Lab 2: Gaits to the future

Bio427 — Biomechanics

This lab explores a range of topics associated with movement on land. We are interested in seeing how well an inverted pendulum model serves as a predictor of maximum walking speed for humans (sex differences, size differences). In addition, we are interested in determining the extent to which pelvic tilt or rotation contributes to our movement on land and the exent to which those kinematic parameters vary with walking speed (and the sex and size differences). All of those motions are a consequence of the torques generated by locomotor muscles. Those muscles, in turn, operate with varying speed ratios (SR) and mechanical advantage values (MA). As with other parameters we measure in this class, speed ratio and mechanical advantage may vary with body size or sex and it is interesting to speculate how, if at all, these parameters might vary. Our goals are for you to:

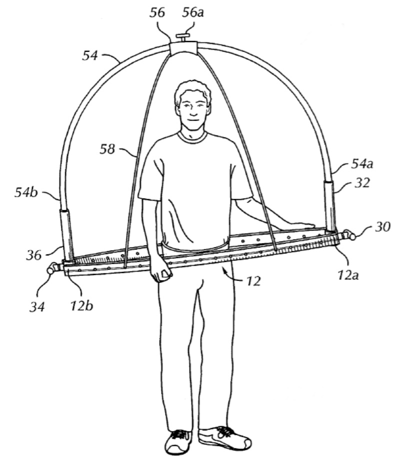

Figure 1: A patented "pelvic extension frame" (U.S. Patent 7029428), designed to help individuals ’develop a "sexy" walk’.

- Use ImageJ for motion analysis[1]
- Use simple physical equations to predict maximum rigid limb walking speeds and test your predictions with measurements
- Examine mechanical advantage and speed ratios in human skeletal systems
- Contribute to crowd data for walking humans (and a possible poster topic!)

[1] http://rsbweb.nih.gov/ij/

Conceptual Basis

An inverted pendulum provides very simple model for walking humans. With a leg forming the radius of an arc through which your body moves, one can use the equation governing centripetal forces to predict the limits to walking on land. To aid our analysis, we make a few assumptions: we neglect air resistance, we assume the legs are rigid and interact with a single point at the ground, we neglect any pelvic motions, and we ignore the inertial roles of arm motions. Given all of these assumptions, we can make a general prediction about the maximum speed one can reach using ridid limb locomotion. The force associated with motion in a circular arc is

$$F = ma_c = \frac{mv^2}{R} \tag{1}$$

where m is the mass of the body, a_c is the inward acceleration of the mass, v is the tangential velocity of the body, and R is radius of the circular orbit. Thus we see that the tangential velocity is constrained by the inward acceleration. Thus for an inverted pendulum

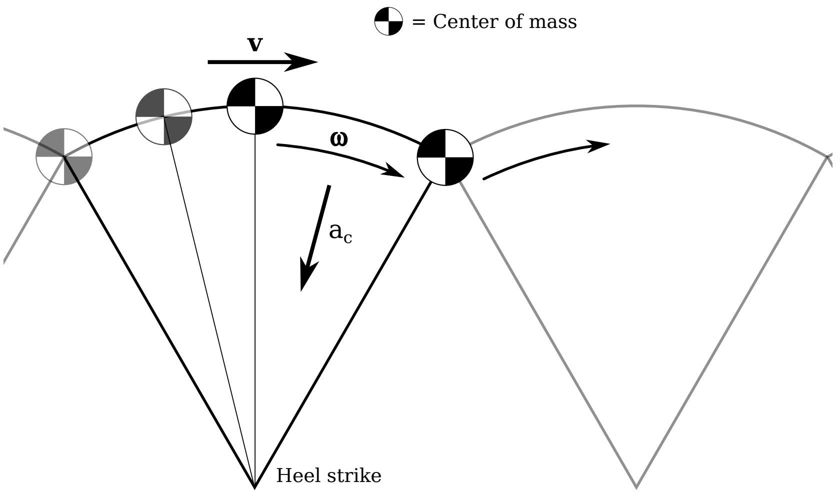

Figure 2: Inverted pendulum walking. Assuming a stiff and straight leg, the muscles accelerate the center of mass to its highest point in the arc of its trajectory, and gravity brings the center of mass back down.

where the inward acceleration can never exceed the gravitational acceleration g we see that:

$$g > \frac{v^2}{R} \tag{2}$$

or

$$v < \sqrt{gL} \tag{3}$$

or

$$Fr = \frac{v}{\sqrt{gL}} < 1 \tag{4}$$

where L is the leg length (the size of the inverted pendulum) and Fr is the Froude number associated with walking on land.

The critical feature of this analysis is that the radius of curvature is necessarily equal to the "leg" length in an inverted pendulum. However, any biomechanical mechanism that permits a larger radius of curvature (and thus a flatter path for the walker) would permit a greater speed. Pelvic tilt and rotation along with plantar (foot) flexion are two such mechanisms.

As mentioned above, the muscles generate torques (τ) about joints in accomplishing locomotor tasks. At equilibrium the torque generated by a muscle in rotating a limb is equal and opposite to the torque that the limb generates on the ground or against an external force:

$$\tau_{\text{in}} = \tau_{\text{out}} \tag{5}$$

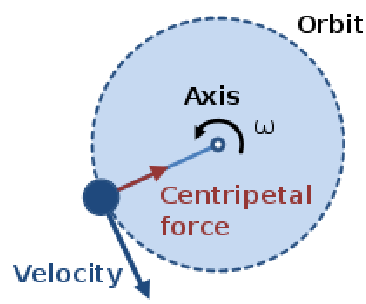

Figure 3: Centripetal force

$$F_{\text{in}} L_{\text{in}} = F_{\text{out}} L_{\text{out}} \tag{6}$$

Thus the mechanical advantage (MA) is the ratio of the output force to the input force

$$\text{MA} = \frac{F_{\text{out}}}{F_{\text{in}}} = \frac{L_{\text{in}}}{L_{\text{out}}} \tag{7}$$

Finally, for a lever rotating under some applied torque, the angular velocity is the same all along the length of the lever. Hence, the speed ratio (SR) is the inverse of the mechanical advantage.

Methods

There are three parts to this lab: pendulum walking, normal walking at two speeds, and calculations of speed ratio and mechanical advantage for specific skeletal elements. For the purposes of the analysis you will be conducting, it is important to ensure at all times that you are walking and not running. The rules for walking are simple: at no time can you have both feet off the ground. Your lab partner will observe your motions carefully to ensure that you are obeying this rule.

Pendulum walking

For the first part of the lab, mark off a known distance over which you will measure the time it takes for you to perform the inverted pendulum gait. A reasonable distance is about 5 m, so that the initial acceleration is not a significant part of the time. Using a second hand on your watch or a timer available on your mobile device, you will time the walking maneuver. This will be done for both lab partners.

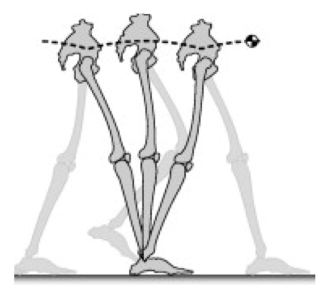

Figure 4: After Kuo, A (2007) The six determinants of gait and the inverted pendulum analogy: A dynamic walking perspective. Human Movement Science: 26:617-656

With your knees locked and your hands by your side, walk on your heels (as best you can) as fast as you can while doing your very best to not use pelvic motions. You may need to try this several times. You can, if you are careful, have your lab partner give a slight push so that your initial acceleration is not too limiting. If so, note the difference in timing.

From both the time and travel distance, calculate your speed (in m/s). Compare this to the speed you predict using your leg length and gravity in the Froude number above. Enter these values along with the other parameters in the table that you will turn in at the end of lab.

Pelvic tilt angle

Walking speed can be increased by changing the effective radius of curvature of your center of mass. This can be done by recruiting

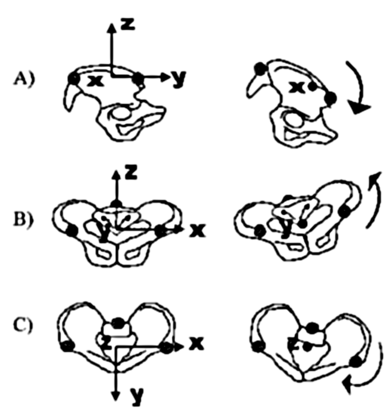

Figure 5: Pelvic rotational motions during walking. A) Anteroposterior pelvic tilt. **B) Pelvic tilt.** C) Pelvic rotation.

rotations associated with your pelvic girdle. These angles can be measured using ImageJ and extensions of your pelvis that we will provide.

Begin by attaching a dowel to the front of your pelvis using a bungie cord – the motions of the dowel will essentially amplify the observable tilt of the pelvis during walking and make this quantity easier to measure. Set up the laptop to record video of you as you walk towards it; ensure that you are able to see the full length of the dowel in the frame for several steps. You will conduct two trials: one in which you walk at a normal comfortable walking speed, and one in which you walk as quickly as you can. Record video, as in the last lab exercise, using guvcview and import this video into ImageJ. Use the line tool to measure the angular extents of the variation in pelvic tilt angle – that is, measure the difference between the maximum and minimum tilt angle achieved by the pelvis. If you have the time and inclination, you may be interested in measuring the pelvic angle in each frame of the walking video so that you can plot the variation in pelvic tilt over the full walk cycle – what kind of function might you expect this variation to resemble?

Mechanical advantage and speed ratios

There are two skeletons in the lab, each with a set of "muscles" labeled on them. Use rulers and tape measures to compute the mechanical advantage and speed ratio of two different muscles that you identify. Fill out the appropriate section in the page you turn in at the end of lab. For the muscles you have chosen, identify the fulcrum and load – what is the class of the lever system?

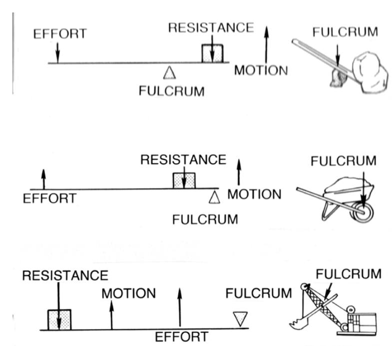

Figure 6: The three lever classes, with some familiar examples. Top: Class 1 lever. Middle: Class 2 lever. Bottom: Class 3 lever.

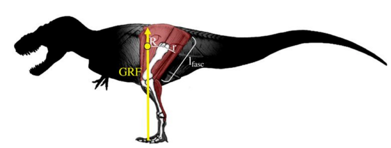

Figure 7: from Pontzer H, Allen V, Hutchinson JR (2009) Biomechanics of Running Indicates Endothermy in Bipedal Dinosaurs. PLoS ONE 4(11): e7783. doi:10.1371/journal.pone.0007783

Lab 2: Gaits to the future

Note: Hand in one worksheet per lab group
Lab Section: ____________________
Name 1: ____________________ Name 2: ____________________

Data

1	Sex	________	________
2	Mass (kg) (1 lb = 0.4536 kg)	________	________
3	Leg length (m)	________	________
4	Locked-knee pendulum walk speed (m/s)	________	________
5	Normal walking speed (m/s)	________	________
6	Normal walking pelvic tilt angle	________	________
7	Fast walking speed (m/s)	________	________
8	Fast walking pelvic tilt angle	________	________
9	Predicted maximum walking speed (pendulum) (m/s)	________	________
10	Predicted Froude number	________	________

Hypotheses

1. State your hypothesis for how pelvic tilt or rotation angles will change with increased walking speeds. Explain the basis for your hypothesis.

2. Select at least two "muscles" on the lab skeletons and, in the space below, enter the dimensions of the input and output lengths as well as the mechanical advantage and speed ratio. In addition, explain why they may have similar (or different) mechanical advantages.

3. In this lab, we only measured pelvic tilt angle. Design and describe an experimental setup to measure pelvic rotation angle during normal and fast walking (assume that due to the federal shutdown, a bug in the grant agency system has awarded you limitless funding for supplies).