

## Reducing Residuals

## What are residuals?

Non-physical forces that account for inconsistencies between experimental GRFs and joint accelerations estimated from experimental markers.

(Conservation of angular and linear momentum.)

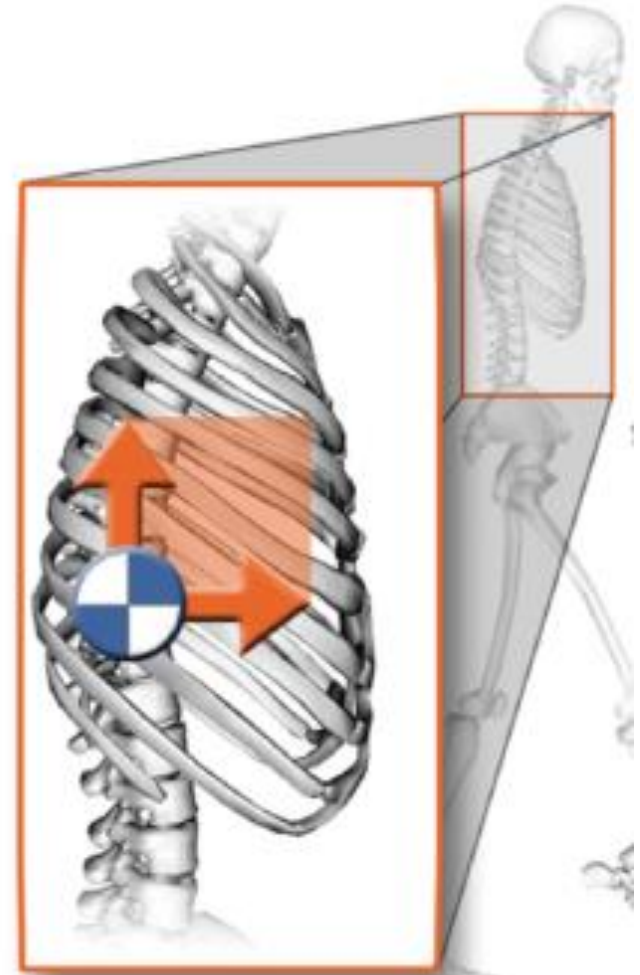
$$F = \sum_i m a_i + R$$

Inconsistencies due to:

1. noise in marker and joint angle data
  - differentiating angles for accelerations
2. inaccuracies in model geometry and mass distribution

# How can you reduce residuals?

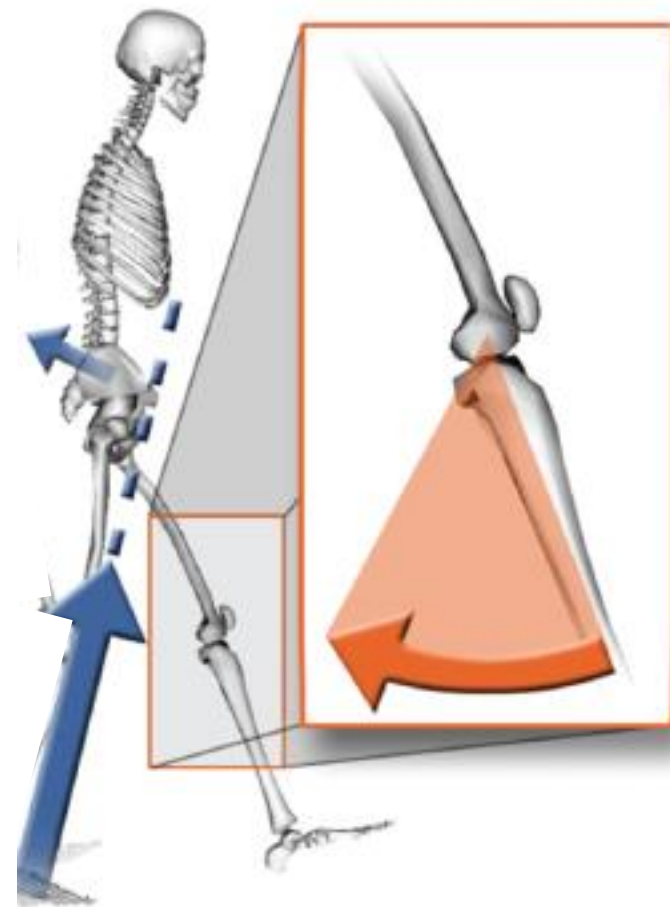
- Torso is most massive and prone to error
  - Modeled as one rigid body (often together with head)
  - Location of torso center of mass also difficult to estimate
1. Adjust mass distribution and torso COM location



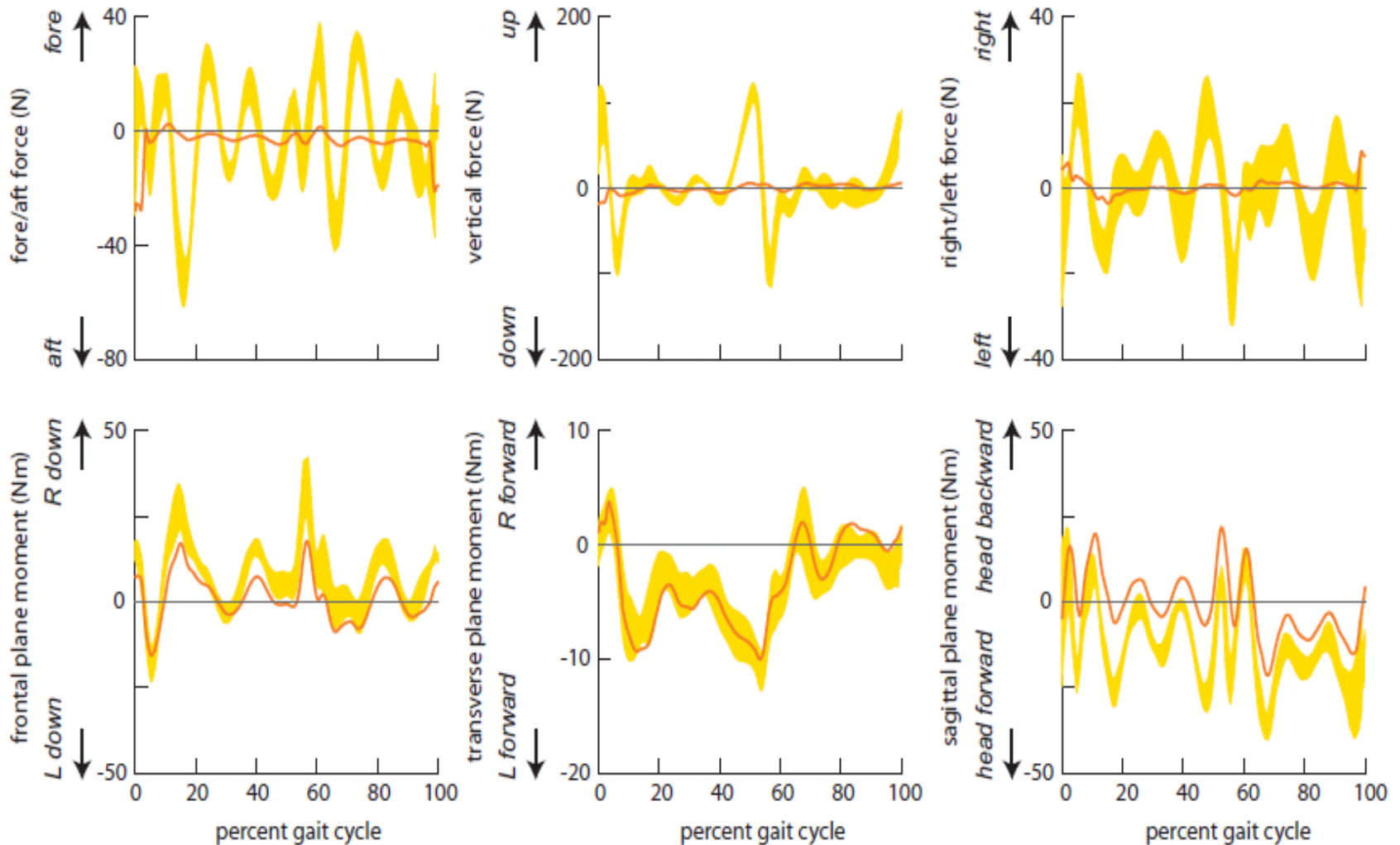
## How can you reduce residuals?

- Joint kinematics estimated from marker position has inaccuracies
  - Differentiation of kinematics can yield non-physical accelerations
1. Adjust mass distribution and torso COM location
  2. Adjust kinematics slightly while satisfying equations of motion

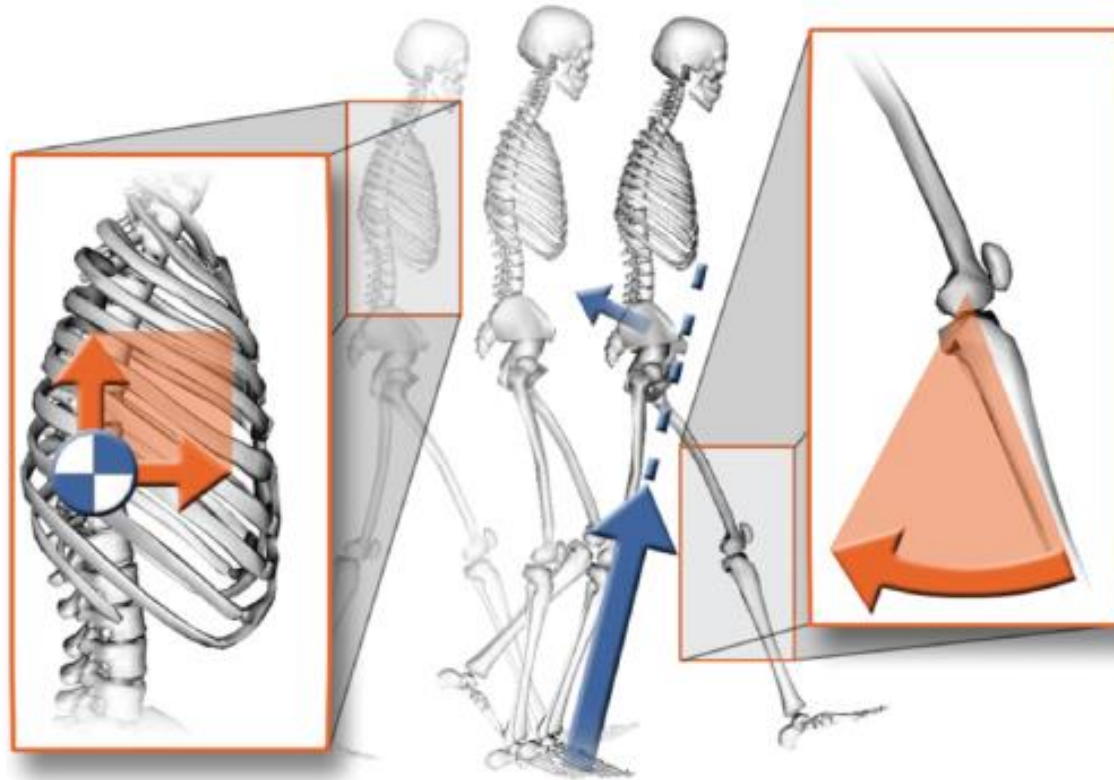
**Since most residuals result from errors in modeling torso, RRA mainly needed if you want to do full body analysis.**



# Sample residual reduction during gait



# Residual Reduction Algorithm (RRA)



## TIPS & TRICKS

Keep optimal forces for residuals low (increase control bounds if necessary)

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

## Demo and tips

### **Troubleshooting:**

- Very large residuals indicate that something is wrong with (i) scaled model, (ii) IK solution, or (iii) applied GRFs.
- If pelvis drift and/or  $F_Y$  not centered around zero, check that the body mass and force calibration are correct.
- In example RRA Actuators.xml file, the residual forces are applied to the center of mass (COM) of the unscaled pelvis.

### **Evaluating your Results:**

- RMS differences in coordinates should be less than 2-5° or less than 2 cm.
- Peak residual forces should typically be less than 10-20 N. Average residuals should typically be less than 5-10 N
- The size of residuals will depend on the type of motion being studied.