Biomechanics of human movement

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Overview of movement analysis

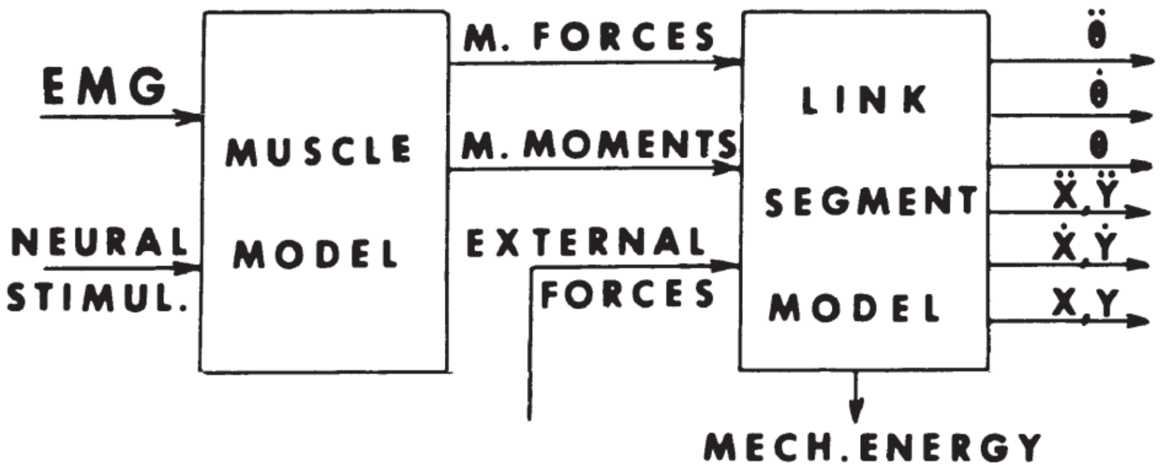


Fig 1. Schematic diagram to show the relationship between the neural, kinetic, and kinematic variables required to describe and analyze human movement

Variables in analysis of movement

1. **Signals**
   - Time domain signals of **EMG, Forces, displacements, accelerations** etc…
2. **Kinematics**
   - Linear and angular **displacements, velocities and accelerations**.
3. **Kinetics**
   - **Internal**(muscle, friction in joints,..) and **external**(Ground reaction) forces.
4. **Anthropometry**
   - **Masses** of limb segments, **location of mass centers**, segment lengths, **centers of rotation**, **angles of pull of muscles** etc…
5. **Muscle and Joint Biomechanics**
   - Time domain signals of **EMG, Forces, displacements, accelerations** etc…
6. **Electromyography**
   - Neural control of each muscle

ANTHROPOMETRY

TABLE 4.1 Anthropometric Data

Segment	Definition	Segment Weight/Total Body Weight	Center of Mass/ Segment Length		Radius of Gyration/ Segment Length			Density
			Proximal	Distal	C of G	Proximal	Distal	
Hand	Wrist axis/knuckle II middle finger	0.006 M	0.506	0.494 P	0.297	0.587	0.577 M	1.16
Forearm	Elbow axis/ulnar styloid	0.016 M	0.430	0.570 P	0.303	0.526	0.647 M	1.13
Upper arm	Glenohumeral axis/elbow axis	0.028 M	0.436	0.564 P	0.322	0.542	0.645 M	1.07
Forearm and hand	Elbow axis/ulnar styloid	0.022 M	0.682	0.318 P	0.468	0.827	0.565 P	1.14
Total arm	Glenohumeral joint/ulnar styloid	0.050 M	0.530	0.470 P	0.368	0.645	0.596 P	1.11
Foot	Lateral malleolus/head metatarsal II	0.0145 M	0.50	0.50 P	0.475	0.690	0.690 P	1.10
Leg	Femoral condyles/medial malleolus	0.0465 M	0.433	0.567 P	0.302	0.528	0.643 M	1.09
Thigh	Greater trochanter/femoral condyles	0.100 M	0.433	0.567 P	0.323	0.540	0.653 M	1.05
Foot and leg	Femoral condyles/medial malleolus	0.061 M	0.606	0.394 P	0.416	0.735	0.572 P	1.09
Total leg	Greater trochanter/medial malleolus	0.161 M	0.447	0.553 P	0.326	0.560	0.650 P	1.06
Head and neck	C7–T1 and 1st rib/ear canal	0.081 M	1.000	— PC	0.495	0.116	— PC	1.11
Shoulder mass	Sternoclavicular joint/glenohumeral axis	—	0.712	0.288	—	—	—	1.04
Thorax	C7–T1/T12–L1 and diaphragm*	0.216 PC	0.82	0.18	—	—	—	0.92
Abdomen	T12–L1/L4–L5*	0.139 LC	0.44	0.56	—	—	—	—
Pelvis	L4–L5/greater trochanter*	0.142 LC	0.105	0.895	—	—	—	—
Thorax and abdomen	C7–T1/L4–L5*	0.355 LC	0.63	0.37	—	—	—	—
Abdomen and pelvis	T12–L1/greater trochanter*	0.281 PC	0.27	0.73	—	—	—	1.01
Trunk	Greater trochanter/glenohumeral joint*	0.497 M	0.50	0.50	—	—	—	1.03
Trunk head neck	Greater trochanter/glenohumeral joint*	0.578 MC	0.66	0.34 P	0.503	0.830	0.607 M	—
Head, arms, and trunk (HAT)	Greater trochanter/glenohumeral joint*	0.678 MC	0.626	0.374 PC	0.496	0.798	0.621 PC	—
HAT	Greater trochanter/mid rib	0.678	1.142	—	0.903	1.456	—	—

*NOTE: These segments are presented relative to the length between the greater trochanter and the glenohumeral joint.
Source Codes: M, Dempster via Miller and Nelson; *Biomechanics of Sport*, Lea and Febiger, Philadelphia, 1973. P, Dempster via Plagenhoef; *Patterns of Human Motion*, Prentice-Hall, Inc. Englewood Cliffs, NJ, 1971. L, Dempster via Plagenhoef from living subjects; *Patterns of Human Motion*, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1971. C, Calculated.

Example problems

Problem 1

Example 1: In a static situation, a person is standing on one foot on a force plate. The ground reaction force is found to act 4 cm anterior to the ankle joint. Note that convention has the ground reaction force R_{y1} always acting upward. We also show the horizontal reaction force R_{x1} to be acting in the positive direction (to the right). If this force actually acts to the left, it will be recorded as a negative number. The subject's mass is 60 kg, and the mass of the foot is 0.9 kg. Calculate the joint reaction forces and net muscle moment at the ankle. R_{y1} = body weight = 60 × 9.8 = 588 N.

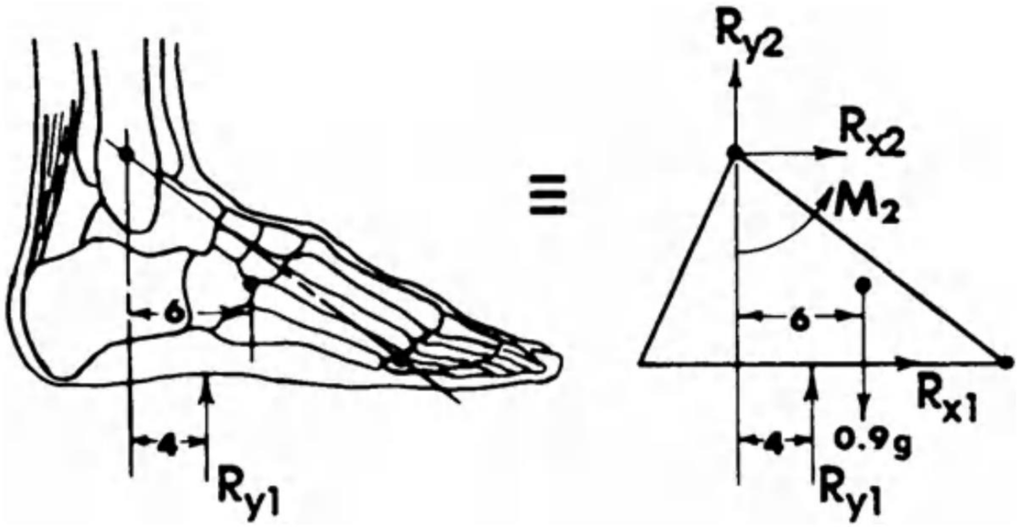


Fig 1: Anatomical and free-body diagram of foot.

Answer key

1. $\Sigma F_x = ma_x,$

   $R_{x2} + R_{x1} = ma_x = 0$

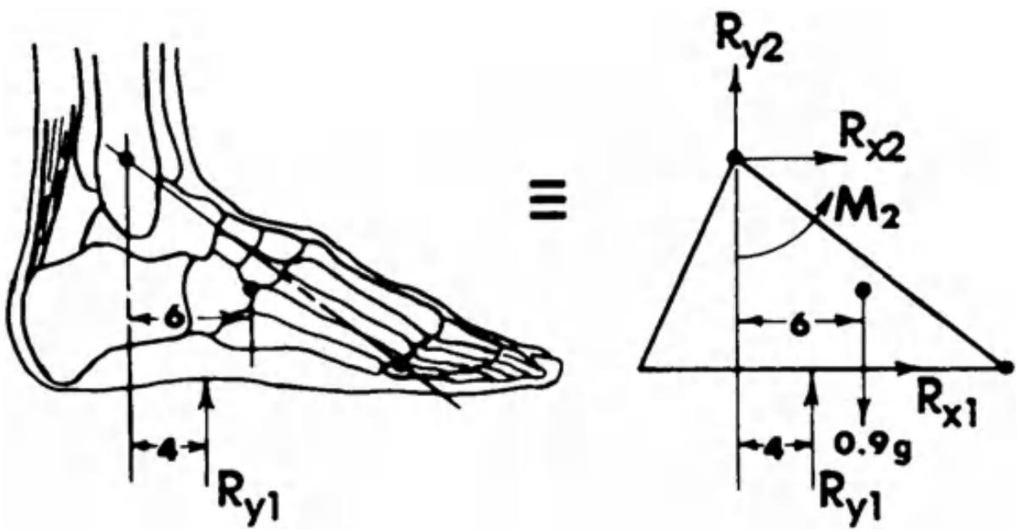
   Note that this is a redundant calculation in static conditions.

2. $\Sigma F_y = ma_y,$

   $R_{y2} + R_{y1} - mg = ma_y$

   $R_{y2} + 588 - 0.9 \times 9.8 = 0$

   $R_{y2} = -579.2\,\text{N}$



3. About the COM, $\Sigma M = I_0\alpha,$

   $M_2 - R_{y1} \times 0.02 - R_{y2} \times 0.06 = 0$

   $M_2 = 588 \times 0.02 + (-579.2 \times 0.06) = -22.99\,\text{N} \cdot \text{m}$

Problem 2

Example 2: From the data collected during the swing of the foot, calculate the muscle moment and reaction forces at the ankle. The subject's mass was 80 kg and the ankle-metatarsal length was 20.0 cm. The inertial characteristics of the foot are calculated as:

$m = 0.0145 \times 80 = 1.16$ kg

$\rho_0 = 0.475 \times 0.20 = 0.095$ m

$I_0 = 1.16(0.095)^2 = 0.0105$ kg $\cdot$ m^2

$\alpha = 21.69$ rad/s^2

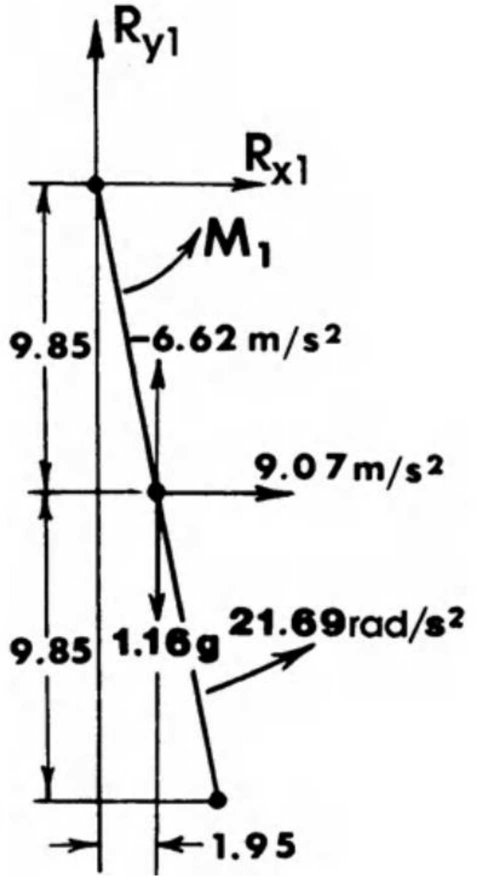


Fig 2: FBD of foot during swing showing the linear accelerations of the COM and the angular acceleration of the segment.

Answer key

1. $\Sigma F_x = ma_x$,

   $R_{x1} = 1.16 \times 9.07 = 10.52\,\mathrm{N}$

2. $\Sigma F_y = ma_y$,

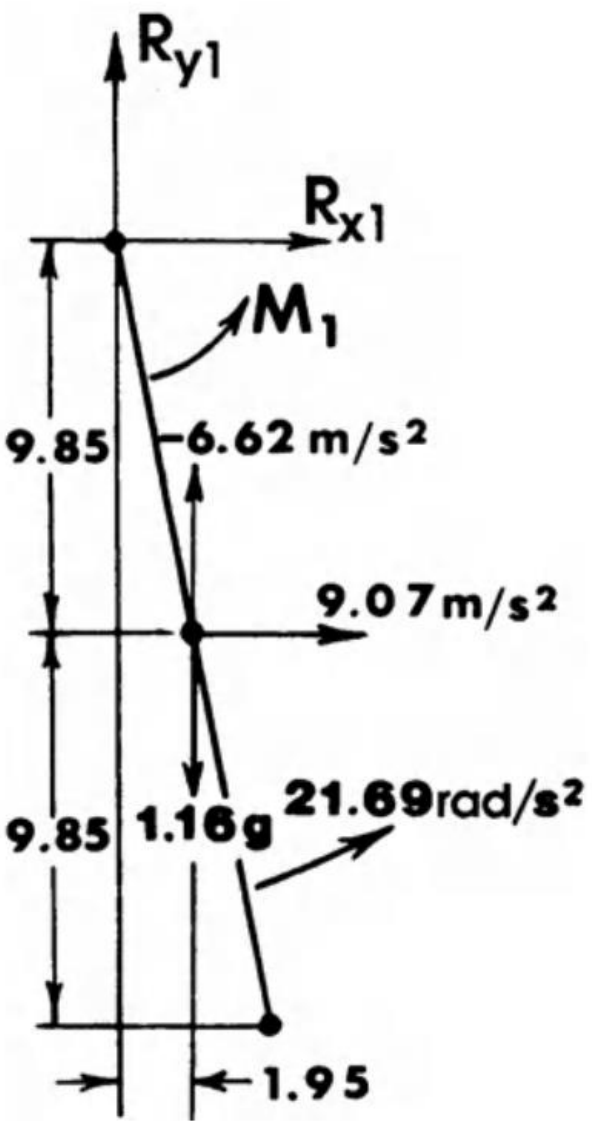
   $R_{y1} - 1.16g = m(-6.62)$

   $R_{y1} = 1.16 \times 9.8 - 1.16 \times 6.62 = 3.69\,\mathrm{N}$

3. At the COM of the foot, $\Sigma M = I_0\alpha$,

   $M_1 - R_{x1} \times 0.0985 - R_{y1} \times 0.0195 = 0.0105 \times 21.69$

   $$M_1 = 0.0105 \times 21.69 + 10.52 \times 0.0985 + 3.69 \times 0.0195$$
   $$= 0.23 + 1.04 + 0.07 = 1.34\,\mathrm{N \cdot m}$$



Problem 3

Example 3: For the same instant in time, calculate the muscle moments and reaction forces at the knee joint. The leg segment was 43.5 cm long:

$m = 0.0465 \times 80 = 3.72$ kg
$\rho_0 = 0.302 \times 0.435 = 0.131$ m
$I_0 = 3.72(0.131)^2 = 0.0638$ kg $\cdot$ m^2
$\alpha = 36.9$ rad/s^2

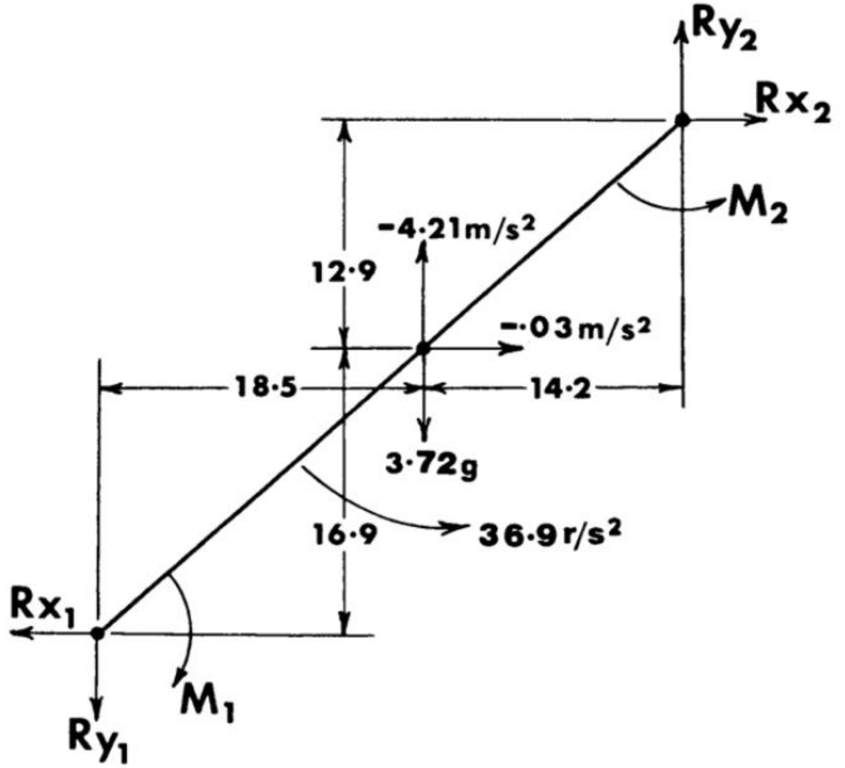


Fig 3: FBD of leg at the same instant in time as the foot in Figure 2. Linear and angular accelerations are as shown. Distances are in centimeters. The distal end and reaction forces and moments have been reversed, recognizing Newton's third law.

Problem 3

From Example 2, $R_{x1} = 10.52\,\mathrm{N}, R_{y1} = 3.69\,\mathrm{N}$, and $M_1 = 1.34\,\mathrm{N \cdot m}$.

1. $\Sigma F_x = ma_x$,

   $R_{x2} - R_{x1} = ma_x$

   $R_{x2} = 10.52 + 3.72(-0.03) = 10.41\,\mathrm{N}$

2. $\Sigma F_y = ma_y$,

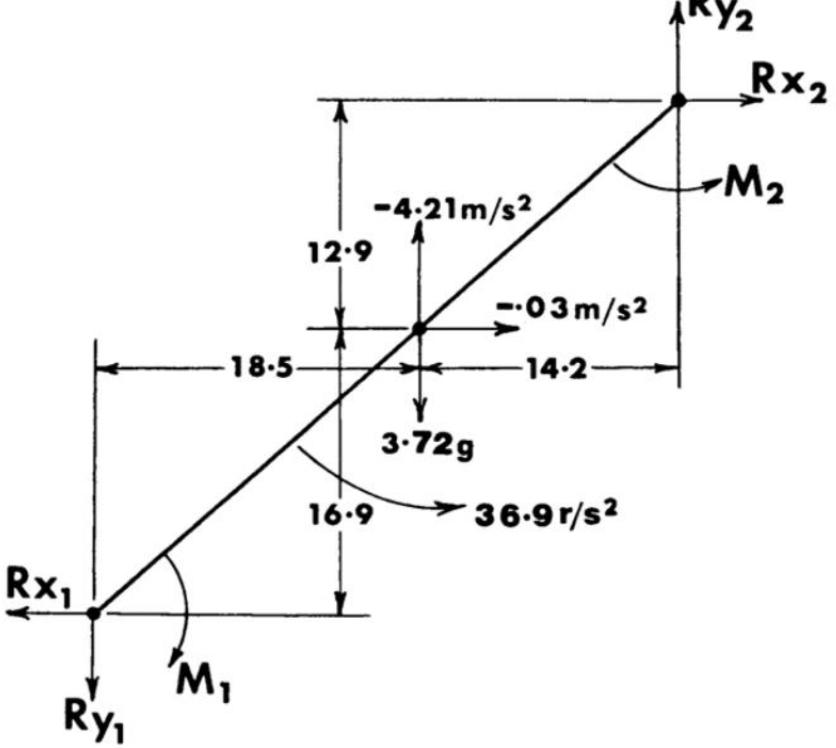
   $R_{y2} - R_{y1} - mg = ma_y$

   $R_{y2} = 3.69 + 3.72 \times 9.8 + 3.72(-4.21) = 24.48\,\mathrm{N}$

3. About the COM of the leg, $\Sigma M = I\alpha$,

   $M_2 - M_1 - 0.169R_{x1} + 0.185R_{y1} - 0.129R_{x2} + 0.142R_{y2} = I\alpha$

   $$M_2 = 1.34 + 0.169 \times 10.52 - 0.185 \times 3.69 + 0.129 \times 10.41$$
   $$- 0.142 \times 24.48 + 0.0638 \times 36.9$$
   $$= 1.34 + 1.78 - 0.68 + 1.34 - 3.48 + 2.35 = 2.65\,\mathrm{N \cdot m}$$



3D Kinetics and Kinematics

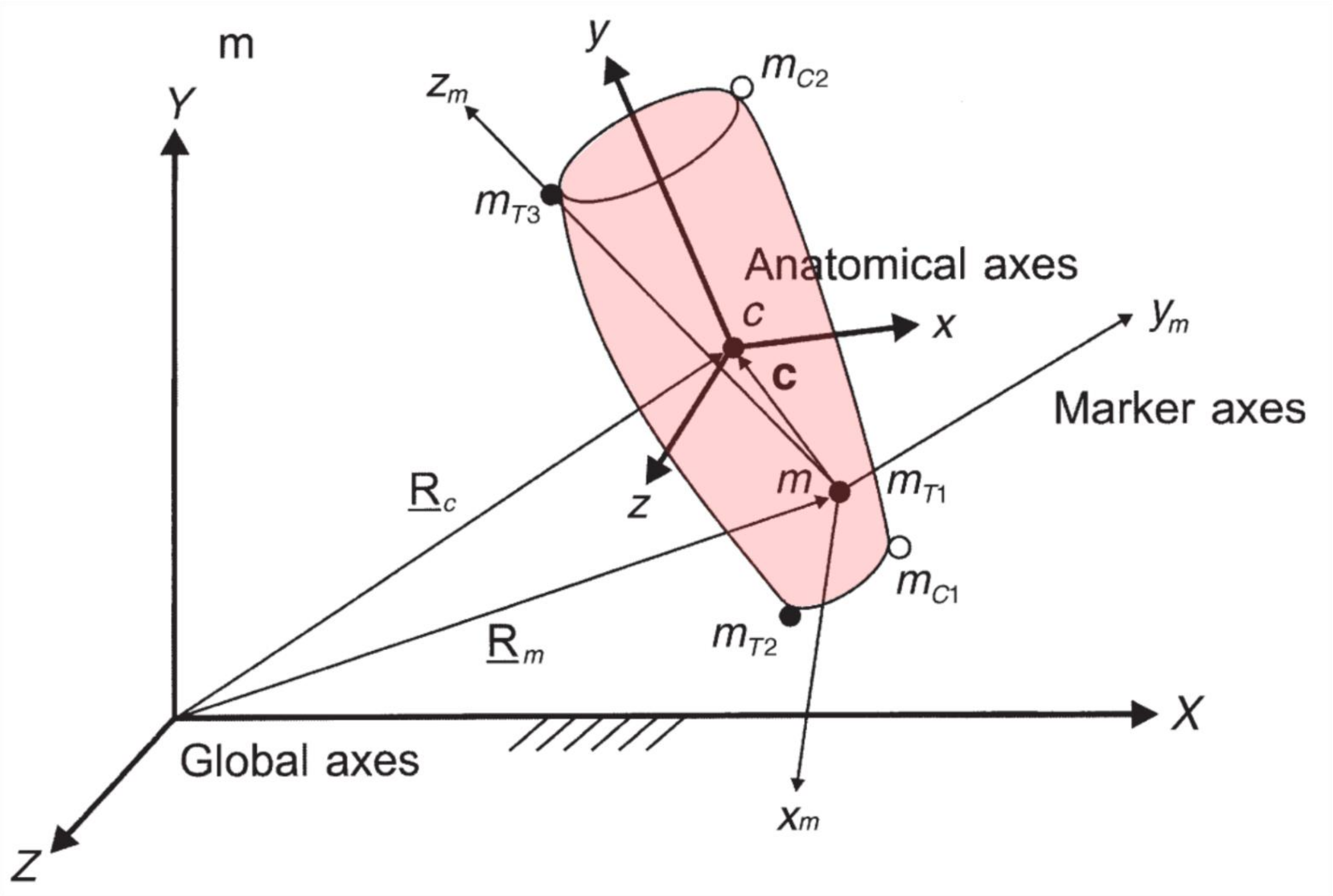


Fig 5: An anatomical segment showing the GRS, the marker axes, and anatomical axes.

Reference Systems

1. **Global Reference System (GRS)**
   - global reference system (GRS) is fixed coordinates in the laboratory or data collection space.
   - X : forward/backward direction,
   - Y : vertical (gravitational) axis,
   - Z : left/right (medial/lateral) axis.
2. **Local Reference Systems**
   - Anatomical axis system is set with its origin at the center of mass (COM) of the segment.
3. **Marker Axes System**
   - marker axis system for each segment can vary from laboratory to laboratory.
   - there must be at least three independent markers per body segment.

Newtonian 3D Equations of Motion

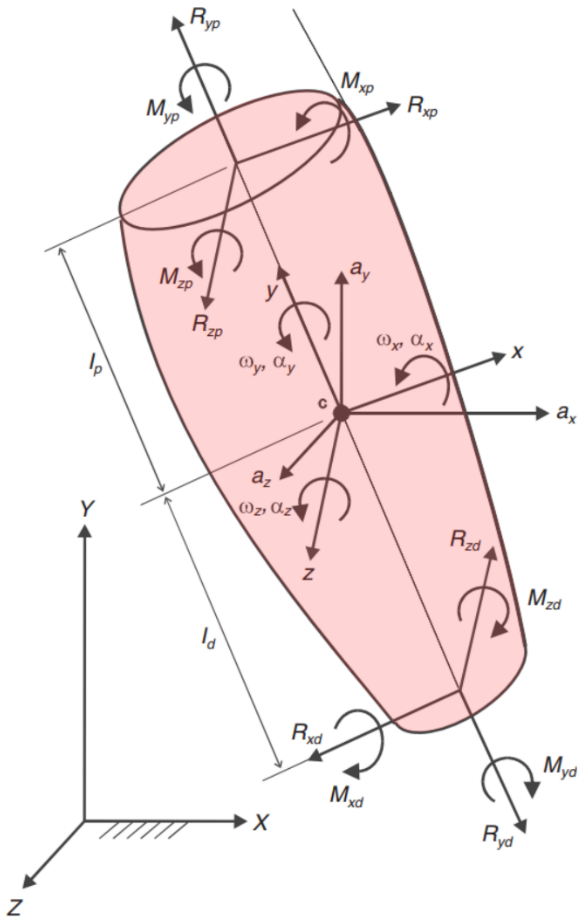
Step 1: Calculate the reaction forces at the proximal end of the segment in the GRS:

$$\Sigma F_X = ma_X \quad or \quad R_{XP} - R_{XD} = ma_X$$
$$\Sigma F_Y = ma_Y \quad or \quad R_{YP} - R_{YD} - mg = ma_Y$$
$$\Sigma F_Z = ma_Z \quad or \quad R_{ZP} - R_{ZD} = ma_Z$$

where a_X , a_Y , a_Z are the segment COM accelerations in the X , Y , Z GRS directions and R_{XP}, R_{XD}, R_{YP}, R_{YD}, R_{ZP}, R_{ZD} are the proximal and distal reaction forces in the X , Y , and Z axes.

Step 2: Transform both proximal and distal reaction forces into the anatomical axes using the [G to A] matrix transformation based on θ_1, θ_2, and θ_3. We will now have the proximal and distal reaction forces in the anatomical axes *x, y, z:* R_{xp}, R_{xd}, R_{yp}, R_{yd}, R_{zp}, R_{zd}.

Step 3: Transform the distal moments from those previously calculated in the GRS using the [G to A] matrix to the anatomical axes, as before, based on θ_1, θ_2, and θ_3: M_{xd}, M_{yd}, M_{zd}. We now have all the variables necessary to calculate the proximal moments in the anatomical axes.



End

Thank you

* Contents ad problems were are adopted from *"David A. Winter-Biomechanics and Motor Control of Human Movement-Wiley (2009)"*