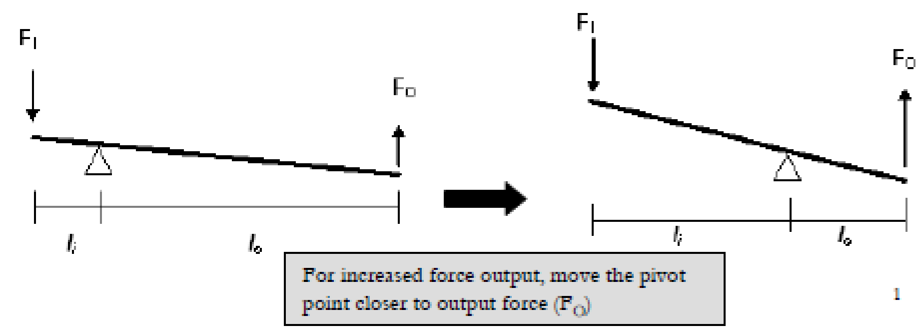
Torques and Levers

Objective:

Examine the consequence of lever systems upon force and velocity output related to lifestyles.

Introduction:

In the vertebrates, muscles generate and skeletal elements apply forces. In this laboratory you will examine some simple biomechanical aspects of the mammalian forearm to gain a better understanding of the relationships between vertebrate form, function, and environmental demands. There are several ways to represent this mechanically. Perhaps the most intuitive representation is with torques and levers. The balance of forces about a point of pivot (fulcrum) depends on the forces, multiplied by their lever arms ($\mathbf{l_o}$ or $\mathbf{l_i}$), the *perpendicular* distance to this point of pivot. This product, force times lever arm, is termed a **moment**. One way to produce more output force is to move the point of pivot closer to the output force ($\mathbf{F_O}$) and farther from the input force ($\mathbf{F_i}$) (see the diagram directly below).



To produce higher output velocity (or distance) advantage, move the pivot point closer to the input force ($\mathbf{F_i}$), the opposite of the change indicated above.

Exercise 1. Output Force

You will measure the in-lever ($\mathbf{l_i}$) and out-lever ($\mathbf{l_o}$) sections on the animals in Figures 1, 2, and 3 below.

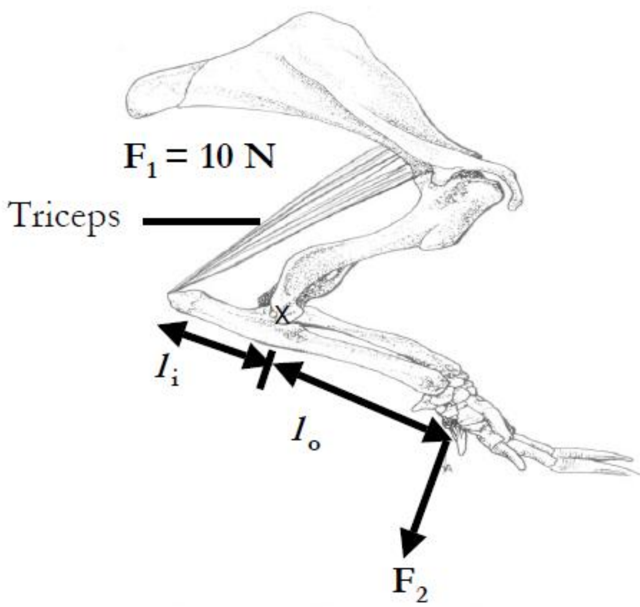
Determine the **output force** ($\mathbf{F_2}$) delivered to the forefoot of representative mammals when the triceps brachii exerts a pull (an input force) of 10 Newtons ($\mathbf{F_1}$) at its insertion. We assume that this force stays constant during rotation of the forearm.

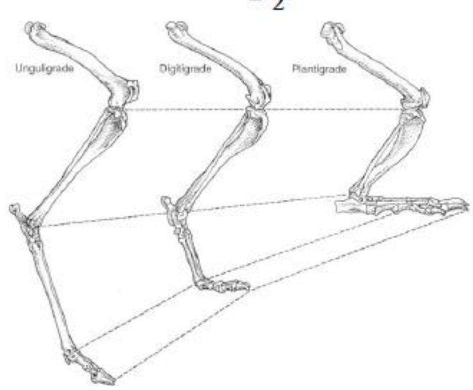
Recall that $\mathbf{F_1 l_i = F_2 l_o}$ so that $\mathbf{F_2 = F_1 l_i / l_o}$.

Use rulers to measure the in-lever (li) and out-lever (lo) **lengths in meters**.

Specifically:

- **in-lever** (l_i) = the distance from the very posterior tip of the olecranon process to the center of the semilunar notch;
- **out-lever** (l_o) = the center of the semilunar notch to the output site on the foot.
- **Output site** on the foot depends upon the foot posture. The output site may be the base of the foot (plantigrade), the midfoot (digitigrade), or the tip of the foot (unguligrade). In Figures 1, 2, and 3 of forearms, a boxed arrow indicates the point of output force application.
- Assume that the triceps brachii is at right angles to the olecranon process of the ulna.
- Consider the scapula and humerus to be fixed in position.
- Use a calculator to make any necessary calculations.
- **Place your data into Table 1.**





This diagram illustrates the forces and lever arms involved in movement of the appendage and denotes measurements you need to record.

TABLE 1 - Data from exercises 1, 2, and 3

Organism	Foot posture	Humerus length (meters)	l_i (meters)	l_o (meters)	$F_2=F_1 li/lo$	Mech. Adv. l_i / l_o	Vel. Ratio 1 / MA	Actual Vel. VR x 1/3 humerus length (meters)
Armadillo Figure 1	Plantigrade							
Cat Figure 2	Digitigrade							
Deer Figure 3	Unguligrade							

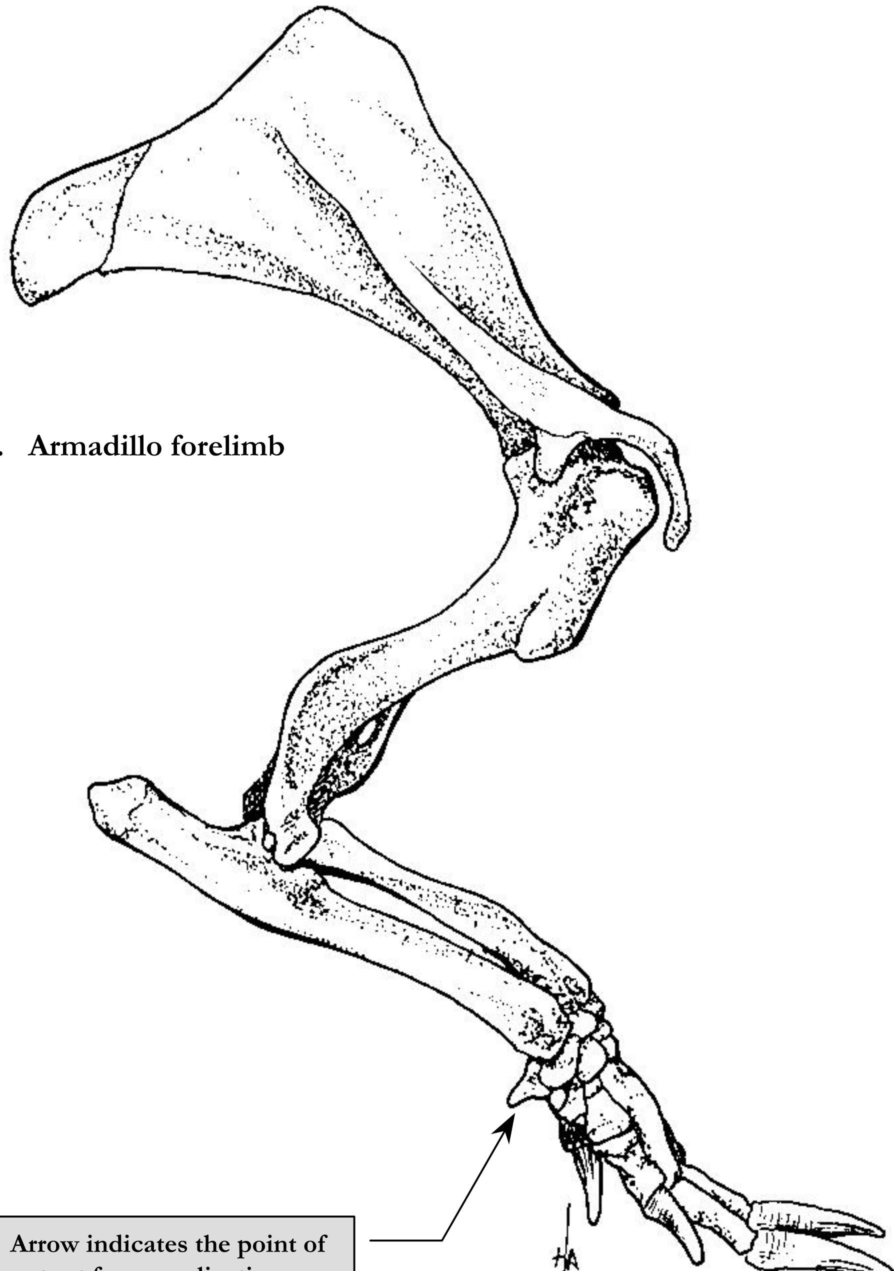
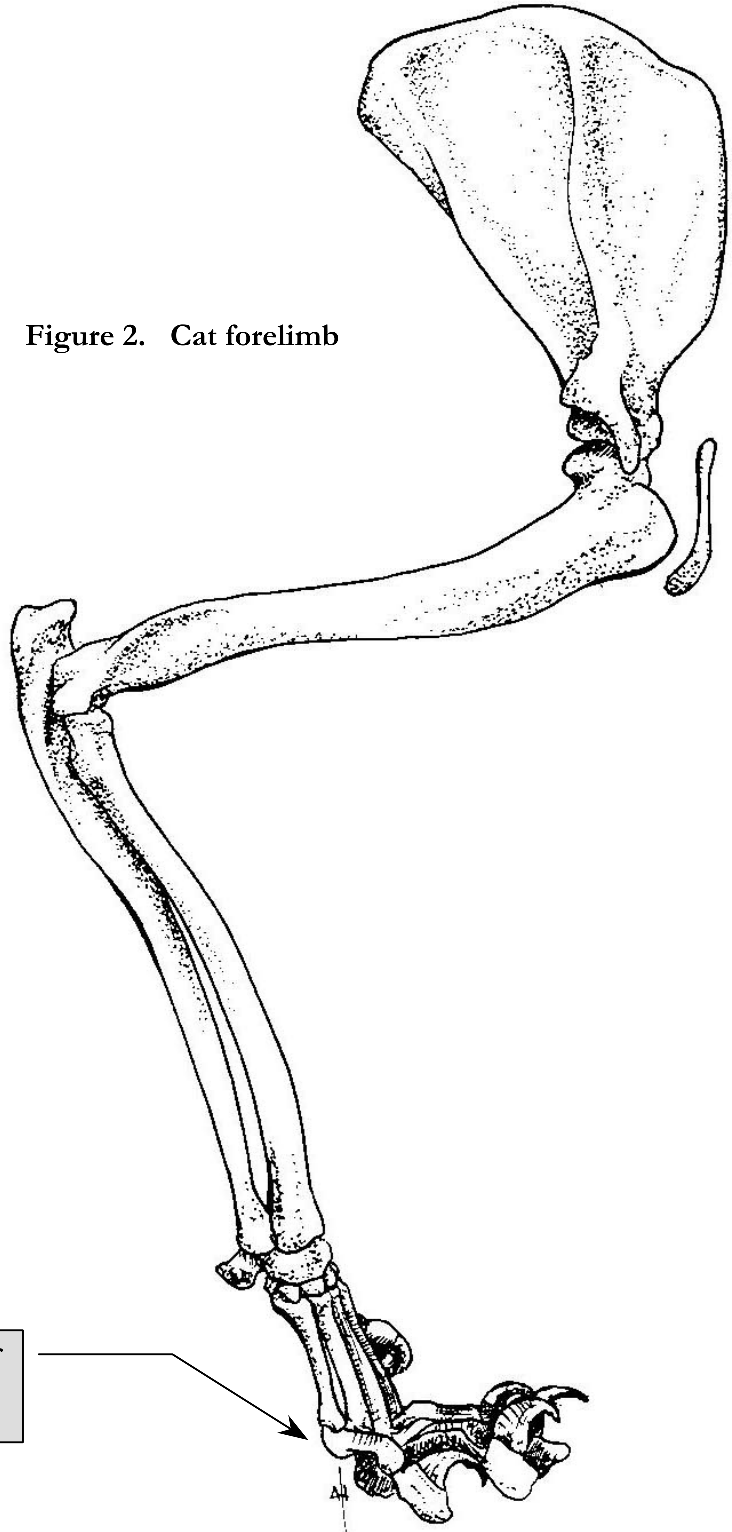


Figure 1. Armadillo forelimb

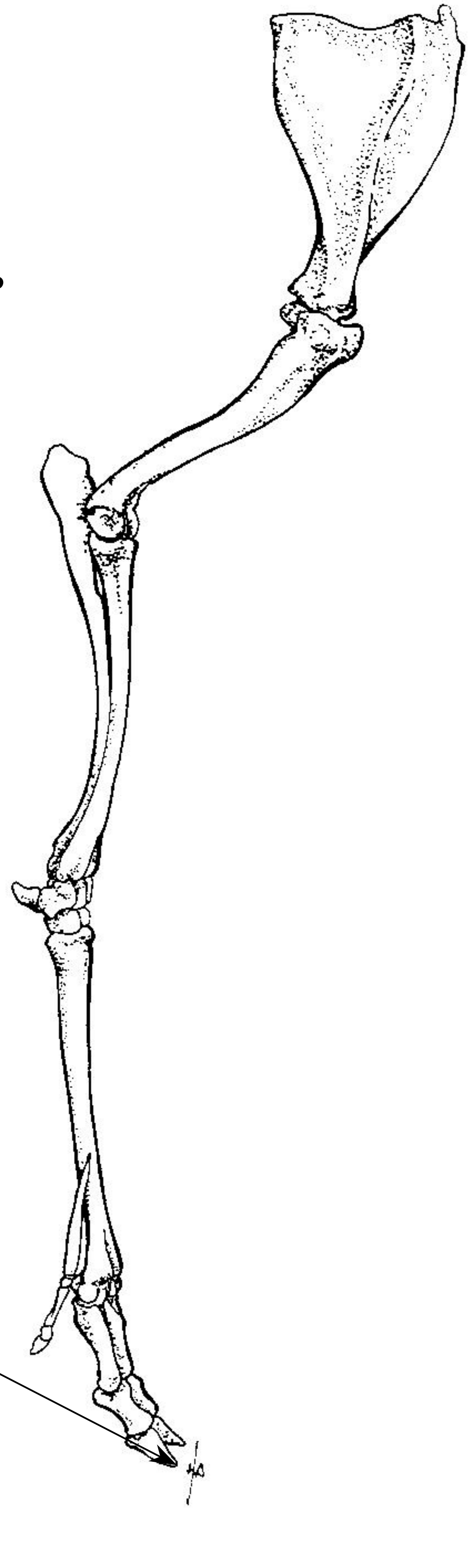
Arrow indicates the point of output force application.

Figure 2. Cat forelimb



Arrow indicates the point of output force application.

Figure 3. Deer forelimb



Exercise 2. Mechanical Advantage

Determine the mechanical advantage for each of the mammals measured. Enter the results in Table 1.

The ratio F_2/F_1 is called the **mechanical advantage** (or **force advantage**). But since $F_2 l_o = F_1 l_i$,one can determine the relative mechanical advantage (MA) without knowing anything about the forces: **MA** $= F_2/F_1 = l_i / l_o$. If the **MA** is less than 1.00, the foot will exert less force on the ground than the triceps brachii muscle exerts on the olecranon process. If the **MA** is greater than 1.00, the foot will exert a greater output force than the muscle input force. The mechanical advantage is simply a way of expressing how much the input force is multiplied by the lever system in producing an output force.

Exercise 3. Velocity A second item of interest is how fast the foot moves with relation to the velocity of contraction of the muscle. This can be determined from the velocity ratio (VR). In an ideal machine without any friction, the velocity ratio **(VR) = 1/MA**.

Using the data from exercises 1 and 2, calculate the actual velocity of the forefoot in each mammal if the muscle were to contract at a rate of 1/3 of its length per second. Assume that the length of the muscle is equal to the length of the humerus. To obtain the **actual velocity** in m/s, multiply **VR** by 1/3 the length of the humerus.

Synthesis:

Answer the following questions.

1. What is the correlation between lifestyles of animals and their mechanical advantage (=force advantage) and velocity ratios?

2. Would you expect to find a high mechanical advantage and a high velocity ratio in the same animal? Explain.