory (15 min)

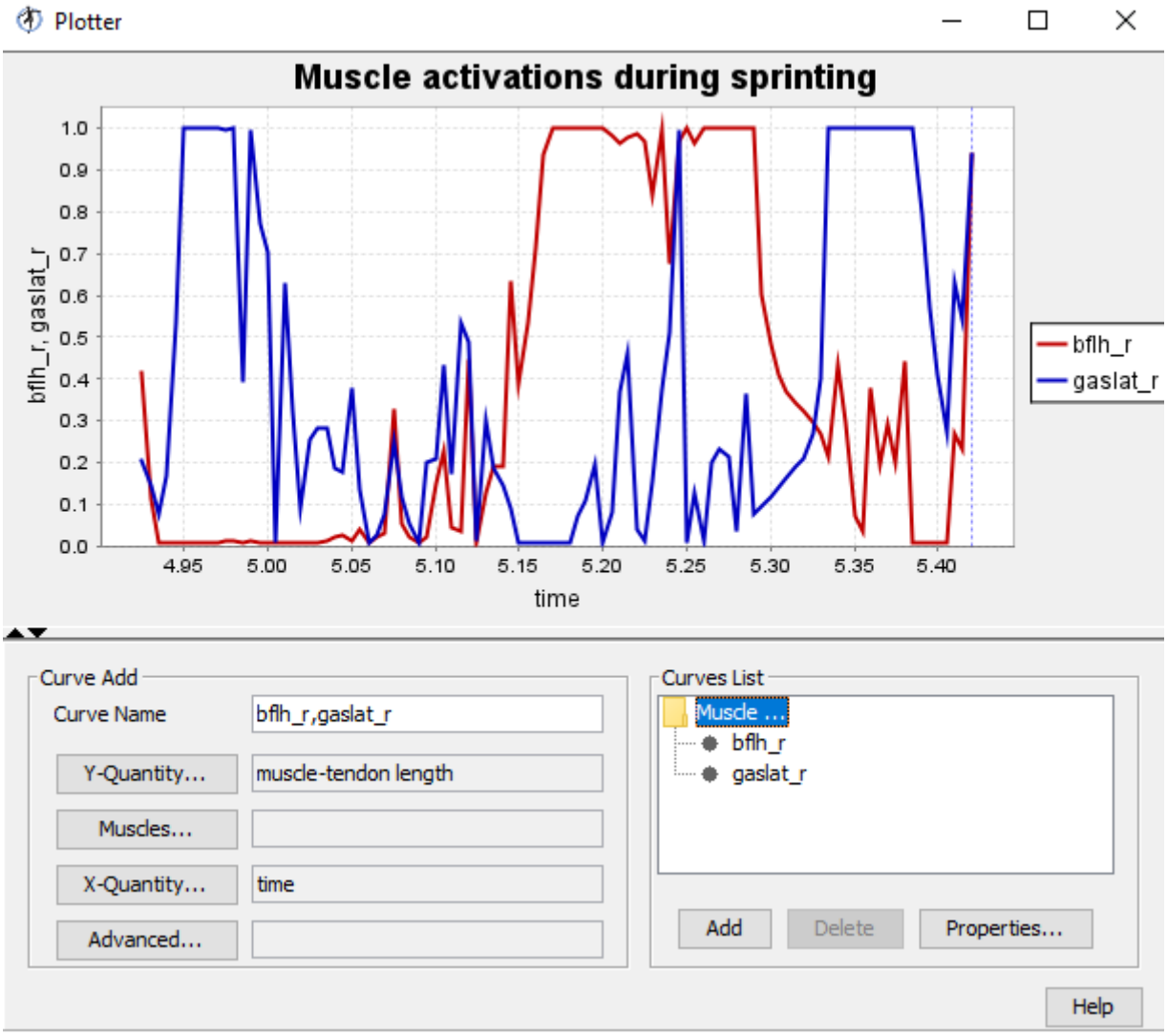
https://simtk-confluence.stanford.edu:8443/display/OpenSim/How+Static+Optimization+Works

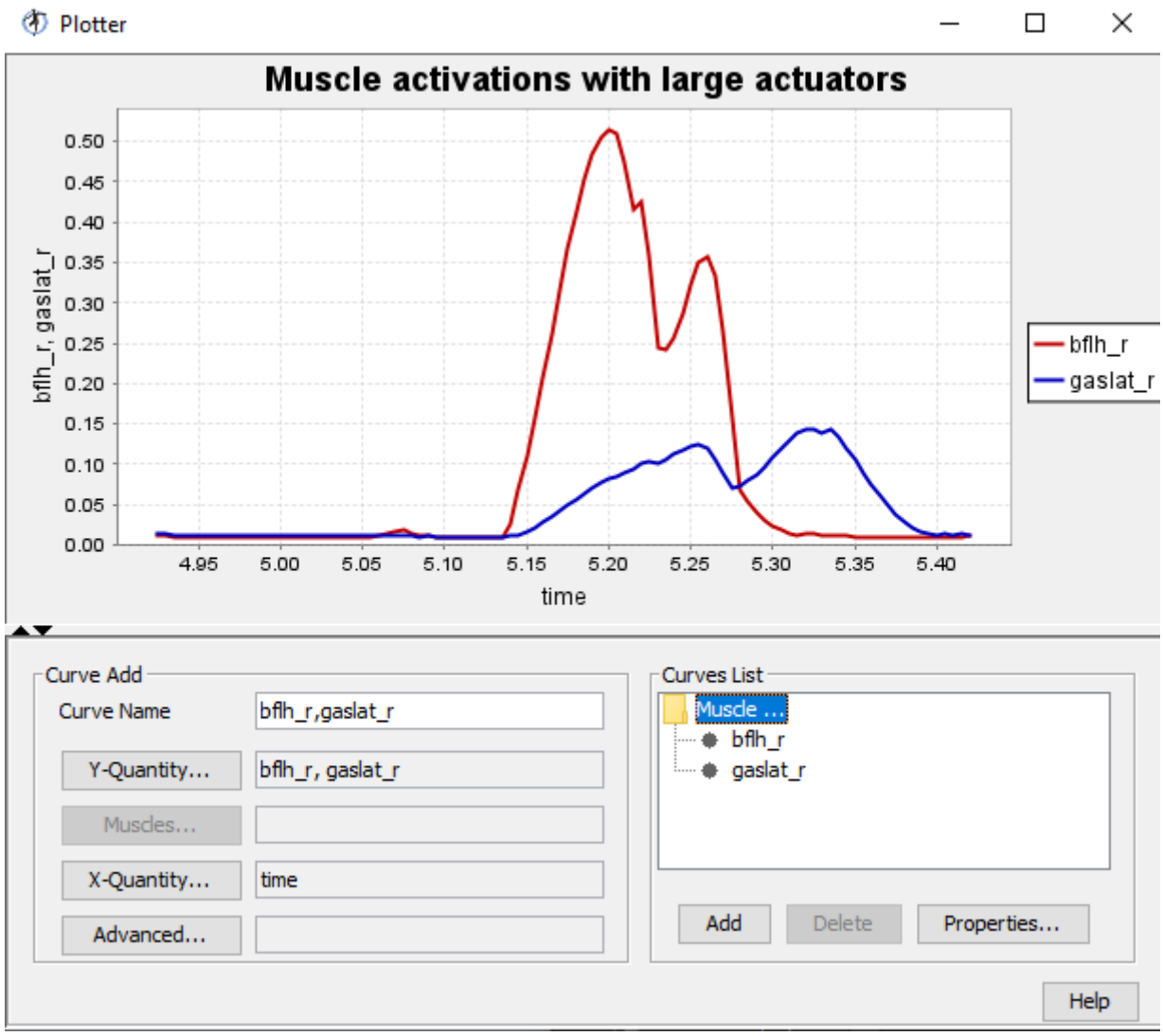
3.1 Calculate muscle forces during sprinting (60 min)

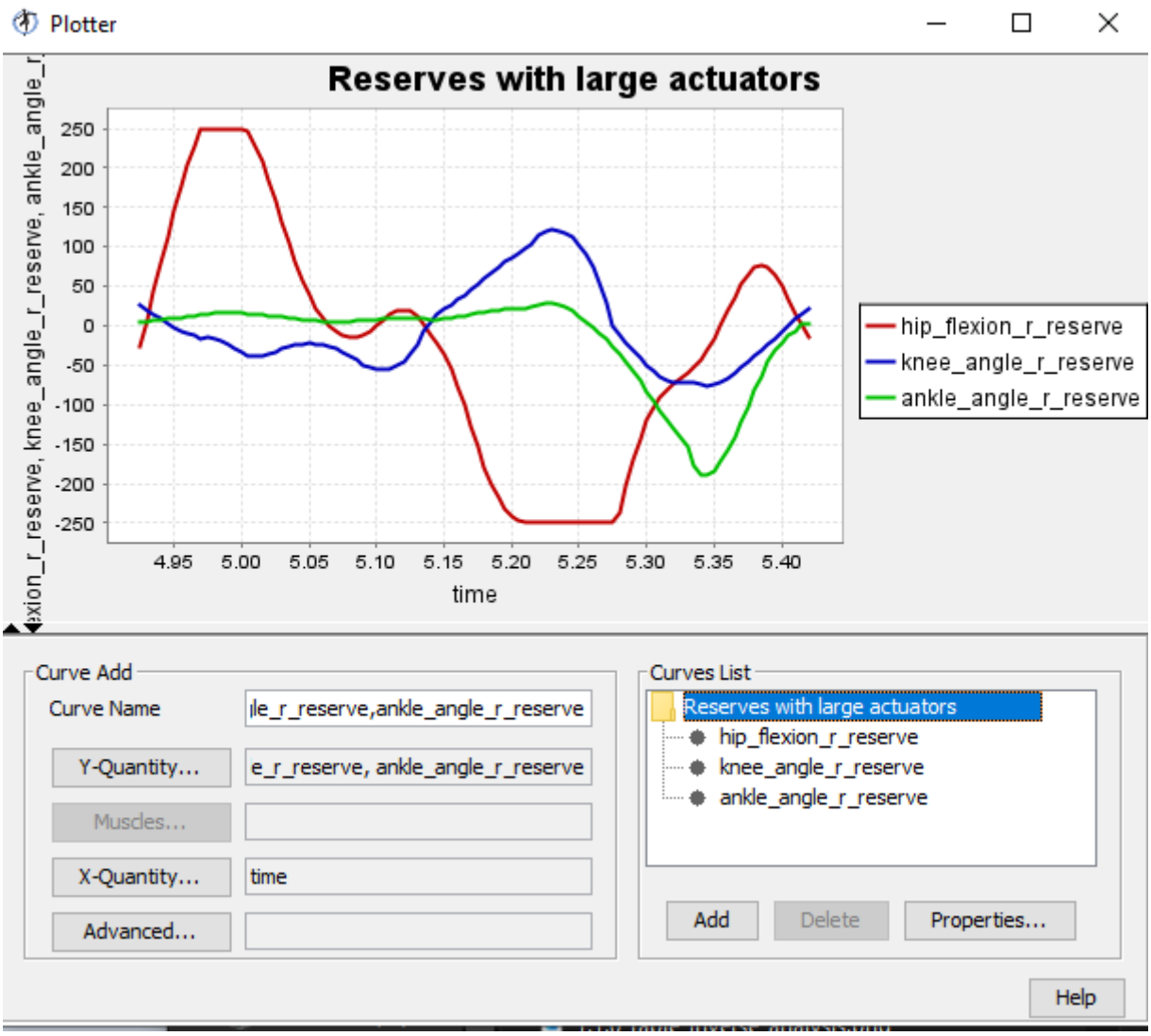
- Load rra adjusted model
- Run SO tool
- Plot muscle forces and muscle activations (bflh_r and gaslat_r)

Questions

- What is the main difference between the actuator.xml files from RRA and SO?
- What are peak force of biceps femoris and soleus muscles?
- How do the muscle activations look?
- What are the errors that show up on the messages window?
- Double the maximum isometric force of all muscles and re-run the simulations. What changed?




Plotter
Muscle activations with large actuators
bflh_r, gaslat_r
time
bflh_r
gaslat_r
Curve Add
Curve Name
bflh_r,gaslat_r
Y-Quantity...
bflh_r, gaslat_r
Muscles...
X-Quantity...
time
Advanced...
Curves List
Muscle ...
bflh_r
gaslat_r
Add
Delete
Properties...
Help



---------- 10 min Break ----------

3.3 Calculate joint reaction loads (30 min)

- Load rra ajudsted model
- Open Analyze tool and run setup_Analyze.xml
- Plot the three components of hip contact force

3.3.1 Questions

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3.4 Explore muscle analysis (45 min)

- plot moment arms (all the hip muscles)
- plot muscle-tendon lengths (all the hip muscles)
- Increase the radius of wrapping surface of Gmax1_r to 0.055 and plot results again
- Do the same for one knee muscle

3.4.1 Questions

- Are there any muscle moment arm dicontinuities?

- What is the hip muscle with longest length during sprinting?
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3.5 Summary

Day 4

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4. Practical examples (3h)

4.1 Bone deformities (45 min)

Protocol described here: https://www.sciencedirect.com/science/article/abs/pii/S0966636223010044

- For each participant follow these steps
- Load torsion model (Bone_deformities\P01\pre\Torsion_model_generic.osim)
- Load scaled model for each participant (Bone_deformities\P01\pre\Static03\Setup_Scale.xml)
- Plot moment arms Glutes and change wrapping surfaces
- Run IK, ID, SO, and JRA for both participants (one trial)
- Plot kinematics, moments, muscle forces (recfem, gmax1, psoas)
- Plot hip contact forces

Questions

- How do subjects differ in kinematics
- How were moments arms affected by the torsion

4.2 Compare muscle forces before and after maximal repeated sprints (45 min)

Protocol described here: https://www.sciencedirect.com/science/article/abs/pii/S1440244021000608

- Load scaled model
- Run IK, ID, RRA, and SO for trial Run_post_fatigue (use the RRA adjusted model)
- Plot muscle forces and muscle activations (bflh_r and gaslat_r)

Questions

- What are peak force of biceps femoris and soleus muscles?

4.3 Simulation and Analysis of a Tendon Transfer Surgery (45 min)

Protocol described here: https://simtk-confluence.stanford.edu:8443/pages/viewpage.action?pageId=92110947

Questions

- How did the MTU length of the rect_fem_r change?

Day 5

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5. Future directions and questions (3h)

Scripting commands

run a simple setup file from cmd

```
opensim-cmd run-tool \path\to\xmlFile\arm26_Setup_InverseKinematics.xml
```