ME6230
Mechanics of Human Movement

Assignment 1

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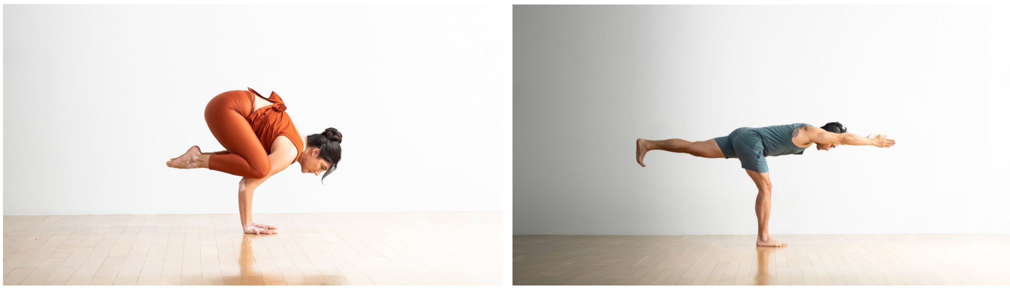
Abstract

In this assignment, two yoga poses, namely Virabhadrasana III and Bakasana, have been chosen. Inverse dynamics analysis is performed on these poses to find the joint reactions and the net moments about the joints. The muscle forces are also determined under the assumption that only one muscle stabilizes each joint. All assumptions are compiled and presented in the assumptions subsection.

1 Introduction

The two poses chosen for this assignment are as follows (refer fig 1.1)

- Bakasana - the crane pose [1]
- Virabhandrasana III - the warrior 3 pose [2]



(a) Bakasana (b) Virabhadrasana III

Figure 1.1: Yoga poses analysed in this assignment

I will first import the data into a graphing tool (such as Geogebra Calculator Suite) and find the approximate angles at each of the joints. Then, using anthropometric data, I will begin the inverse dynamics analysis. In the case of Bakasana (refer fig 1.1a), I will begin the analysis with the 2 palms, as the ground reaction force is acting on them. While analysing virabhadrasana, I will begin the analysis from the right leg (refer fig 1.1b), for the same reason.

2 Anthropometric data

The physical measurements of the human body (anthropometric data) was compiled by [3] and is used in this assignment.

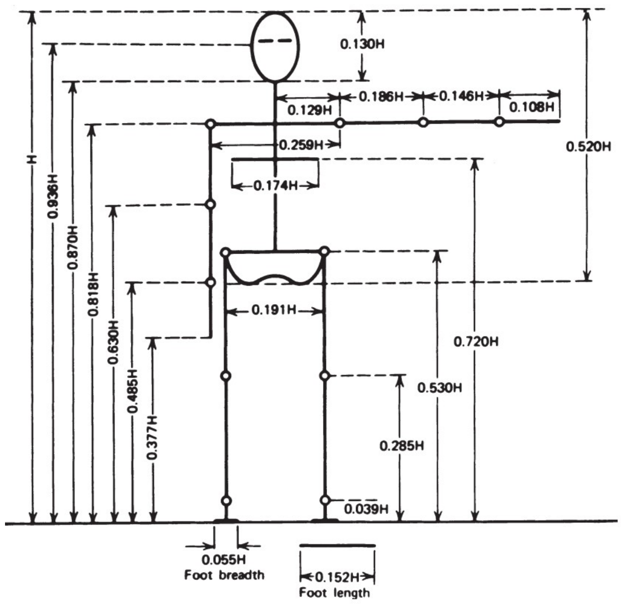


Figure 2.2: Segment lengths

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	—	—

Figure 2.3: Anthropometric data

3 Analysing Bakasana

3.1 Joint Forces and Moments

3.1.1 Assumptions

- The angles made by each link with respect to the horizontal have been approximated using GeoGebra (a graphing calculator)
- The mass of each segment is taken from the anthropometric data present in figure 2.3
- The length and the positions of the centre of mass of each segment have been taken

from the anthropometric data present in figure 2.2

- In this yoga pose, there is symmetry about the cardinal sagittal plane. As a result, the analysis has been performed for one-half of the body (i.e. one of each limb and half of the torso)
- As shown in figure 2.2 and as done in [3], I will work with a structure wherein the L5-sacrum joint and the hip joints lie on the same line (normal to the sagittal plane).
- The units of W is taken to be Newtons and the units of H is taken to be metres.
- The following is a table containing the lengths and masses of each segment of the body.

Link	m	l
AB (link 1)	0.006W	0.108H
BC (link 2)	0.016W	0.146H
CD (link 3)	0.028W	0.186H
DE (link 4)	0.289W	0.34H
EF (link 5)	0.1W	0.245H
FG (link 6)	0.0465W	0.246H
GH (link 7)	0.0145W	0.152H

- The angles made by each link with the horizontal is given in figure 3.4

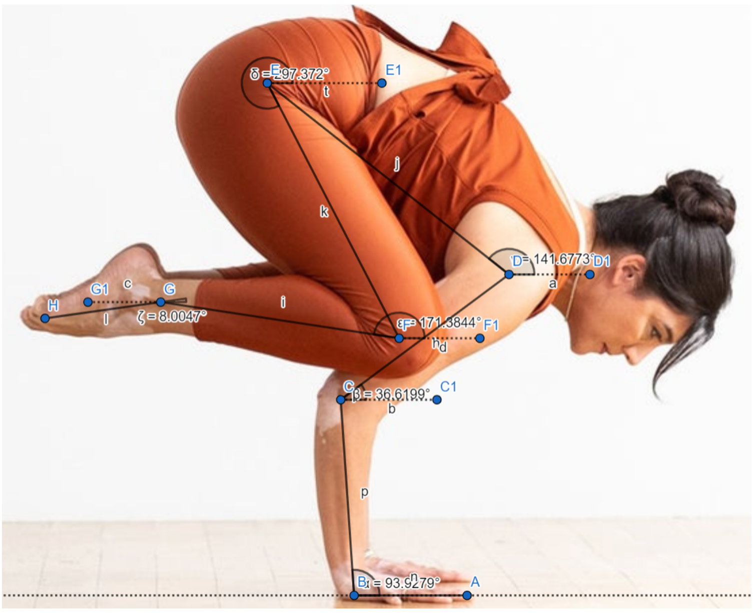


Figure 3.4: Angles at the joints during Bakasana

3.1.2 Analysis

The first step is to find the point at which the GRF acts on the hand (link AB). For this, the centre of mass needs to be found. Taking point B to be the origin, the centre of mass of each link is first found as follows:

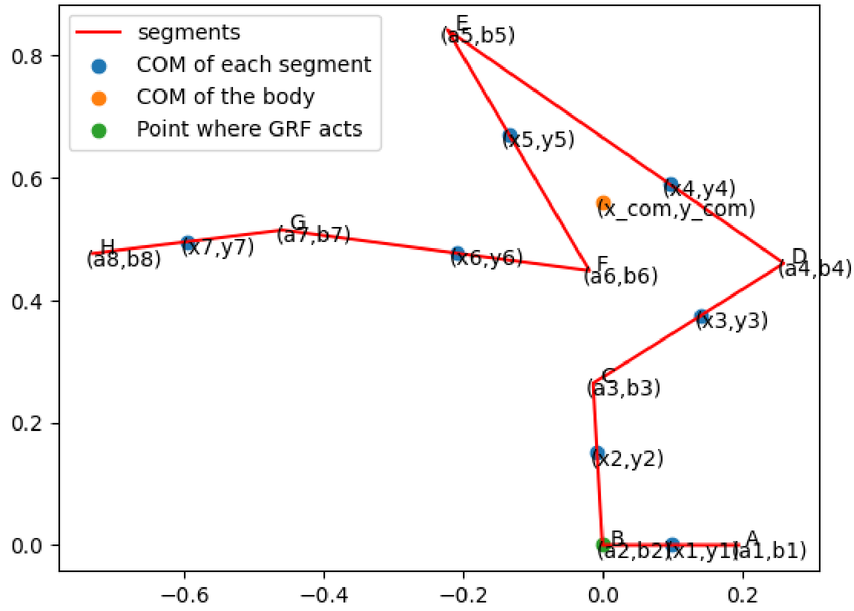


Figure 3.5: Coordinates of segments and COMs - Bakasana

$$
\begin{aligned}
x1 &= 0.506l1 \\
y1 &= 0 \\
x2 &= (0.57)l2\cos\alpha \\
y2 &= (0.57)l2\sin\alpha \\
x3 &= l2\cos\alpha + (0.564)l3\cos\beta \\
y3 &= l2\sin\alpha + (0.564)l3\sin\beta \\
x4 &= l2\cos\alpha + l3\cos\beta + (0.34)l4\cos\gamma \\
y4 &= l2\sin\alpha + l3\sin\beta + (0.34)l4\sin\gamma \\
x5 &= l2\cos\alpha + l3\cos\beta + l4\cos\gamma + (0.433)l5\cos\delta \\
y5 &= l2\sin\alpha + l3\sin\beta + l4\sin\gamma + (0.433)l5\sin\delta \\
x6 &= l2\cos\alpha + l3\cos\beta + l4\cos\gamma + l5\cos\delta + (0.433)l6\cos\epsilon \\
y6 &= l2\sin\alpha + l3\sin\beta + l4\sin\gamma + l5\sin\delta + (0.433)l6\sin\epsilon \\
x7 &= l2\cos\alpha + l3\cos\beta + l4\cos\gamma + l5\cos\delta + l6\cos\epsilon + (0.5)l7\cos\zeta \\
y7 &= l2\sin\alpha + l3\sin\beta + l4\sin\gamma + l5\sin\delta + l6\sin\epsilon + (0.5)l7\sin\zeta
\end{aligned}
$$

$$x_{COM} = \frac{\sum_i x_i m_i}{\sum_i m_i} \qquad y_{COM} = \frac{\sum_i y_i m_i}{\sum_i m_i} \tag{1}$$

$$\therefore x_{COM} = 0.0004H \;\; and \;\; y_{COM} = 0.3092H \tag{2}$$

Considering the body as a whole, there are only 2 forces acting on it - the weight of the body (gravity force) and the GRF. Hence the GRF should act on the same vertical line as the centre of mass of the body.

$$x_{GRF} = x_{COM} = 0.0004H \tag{3}$$

Similar to how the coordinates of the COMs of each link was found, we now find the coordinates of the endpoints of each link. This would make our equations more uniform at the next stage

$$
\begin{aligned}
a1 &= l1 \\
b1 &= 0 \\
a2 &= 0 \\
b2 &= 0 \\
a3 &= l2\cos\alpha \\
b3 &= l2\sin\alpha \\
a4 &= l2\cos\alpha + l3\cos\beta \\
b4 &= l2\sin\alpha + l3\sin\beta \\
a5 &= l2\cos\alpha + l3\cos\beta + l4\cos\gamma \\
b5 &= l2\sin\alpha + l3\sin\beta + l4\sin\gamma \\
a6 &= l2\cos\alpha + l3\cos\beta + l4\cos\gamma + l5\cos\delta \\
b6 &= l2\sin\alpha + l3\sin\beta + l4\sin\gamma + l5\sin\delta \\
a7 &= l2\cos\alpha + l3\cos\beta + l4\cos\gamma + l5\cos\delta + l6\cos\epsilon \\
b7 &= l2\sin\alpha + l3\sin\beta + l4\sin\gamma + l5\sin\delta + l6\sin\epsilon \\
a8 &= l2\cos\alpha + l3\cos\beta + l4\cos\gamma + l5\cos\delta + l6\cos\epsilon + l7\cos\zeta \\
b8 &= l2\sin\alpha + l3\sin\beta + l4\sin\gamma + l5\sin\delta + l6\sin\epsilon + l7\sin\zeta
\end{aligned}
$$

Now, the joint forces and moments about the joints are found. The free-body diagrams are drawn in figure 3.6

Link AB:

$$M_2 = m_1 x1 - \frac{W}{2} x_{GRF} \tag{4}$$

$$J_2 = m_1 - \frac{W}{2} \tag{5}$$

$$M_2 = 0.000127WH \qquad J_2 = -0.494W \tag{6}$$

Link BC:

$$M_3 = M_2 + m_2(x2 - a3) + J2(a2 - a3) \tag{7}$$

$$J_3 = J_2 + m_2 \tag{8}$$

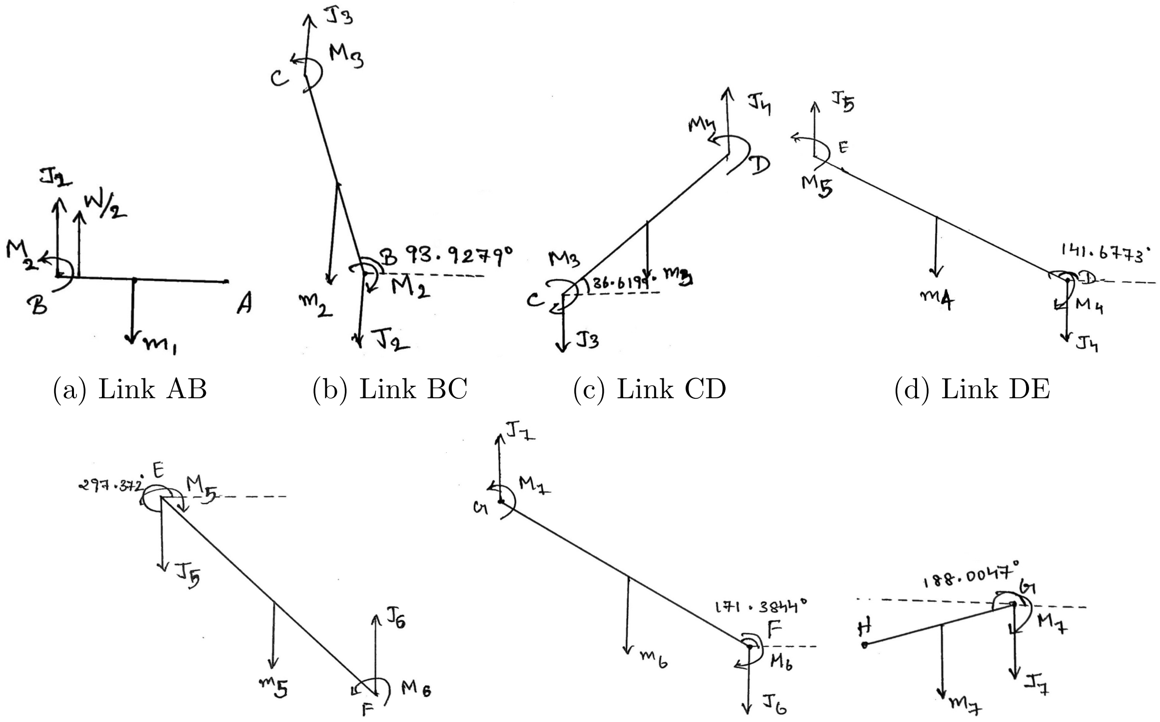
$$M_3 = -0.003505WH \qquad J_3 = -0.478W \tag{9}$$

Link CD:

$$M_4 = M_3 + m_3(x3 - a4) + J3(a3 - a4) \tag{10}$$

$$J_4 = J_3 + m_3 \tag{11}$$

$$M_4 = 0.06692WH \qquad J_4 = -0.45W \tag{12}$$



(a) Link AB (b) Link BC (c) Link CD (d) Link DE

(e) Link EF (f) Link FG (g) Link GH

Figure 3.6: FBD of every link - Bakasana

Link DE:

$$M_5 = M_4 + m_4(x4 - a5) + J4(a4 - a5) \tag{13}$$
$$J_5 = J_4 + m_4 \tag{14}$$
$$M_5 = -0.002233WH \qquad J_5 = -0.161W \tag{15}$$

Link EF:

$$M_6 = M_5 + m_5(x5 - a6) + J5(a5 - a6) \tag{16}$$
$$J_6 = J_5 + m_5 \tag{17}$$
$$M_6 = 0.009515WH \qquad J_6 = -0.061W \tag{18}$$

Link FG:

$$M_7 = M_6 + m_6(x6 - a7) + J6(a6 - a7) \tag{19}$$
$$J_7 = J_6 + m_6 \tag{20}$$
$$M_7 = 0.001091WH \qquad J_7 = -0.0145W \tag{21}$$

Link GH:

$$M_8 = M_7 + m_7(x7 - a8) + J7(a7 - a8) \tag{22}$$
$$J_8 = J_7 + m_7 \tag{23}$$
$$M_2 = 0 \qquad J_2 = 0 \tag{24}$$

3.2 Muscle Forces

3.2.1 Assumptions

The following are the assumptions made about the dominant muscles, their line of action and their point of attachment. The dominant muscle was decided from the sign of the moment about the joint.

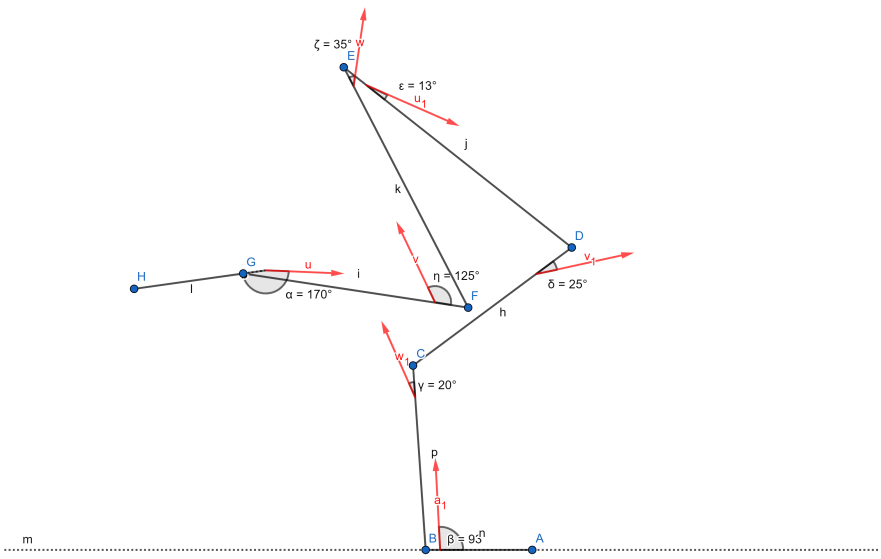


Figure 3.7: Muscle attachment points and angles

Joint	Segment where muscle attaches	Dominant Muscle	Distance of attachment from the joint (m)	Angle of action (°)
Wrist (B)	Hand	Wrist Extensors	0.0111H	93
Elbow (C)	Forearm	Triceps Brachi	0.0552H	20
Shoulder (D)	Upper arm	Deltoid	0.08287H	25
L5-Sacral (D)	Torso	Erector Spinae	0.08287H	13
Hip (E)	Thigh	Iliopsoas	0.0276H	35
Knee (F)	Shank	Hamstrings	0.0552H	125
Ankle (G)	Foot	Triceps Surae	-0.0276H	170

3.2.2 Analysis

Using these assumptions, we can replace these moments with force acting at an offset.

Wrist Extensors:

$$M_z = F_m a \sin\theta_m$$

$$\implies F_m = \frac{M_z}{a\sin\theta_m}$$

$$F_m = \frac{0.00013WH}{0.011H\sin 93°} = 0.0118W$$

Triceps Brachi: Analysis can be done in a similar way

$$F_m = \frac{0.00351WH}{0.0552H\sin 20°} = 0.186W \qquad (25)$$

Deltoid:

$$F_m = \frac{0.06692WH}{0.08287H\sin 25^\circ} = 1.9108W \tag{26}$$

Erector Spinae:

$$F_m = \frac{0.00446WH}{0.08287H\sin 13^\circ} = 0.239W \tag{27}$$

Iliopoas:

$$F_m = \frac{0.00223WH}{0.0276H\sin 35^\circ} = 0.141W \tag{28}$$

Hamstrings:

$$F_m = \frac{0.00952WH}{0.0552H\sin 125^\circ} = 0.21054W \tag{29}$$

Triceps Surae:

$$F_m = \frac{0.00109WH}{0.0552H\sin 170^\circ} = 0.1137W \tag{30}$$

3.3 Results and Conclusions

The following are the results obtained for the joint forces and moments:

	In terms of W and H		$W = 800N, H = 1.81m$	
Joint	M_z	J	M_z	J
Wrist (B)	0.00013 WH	0.494 W	0.184	395.2
Elbow (C)	0.00351 WH	0.478 W	5.076	382.4
Shoulder (D)	0.06692 WH	0.45 W	96.903	360
L5-Sacrum (E)	0.00446 WH	0.322 W	6.468	257.6
Hip (E)	0.00223 WH	0.161 W	3.234	128.8
Knee (F)	0.00952 WH	0.061 W	13.778	48.8
Ankle (G)	0.00109 WH	0.0145 W	1.580	11.6

The following are the results obtained for the muscle forces:

Muscle	F_m	F_m (N)
Wrist Extensors	0.0118 W	9.44
Triceps Brachi	0.186 W	148.8
Deltoid	1.9108 W	1528.64
Erector Spinae	0.239 W	191.2
Iliopsoas	0.141 W	112.8
Hamstrings	0.2105 W	168.4
Triceps Surae	0.1137 W	90.96

In this way, we have obtained the forces exerted by the major muscles in our body while performing Bakasana. The maximum force is exerted by the deltoid muscles. Moreover, the joint forces are high in the wrists, elbows and shoulders. Hence, we can conclude that Bakasana helps strengthen the forearms, wrists and shoulders.

4 Analysing Virabhadrasana III

4.1 Joint Forces and Moments

4.1.1 Assumptions

- The angles made by each link with respect to the horizontal have been approximated using GeoGebra (a graphing calculator)
- The mass of each segment is taken from the anthropometric data present in figure 2.3
- The length and the positions of the centre of mass of each segment have been taken from the anthropometric data present in figure 2.2
- As shown in figure 2.2 and as assumed in [3], I will work with a structure wherein the L5-sacrum joint and the hip joints lie on the same line (normal to the sagittal plane).
- The units of W is taken to be Newtons, and the units of H taken to be metres. Here, H and W indicate the total height and weight of the body, respectively.
- The following table contains the lengths and masses of each segment of the body.

Link	m	l
AB (link 1)	0.0145W	0.152H
BC (link 2)	0.0465W	0.246H
CD (link 3)	0.1W	0.245H
DE (link 4)	0.289W	0.34H
EF (link 5)	0.028W	0.186H
FG (link 6)	0.016W	0.146H
GH (link 7)	0.006W	0.108H
DI (link 8)	0.1W	0.245H
IJ (link 9)	0.0465W	0.246H
JK (link 10)	0.0145W	0.152H

- The angles made by each link with the horizontal is given in figure 4.8

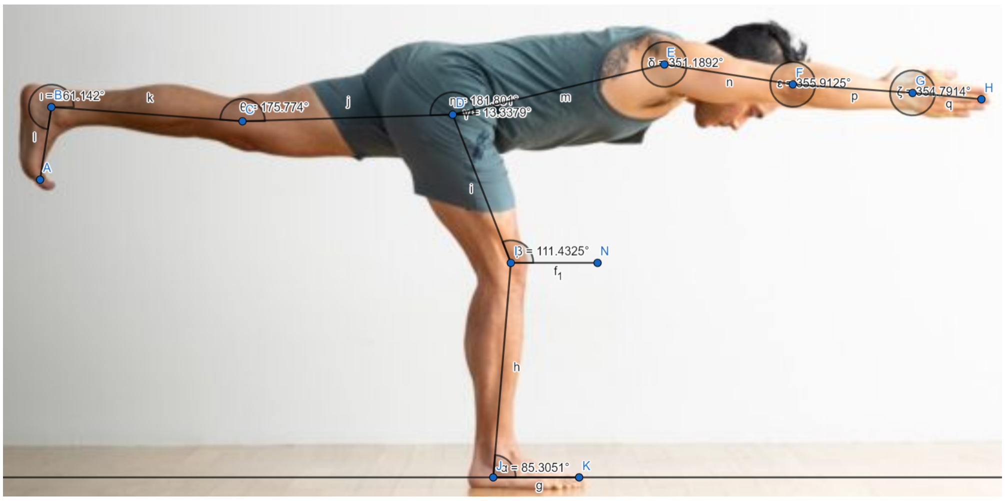


Figure 4.8: Angles at the joints during Virabhadrasana III

4.1.2 Analysis

Similar to the previous pose, we start by finding the coordinates of the COMs. The point J is considered to be the origin.

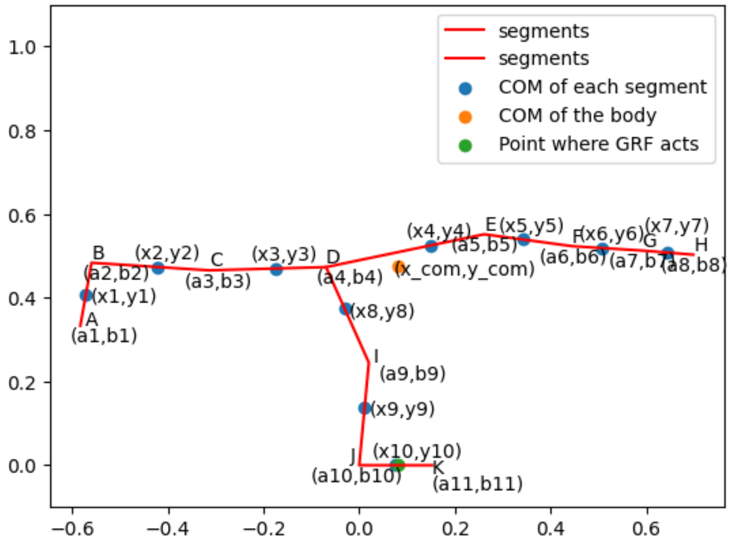


Figure 4.9: Coordinates of the segments and COMs - Virabhadrasana III

$$x10 = l10(0.5)$$
$$y10 = 0$$
$$x9 = l9\cos\alpha(0.567)$$
$$y9 = l9\sin\alpha(0.567)$$
$$x8 = l9\cos\alpha + l8\cos\beta(0.567)$$
$$y8 = l9\sin\alpha + l8\sin\beta(0.567)$$
$$x4 = l9\cos\alpha + l8\cos\beta + l4\cos\gamma(0.66)$$
$$y4 = l9\sin\alpha + l8\sin\beta + l4\sin\gamma(0.66)$$
$$x5 = l9\cos\alpha + l8\cos\beta + l4\cos\gamma + l5\cos\delta(0.436)$$
$$y5 = l9\sin\alpha + l8\sin\beta + l4\sin\gamma + l5\sin\delta(0.436)$$
$$x6 = l9\cos\alpha + l8\cos\beta + l4\cos\gamma + l5\cos\delta + l6\cos\epsilon(0.43)$$
$$y6 = l9\sin\alpha + l8\sin\beta + l4\sin\gamma + l5\sin\delta + l6\sin\epsilon(0.43)$$
$$x7 = l9\cos\alpha + l8\cos\beta + l4\cos\gamma + l5\cos\delta + l6\cos\epsilon + l7\cos\zeta(0.506)$$
$$y7 = l9\sin\alpha + l8\sin\beta + l4\sin\gamma + l5\sin\delta + l6\sin\epsilon + l7\sin\zeta(0.506)$$
$$x3 = l9\cos\alpha + l8\cos\beta + l3\cos\eta(0.433)$$
$$y3 = l9\sin\alpha + l8\sin\beta + l3\sin\eta(0.433)$$
$$x2 = l9\cos\alpha + l8\cos\beta + l3\cos\eta + l2\cos\theta(0.433)$$
$$y2 = l9\sin\alpha + l8\sin\beta + l3\sin\eta + l2\sin\theta(0.433)$$
$$x1 = l9\cos\alpha + l8\cos\beta + l3\cos\eta + l2\cos\theta + l1\cos\iota(0.5)$$
$$y1 = l9\sin\alpha + l8\sin\beta + l3\sin\eta + l2\sin\theta + l1\sin\iota(0.5)$$

$$x_{COM} = \frac{\sum_i x_i m_i}{\sum_i m_i} \qquad y_{COM} = \frac{\sum_i y_i m_i}{\sum_i m_i} \tag{31}$$

$$\therefore x_{COM} = 0.08241H \ \ and \ \ y_{COM} = 0.47518H \tag{32}$$

Considering the body as a whole, there are only 2 forces acting on it - the weight of the body (gravity force) and the GRF. Hence the GRF should act on the same vertical line as the centre of mass of the body.

$$x_{GRF} = x_{COM} = 0.08241H \tag{33}$$

Next, we find the coordinates of the endpoints of the segments

$$\begin{aligned}
&a11 = l10 \\
&b11 = 0 \\
&a10 = 0 \\
&b10 = 0 \\
&a9 = l9 \cos\alpha \\
&b9 = l9 \sin\alpha \\
&a4 = l9 \cos\alpha + l8 \cos\beta \\
&b4 = l9 \sin\alpha + l8 \sin\beta \\
&a5 = l9 \cos\alpha + l8 \cos\beta + l4 \cos\gamma \\
&b5 = l9 \sin\alpha + l8 \sin\beta + l4 \sin\gamma \\
&a6 = l9 \cos\alpha + l8 \cos\beta + l4 \cos\gamma + l5 \cos\delta \\
&b6 = l9 \sin\alpha + l8 \sin\beta + l4 \sin\gamma + l5 \sin\delta \\
&a7 = l9 \cos\alpha + l8 \cos\beta + l4 \cos\gamma + l5 \cos\delta + l6 \cos\epsilon \\
&b7 = l9 \sin\alpha + l8 \sin\beta + l4 \sin\gamma + l5 \sin\delta + l6 \sin\epsilon \\
&a8 = l9 \cos\alpha + l8 \cos\beta + l4 \cos\gamma + l5 \cos\delta + l6 \cos\epsilon + l7 \cos\zeta \\
&b8 = l9 \sin\alpha + l8 \sin\beta + l4 \sin\gamma + l5 \sin\delta + l6 \sin\epsilon + l7 \sin\zeta \\
&a3 = l9 \cos\alpha + l8 \cos\beta + l3 \cos\eta \\
&b3 = l9 \sin\alpha + l8 \sin\beta + l3 \sin\eta \\
&a2 = l9 \cos\alpha + l8 \cos\beta + l3 \cos\eta + l2 \cos\theta \\
&b2 = l9 \sin\alpha + l8 \sin\beta + l3 \sin\eta + l2 \sin\theta \\
&a1 = l9 \cos\alpha + l8 \cos\beta + l3 \cos\eta + l2 \cos\theta + l1 \cos\iota \\
&b1 = l9 \sin\alpha + l8 \sin\beta + l3 \sin\eta + l2 \sin\theta + l1 \sin\iota
\end{aligned}$$

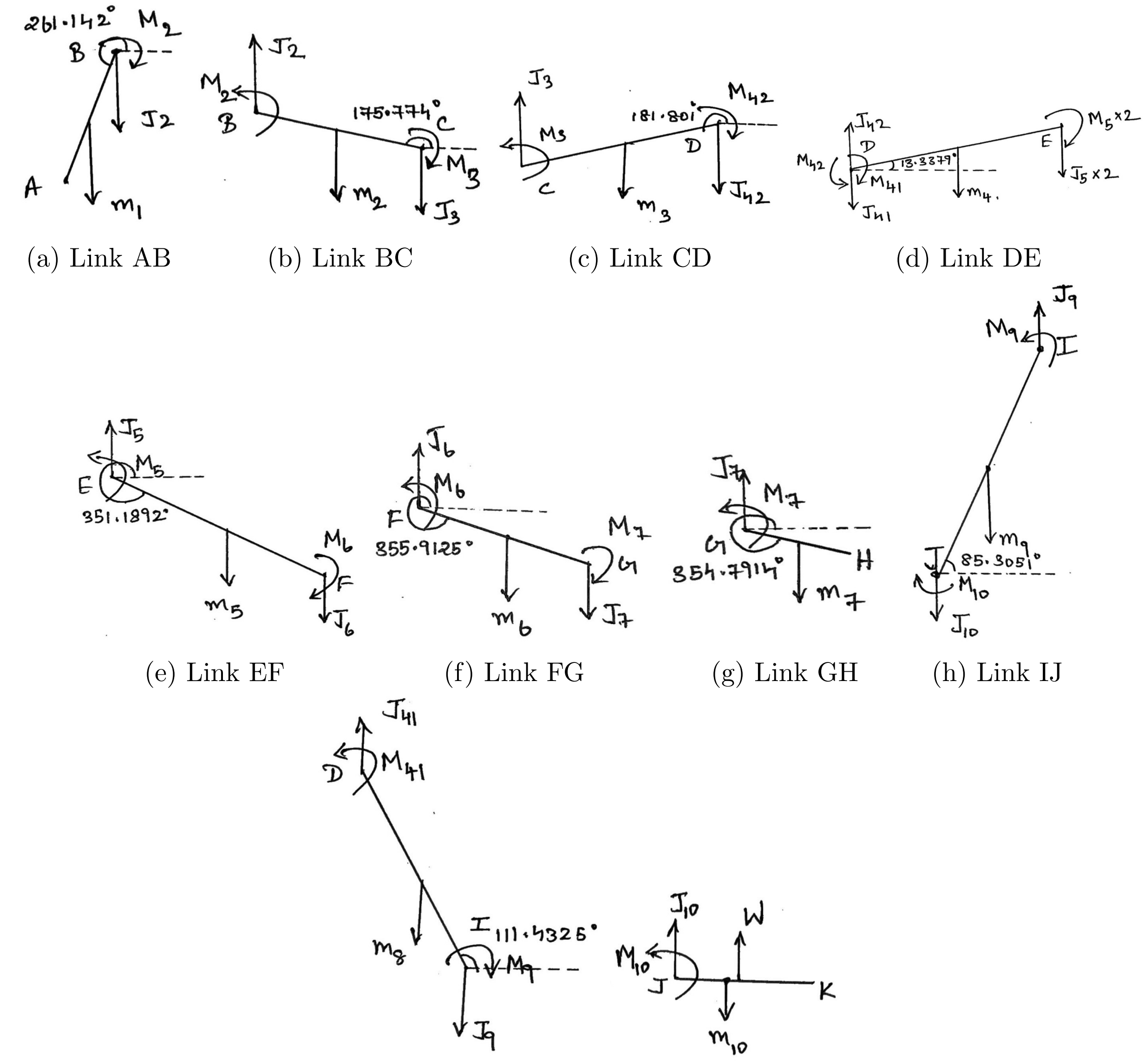
Now, the joint forces and moments about the joints are found. The free-body diagrams are drawn in figure 4.10

Link JK:

$$M_{10} = m_{10} x_{10} - W x_{GRF} \tag{34}$$

$$J_{10} = m_{10} - W \tag{35}$$

$$M_{10} = -0.08131WH \qquad J_{10} = -0.9855W \tag{36}$$



(a) Link AB (b) Link BC (c) Link CD (d) Link DE

(e) Link EF (f) Link FG (g) Link GH (h) Link IJ

(i) Link DI (j) Link JK

Figure 4.10: FBD of every link - virabhadrasana

Link IJ:

$$M_9 = M_{10} + m_9(x_9 - a_9) + J_{10}(a_{10} - a_9) \tag{37}$$

$$J_9 = J_{10} + m_9 \tag{38}$$

$$M_9 = -0.0619WH \qquad J_9 = -0.939W \tag{39}$$

Link DI:

$$M_{4,1} = M_9 + m_8(x_8 - a_4) + J_9(a_9 - a_4) \tag{40}$$

$$J_{4,1} = J_9 + m_8 \tag{41}$$

$$M_{4,1} = -0.14206WH \qquad J_{4,1} = -0.839W \tag{42}$$

Link DE:

$$M_7 = m_7(x_7 - a_7) \tag{43}$$
$$J_7 = m_7 \tag{44}$$
$$M_7 = 0.000326WH \qquad J_7 = 0.006W \tag{45}$$

Link EF:

$$M_6 = M7 + m6(x6 - a6) + J7(a7 - a6) \tag{46}$$
$$J_6 = J7 + m_6 \tag{47}$$
$$M_6 = 0.0022WH \qquad J_6 = 0.022W \tag{48}$$

Link FG:

$$M_5 = M_6 + m_5(x_5 - a_5) + J_6(a_6 - a_5) \tag{49}$$
$$J_5 = J_6 + m_5 \tag{50}$$
$$M_5 = 0.00849WH \qquad J_5 = 0.05W \tag{51}$$

Link GH:

$$M_{4,2} = M_{4,1} + 2M_5 + (x_4 - a_4)m_4 + (a_5 - a_4)2J_5 \tag{52}$$
$$J_{4,2} = m_4 + J_{4,1} + 2J_5 \tag{53}$$
$$M_{4,2} = 0.0342WH \qquad J_{4,2} = 0.161W \tag{54}$$

Link DC:

$$M_3 = M_{4,2} + m3(x3 - a3) + J42(a4 - a3) \tag{55}$$
$$J_3 = J_{4,2} + m3 \tag{56}$$
$$M_3 = 0.00867WH \qquad J_3 = -0.061W \tag{57}$$

Link CB:

$$M_2 = M_3 + m2(x2 - a2) + J3(a3 - a2) \tag{58}$$
$$J_2 = J_3 + m2 \tag{59}$$
$$M_2 = 0.000169WH \qquad J_2 = -0.0145W \tag{60}$$

Link BA:

$$M_1 = M_2 + m1(x1 - a1) + J2(a2 - a1) \tag{61}$$
$$J_1 = J_2 + m1 \tag{62}$$
$$M_1 = 0 \qquad J_1 = 0 \tag{63}$$

4.2 Muscle Forces

4.2.1 Assumptions

The following are the assumptions made about the dominant muscles, their line of action and their point of attachment. The dominant muscle was decided from the sign of the moment about the joint.

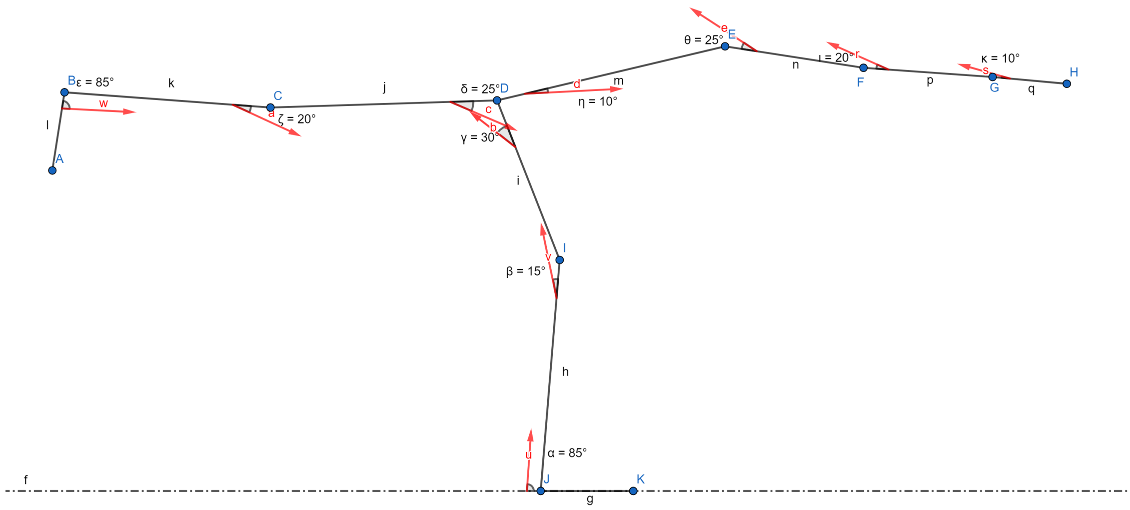


Figure 4.11: Muscle attachment points and angles

Joint	Segment where muscle attaches	Dominant Muscle	Distance of attachment from the joint (m)	Angle of action (°)
L.Ankle(B)	L.Foot	Tibialis Anterior	0.0442H	85
L.Knee(C)	L.Shank	Quadriceps	0.08287H	20
L.Hip(D)	L.Thigh	Iliopsoas	0.1105H	30
L5-Sacral(D)	Torso	Rectus Abdominous	0.221H	10
R.Hip(D)	R.Thigh	Gluteus Maximus	0.1105H	30
Shoulder(E)	Upper arm	Deltoid	0.08287H	25
Elbow(F)	Forearm	Biceps Brachi	0.0552H	20
Wrist(G)	Hand	Radial Deviator Muscles	0.0442H	10
R.Knee(I)	R.Shank	Hamstrings	0.08287	15
R.Ankle(J)	R.Foot	Triceps Surae	0.0276	85

4.2.2 Analysis

Using these assumptions, we can replace these moments with force acting at an offset.

Tibialis Anterior:

$$\begin{aligned} M_z &= F_m a \sin\theta_m \\ \implies F_m &= \frac{M_z}{a \sin\theta_m} \\ F_m &= \frac{0.000169WH}{0.0442H \sin 85^\circ} = 0.0038W \end{aligned}$$

Quadriceps: Analysis can be done in a similar way

$$F_m = \frac{0.008667WH}{0.08287H \sin 20^\circ} = 0.3058W \tag{64}$$

Iliopsoas:

$$F_m = \frac{0.03421WH}{0.1105H\sin 30^\circ} = 0.619W \tag{65}$$

Rectus Abdominous:

$$F_m = \frac{0.13864WH}{0.221H\sin 10^\circ} = 3.613W \tag{66}$$

Gluteus Maximus:

$$F_m = \frac{0.14206WH}{0.1105H\sin 30^\circ} = 2.571W \tag{67}$$

Deltoid:

$$F_m = \frac{0.00849WH}{0.08287H\sin 25^\circ} = 0.2424W \tag{68}$$

Biceps Brachi:

$$F_m = \frac{0.002202WH}{0.0552H\sin 20^\circ} = 0.1166W \tag{69}$$

Radial Deviator Muscles:

$$F_m = \frac{0.0003265WH}{0.0442H\sin 10^\circ} = 0.0425W \tag{70}$$

R.Knee:

$$F_m = \frac{0.06187WH}{0.08287H\sin 15^\circ} = 2.88W \tag{71}$$

R.Ankle:

$$F_m = \frac{0.08131WH}{0.0276H\sin 85^\circ} = 2.957W \tag{72}$$

4.3 Results and Conclusions

The following are the results obtained for the joint forces and moments:

	In terms of W and H		$W = 800N, H = 1.81m$	
Joint	M_z	J	M_z	J
L. Ankle (B)	0.000169 WH	-0.0145 W	0.2457	-11.6
L. Knee (C)	0.0086667 WH	-0.061 W	12.5492	-48.8
L. Hip (D_l)	0.034207 WH	-0.161 W	49.53245	-128.8
R. Hip (D_r)	-0.14206 WH	-0.839 W	-205.702	-671.2
L5-Sacrum	0.13864 WH	1 W	200.751	800
Shoulder (E)	0.008489 WH	0.05 W	12.29328	40
Elbow (F)	0.002202 WH	0.022 W	3.1889	17.6
Wrist (G)	0.0003265 WH	-0.006 W	0.4728	4.8
R. Knee (I)	-0.061873 WH	-0.939 W	-89.592	-751.2
R. Ankle (J)	-0.08131 WH	-0.9855 W	-117.7377	-788.4

The following are the results obtained for the muscle forces:

Muscle	F_m	F_m (N)
Tibialis Anterior	0.0038W	3.04
Quadriceps	0.3058W	244.64
Iliopsoas	0.619W	495.2
Rectus Abdominous	3.613W	2890.4
Gluteus Maximus	2.571W	2056.8
Deltoid	0.2424W	193.92
Biceps Brachi	0.1166W	93.28
Radial Deviator Muscles	0.0425W	34
Hamstrings	2.88W	2304
Triceps Surae	2.957W	2365.6

In this way, the muscle forces, joint forces and moments about the joints are obtained. The results show that the maximum muscle force is applied by the Rectus abdominous, the Gluteus Maximus, the Hamstrings and the Triceps Surae. The joint forces are high for the leg in stance (right leg in this case). Hence, virabhadrasana III strengthens the leg, glutes and abdominal (core) muscles.

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