CARTWHEEL BIOMECHANICS

Jena Nakata

Bio 438

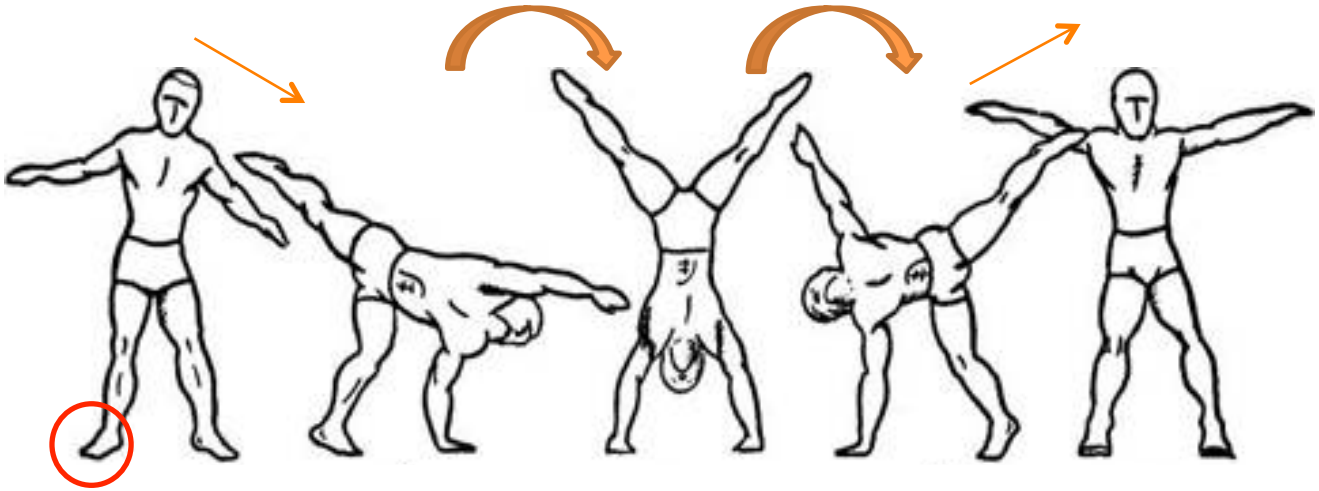
Spring 2011

Goals

- Momentum
- Mechanical Energy
  - Moment of Inertia
  - Torque
  - Centripetal Force
  - Power
  - Work

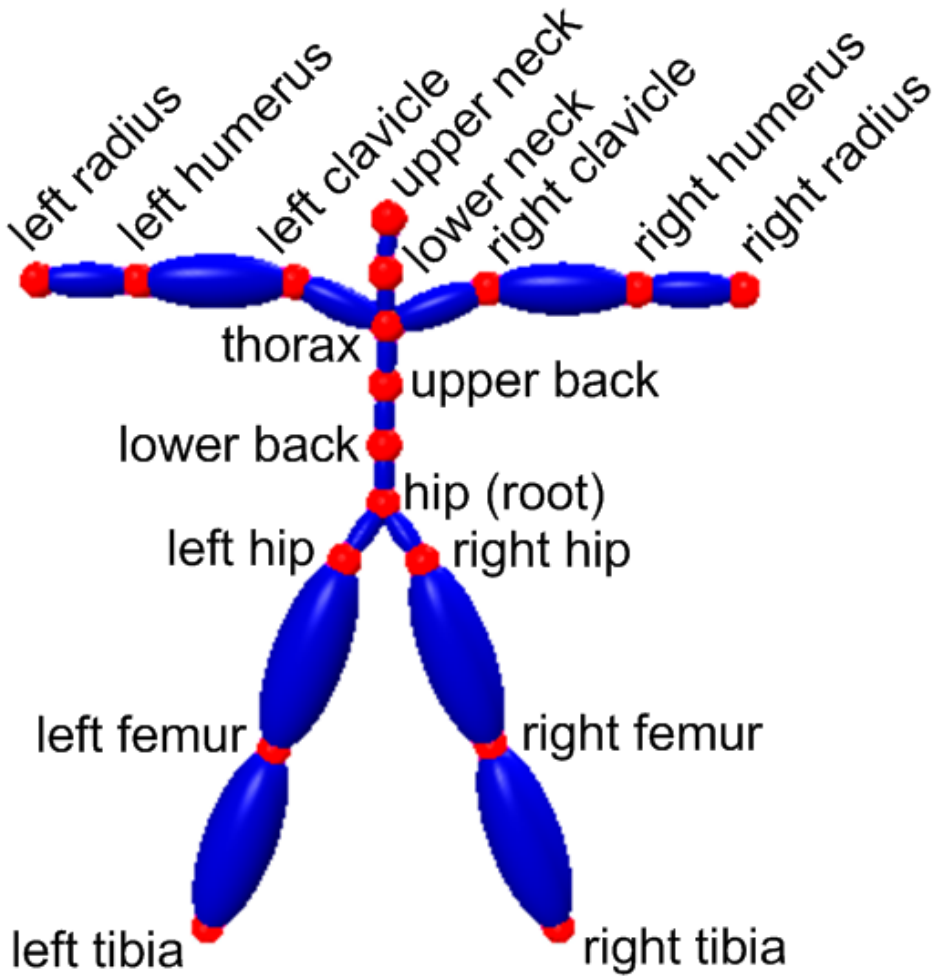
- Robot doing a cartwheel
  - http://www.youtube.com/watch?v=EmOl5Nha2ac

Overview



1. Lunge
2. Split
3. Lunge

Muscles involved



Methods

- High speed camera
- LoggerPro 3

FOOT CALCULATIONS

Resting State:

- Potential Energy = 0.9 J
  - = mgh = 0.9 kg X 9.8 m/s^2 X 0.1 m
- Momentum = 0 N s
  - p = mv
    - v_i = 0 m/s
    - m = 56.25 kg

	Energy (J)	***p*(N s)**	**τ (N m)**	**F (N)**	**W (J)**	**P (W)**
Resting State	0.9	0	0	0	0	0

Part 1: Lunge

Calculations: Lunge

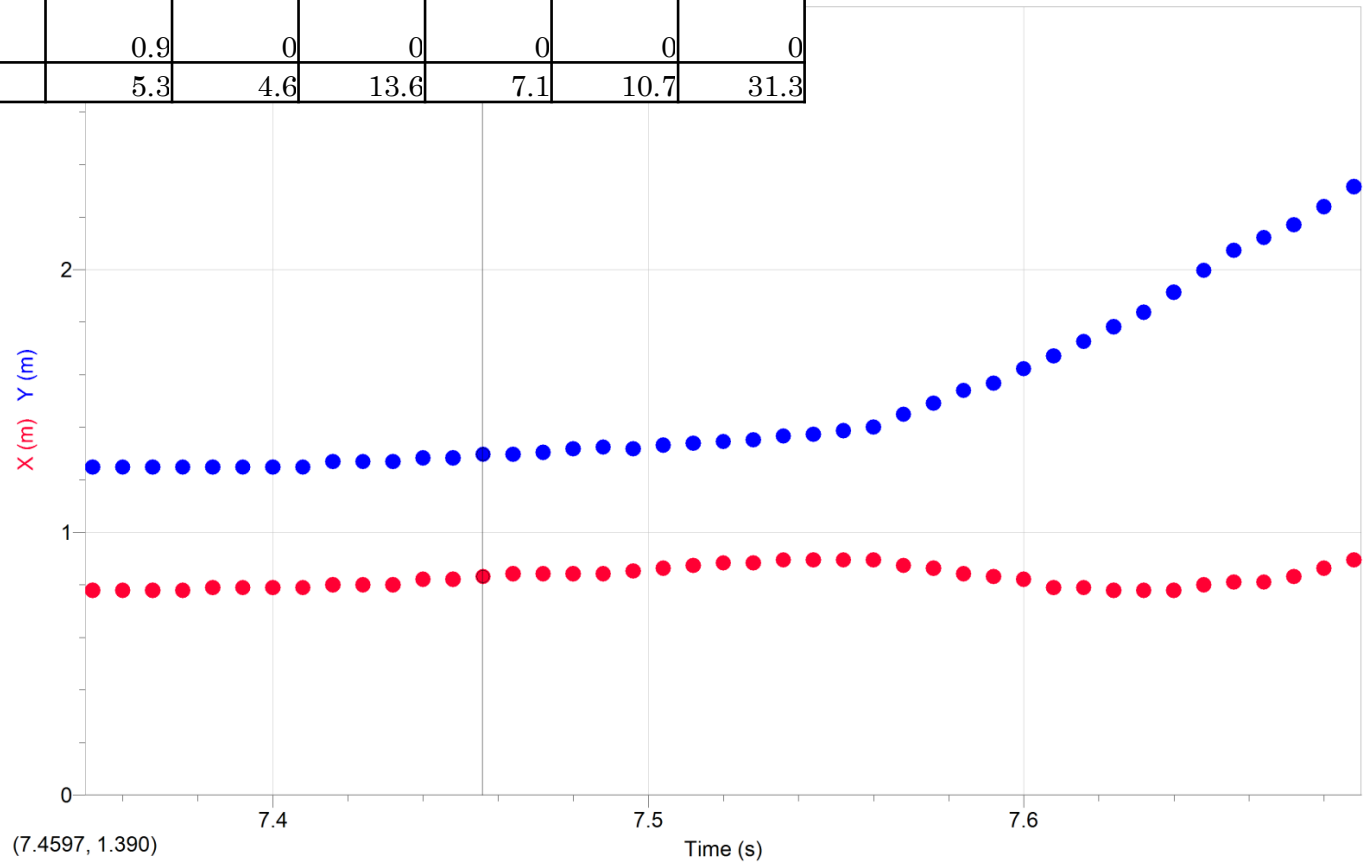
- $\omega = 0.25\pi$ rad/0.34s = 2.3 rad/s
- α = 2.3 rad/s/0.34s = 6.8 rad/s^2
- Kinetic Energy = 5.3 J
  - = ½Iω^2
    - Moment of Inertia (I) = mr^2
      - Mass of Foot = 0.9 kg
      - r = 1.5 m
      - = (0.9 kg)(1.5 m)^2 = 2.0 kg m^2
  - = ½ (2.0 kg m^2)(2.3 rad/s)^2
- Angular Momentum (L) = 4.6 N s
  - = Iω
  - = (2.0 kg m^2)(2.3 rad/s)

Other calculations

- Torque (τ) = 13.6 N m
  - = I α
  - = (2.0 kg m^2)(6.8 rad/s^2)
- Centripetal Force = mr ω^2 = 7.1 N
  - = (0.9 kg)(1.5 m)(2.3 $rad/s)^2$
- Work = 10.7 J
  - = τ θ
  - = (13.6 N m)(0.25π rad)
- Power = 31.3 W
  - = τ ω
  - = (13.6 N m)(2.3 rad/s)

RESULTS

	Energy (J)	*p*(N s)	τ (N m)	F (N)	W (J)	P (W)
Resting State	0.9	0	0	0	0	0
Lunge	5.3	4.6	13.6	7.1	10.7	31.3



Part 2: Split

Calculations: Split

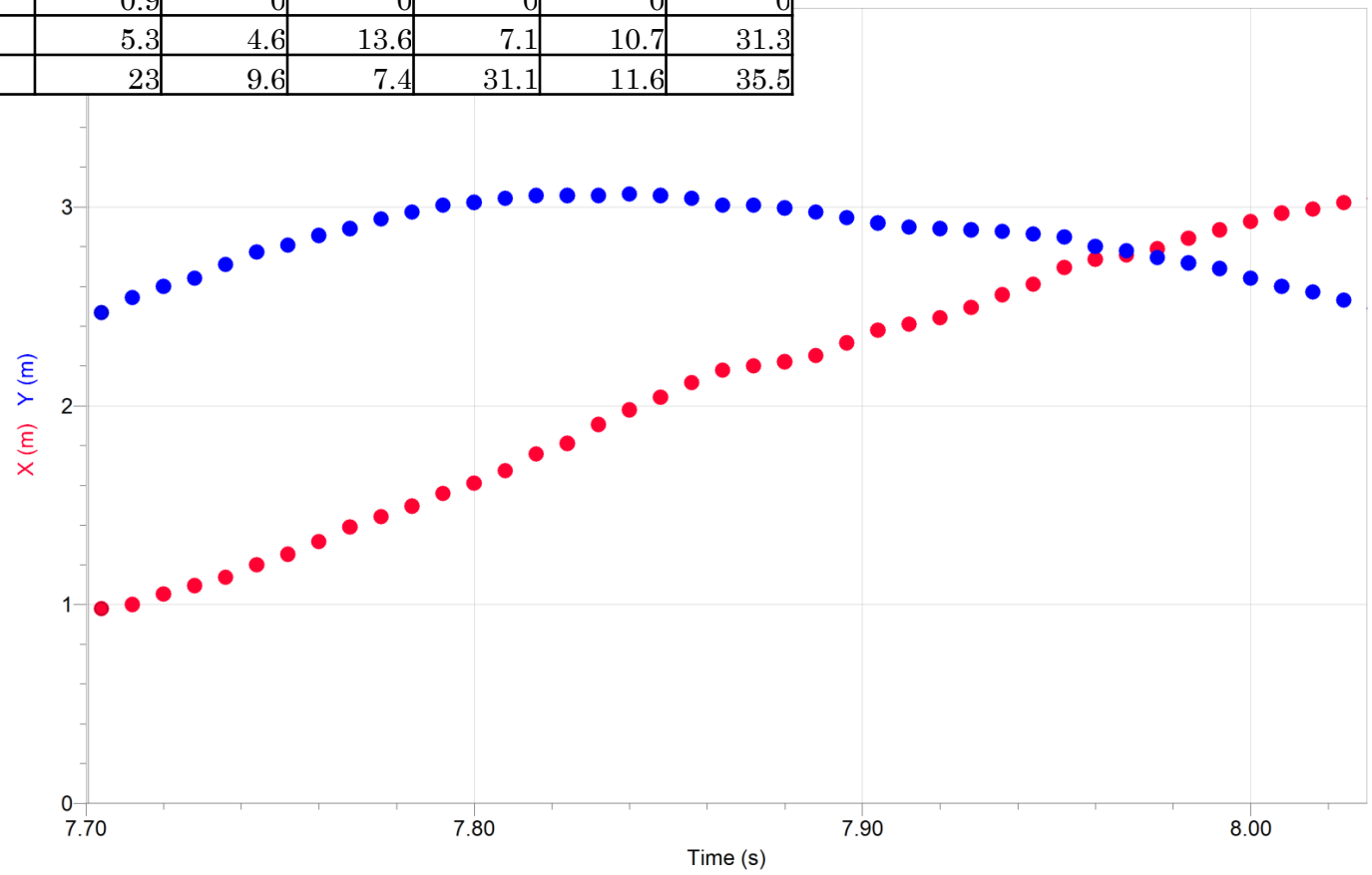
- $\omega = 0.5\pi$ rad/0.33s = 4.8 rad/s
- α = 2.5 rad/s/0.68s = 3.7 rad/s^2
- Kinetic Energy = 23 J
  - = ½Iω^2
    - Moment of Inertia (I) = mr^2
      - Mass of Foot = 0.9 kg
      - r = 1.5 m
      - = (0.9 kg)(1.5 m)^2 = 2.0 kg m^2
  - = ½ (2.0 kg m^2)(4.8 rad/s)^2
- Angular Momentum (L) = 9.6 N s
  - = Iω
  - = (2.0 kg m^2)(4.8 rad/s)

Other calculations

- Torque (τ) = 7.4 N m
  - = I α
  - = (2.0 kg m^2)(3.7 rad/s^2)
- Centripetal Force = mr ω^2 = 31.1 N
  - = (0.9 kg)(1.5 m)(4.8 $rad/s)^2$
- Work = 11.6 J
  - = τ θ
  - = (7.4 N m)(0.5π rad)
- Power = 35.5 W
  - = τ ω
  - = (7.4 N m)(4.8 rad/s)

RESULTS

	Energy (J)	p(N s)	τ (N m)	F (N)	W (J)	P (W)
Resting State	0.9	0	0	0	0	0
Lunge	5.3	4.6	13.6	7.1	10.7	31.3
Split	23	9.6	7.4	31.1	11.6	35.5



Part 3: Lunge

Calculations: Lunge

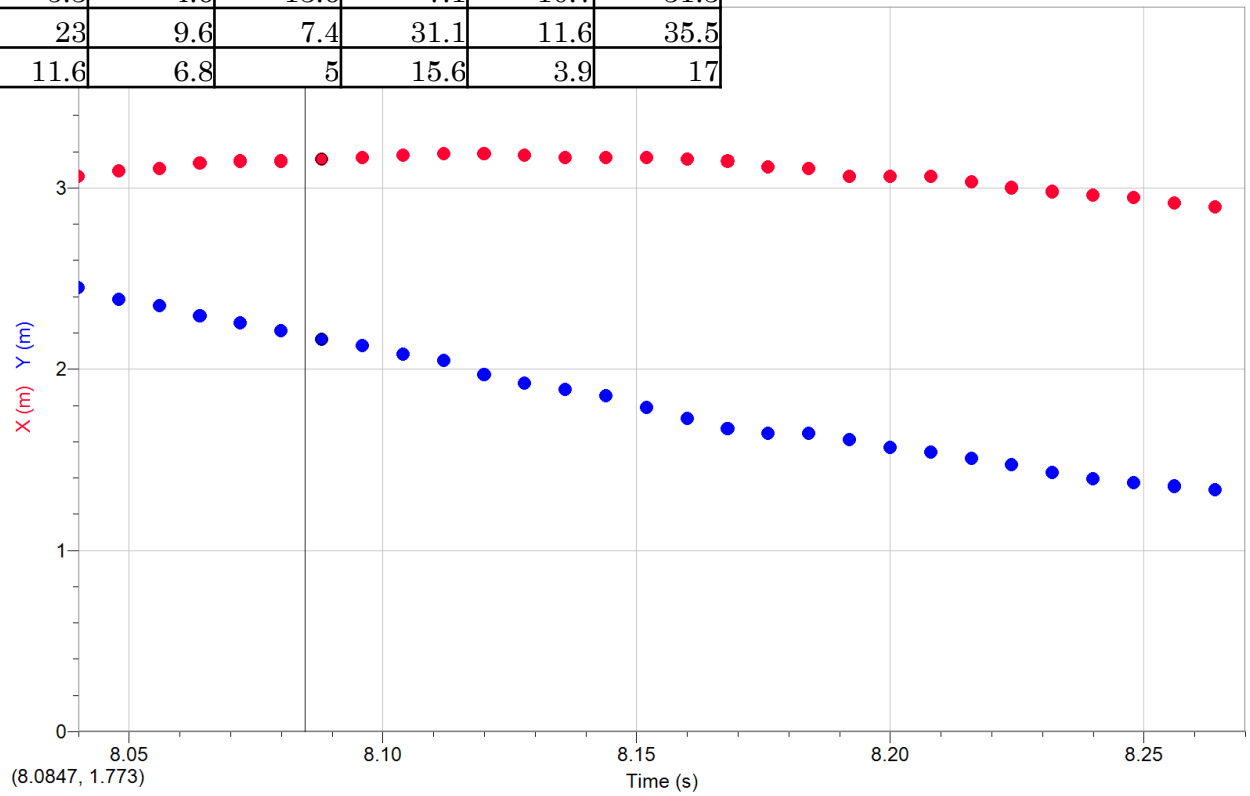
- $\omega = 0.25\pi$ rad/0.23s = 3.4 rad/s
- α = -1.4 rad/s/0.57s = -2.5 rad/s^2
- Kinetic Energy = 11.6 J
  - = ½Iω^2
    - Moment of Inertia (I) = mr^2
      - Mass of Foot = 0.9 kg
      - r = 1.5 m
      - = (0.9 kg)(1.5 m)^2 = 2.0 kg m^2
  - = ½ (2.0 kg m^2)(3.4 rad/s)^2
- Angular Momentum (L) = 6.8 N s
  - = Iω
  - = (2.0 kg m^2)(3.4 rad/s)

Other calculations

- Torque (τ) = 5 N m
  - = I α
  - = (2.0 kg m^2)(2.5 rad/s^2)
- Centripetal Force = mr ω^2= 15.6 N
  - = (0.9 kg)(1.5 m)(3.4 $rad/s)^2$
- Work = 3.9 J
  - = τ θ
  - = (5 N m)(0.25π rad)
- Power = 17 W
  - = τ ω
  - = (5 N m)(3.4 rad/s)

RESULTS

	Energy (J)	*p*(N s)	τ (N m)	F (N)	W (J)	P (W)
Resting State	0.9	0	0	0	0	0
Lunge	5.3	4.6	13.6	7.1	10.7	31.3
Split	23	9.6	7.4	31.1	11.6	35.5
Lunge	11.6	6.8	5	15.6	3.9	17



ASSUMPTIONS

- Mass of foot
- Rounded height
- Twisting of torso
- Perfect circle
- Closed system

PROFESSIONALS

- http://www.youtube.com/watch?v=dy0PPknHVG
  - 7-10secs
- Movements:
  - Perfect handstand
  - Locked arms around ears
  - No arching of head
  - Tight body
  - Straight legs

Future directions

- One-handed Cartwheel

- Aerials

- Twisting of Torso
- Differences in gender, body weight, and height

Full body calculations

- Resting State
  - PE = mgh = (56.25 kg)(9.8 m/s^2)(1.5m) = 413 J

Calculations: Lunge

- $\omega = 0.25\pi$ rad/0.34s = 2.3 rad/s
- α = 2.3 rad/s/0.34s = 6.8 rad/s^2
- Kinetic Energy = 334.9 J
  - = ½Iω^2
    - Moment of Inertia (I) = mr^2
      - Mass of Full body = 56.25 kg
      - r = 1.5 m
      - = (56.25 kg)(1.5 m)^2 = 126.6 kg m^2
  - = ½ (126.6 kg m^2)(2.3 rad/s)^2
- Angular Momentum (L) = 291.2 N s
  - = Iω
  - = (126.6 kg m^2)(2.3 rad/s)

Other calculations

- Torque (τ) = 860.9 N m
  - = I α
  - = (126.6 kg m^2)(6.8 rad/s^2)
- Centripetal Force = mr ω^2= 446.3 N
  - = (56.25 kg)(1.5 m)$(2.3 rad/s)^2$
- Work = 676.1 J
  - = τ θ
  - = (860.9 N m)(0.25π rad)
- Power = 1980.1 W
  - = τ ω
  - = (860.9 N m)(2.3 rad/s)

Calculations: split

- $\omega = 0.5\pi$ rad/0.33s = 4.8 rad/s
- α = 2.5 rad/s/0.68s = 3.7 rad/s^2
- Kinetic Energy = 1458.4 J
  - = ½Iω^2
    - Moment of Inertia (I) = mr^2
      - Mass of Full Body = 56.25 kg
      - r = 1.5 m
      - = (56.25 kg)(1.5 m)^2 = 126.6 kg m^2
  - = ½ (126.6 kg m^2)(4.8 rad/s)^2
- Angular Momentum (L) = 607.7 N s
  - = Iω
  - = (126.6 kg m^2)(4.8 rad/s)

Other calculations

- Torque (τ) = 468.4 N m
  - = I α
  - = (126.6 kg m^2)(3.7 rad/s^2)
- Centripetal Force = mr ω^2= 1944 N
  - = (56.25 kg)(1.5 m)$(4.8 rad/s)^2$
- Work = 367.9 J
  - = τ θ
  - = (468.4 N m)(0.25π rad)
- Power = 2248.3 W
  - = τ ω
  - = (468.4 N m)(4.8 rad/s)

Calculations: Lunge

- $\omega = 0.25\pi$ rad/0.23s = 3.4 rad/s
- α = -1.4 rad/s/0.57s = -2.5 rad/s^2
- Kinetic Energy = 731.7 J
  - = ½Iω^2
    - Moment of Inertia (I) = mr^2
      - Mass of Full Body = 56.25 kg
      - r = 1.5 m
      - = (56.25 kg)(1.5 m)^2 = 126.6 kg m^2
  - = ½ (126.6 kg m^2)(3.4 rad/s)^2
- Angular Momentum (L) = 430.4 N s
  - = Iω
  - = (126.6 kg m^2)(3.4 rad/s)

Other calculations

- Torque (τ) = 316.5 N m
  - = I α
  - = (126.6 kg m^2)(2.5 rad/s^2)
- Centripetal Force = mr ω^2 = 286.9 N
  - = (56.25 kg)(1.5 m)(3.4 rad/s)^2
- Work = 248.6 J
  - = τ θ
  - = (316.5 N m)(0.25π rad)
- Power = 1076.1 W
  - = τ ω
  - = (316.5 N m)(3.4 rad/s)

COMPARISON

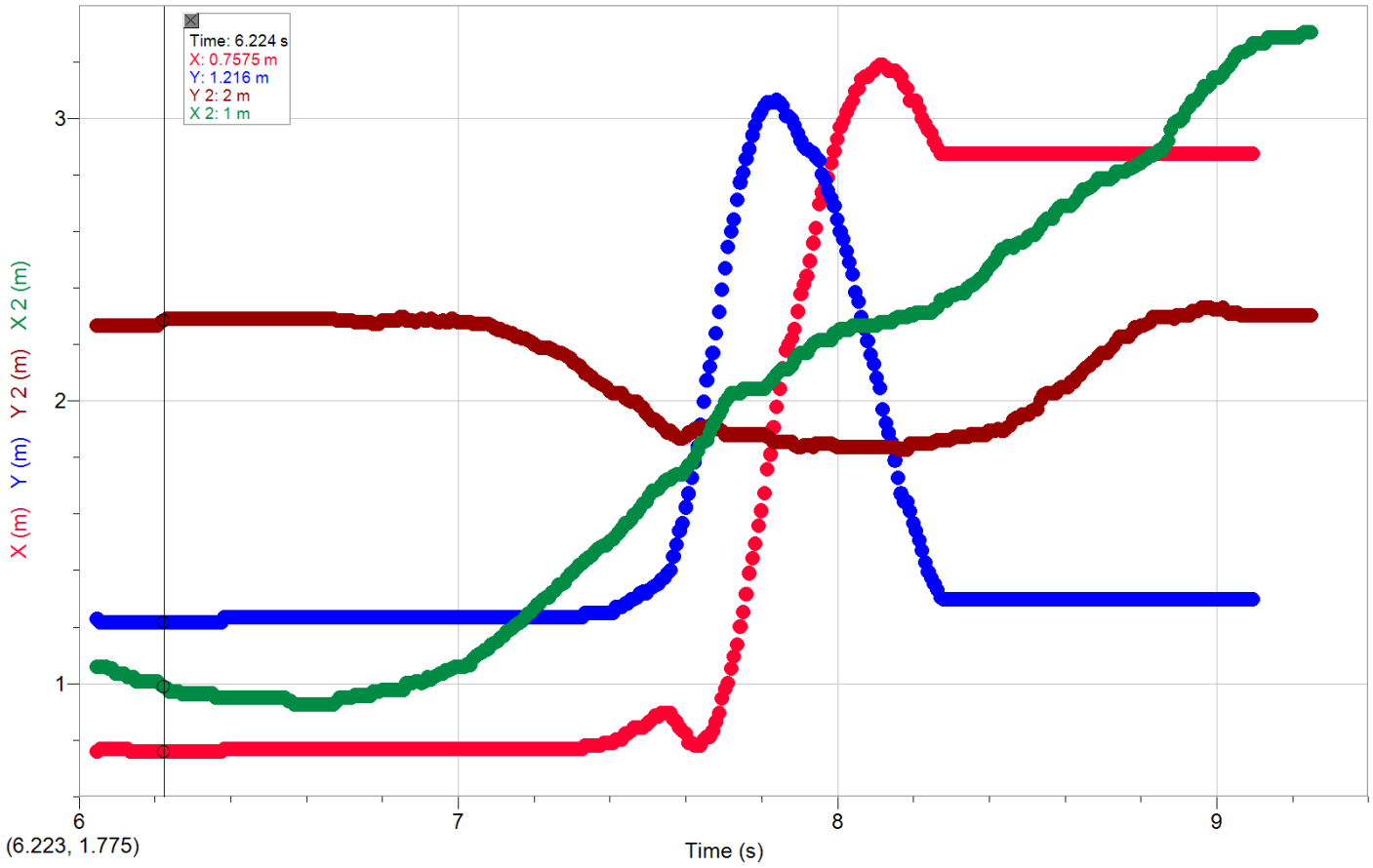
- Foot Calculations:

	Energy (J)	***p*(N s)**	**τ (N m)**	**F (N)**	**W (J)**	**P (W)**
Resting State	0.9	0	0	0	0	0
Lunge	5.3	4.6	13.6	7.1	10.7	31.3
Split	23	9.6	7.4	31.1	11.6	35.5
Lunge	11.6	6.8	5	15.6	3.9	17

- Full Body Calculations:

	Energy (J)	**p(N s)**	**τ (N m)**	**F (N)**	**W (J)**	**P (W)**
Resting State	413	0	0	0	0	0
Lunge	334.9	291.2	860.9	446.3	676.1	1980.1
Split	1458.4	607.7	468.4	1944	367.9	2248.3
Lunge	731.7	430.4	316.5	286.9	248.6	1076.1

Full LoggerPro Graph



X = Foot x position X 2 = Full Body x position

Y = Foot y position Y 2 = Full Body y position