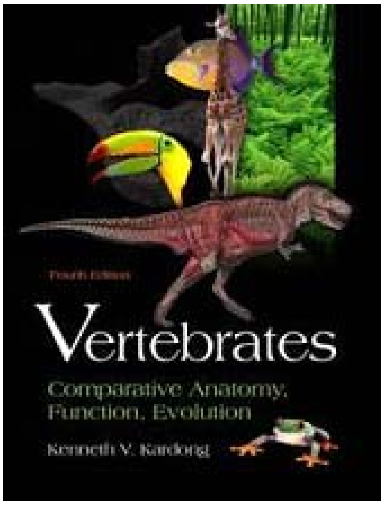


Torques and Levers:

Burrowers and Runners

Follow up in Textbook: 139-141; 378-381

A. Objective:

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

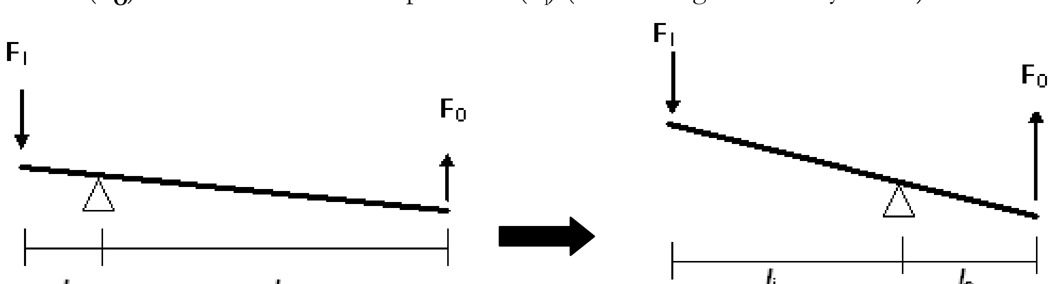
B. Textbook Reference:

No textbooks need accompany this exercise. Work in seminar teams, but each member is responsible for compiling a chart.

C. 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).



For increased force output, move the pivot point closer to output force (F_O)

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

D. Preparation & Procedures:

Exercise 1. Output Force

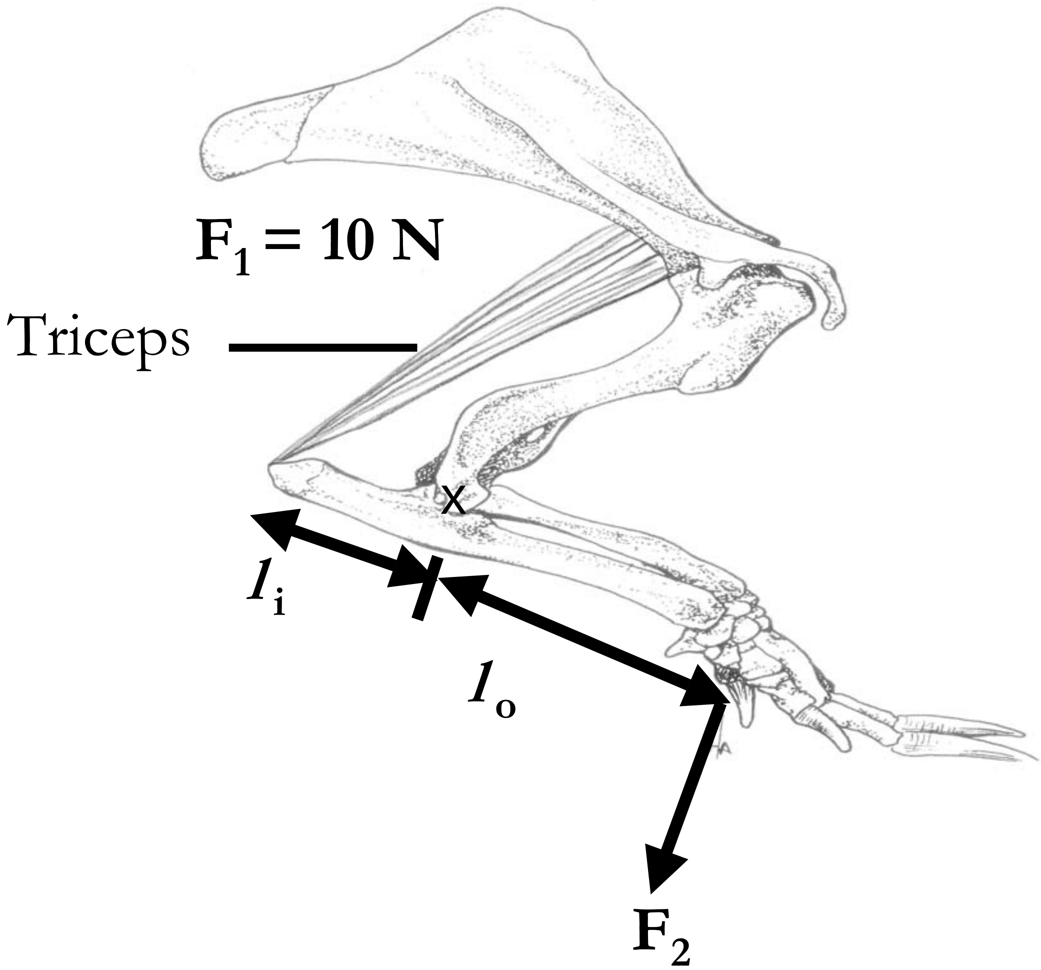
You will measure the in-lever (l_i) and out-lever (l_o) sections on the animals in Figures 1, 2, and 3 below and/or on actual skeletal specimens provided by your instructor. Your instructor will clarify what you are expected to measure.

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

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.**


F1 = 10 N
Triceps
x
li
lo
F2

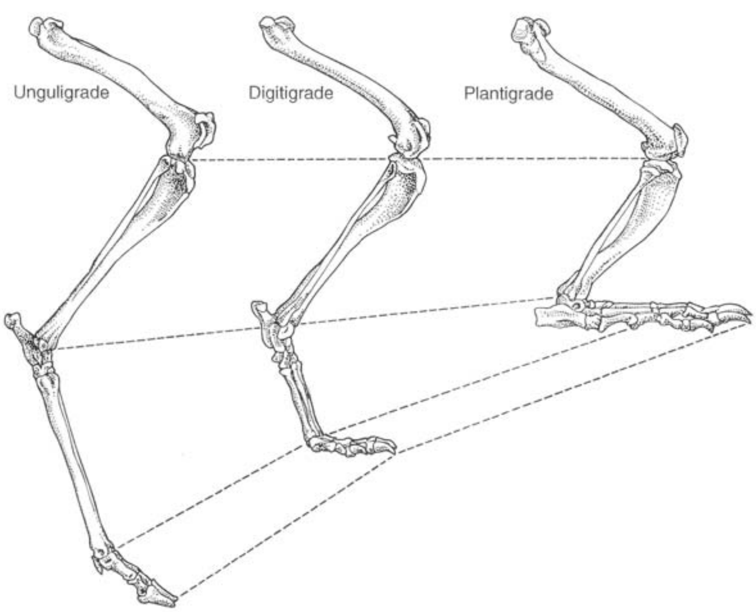
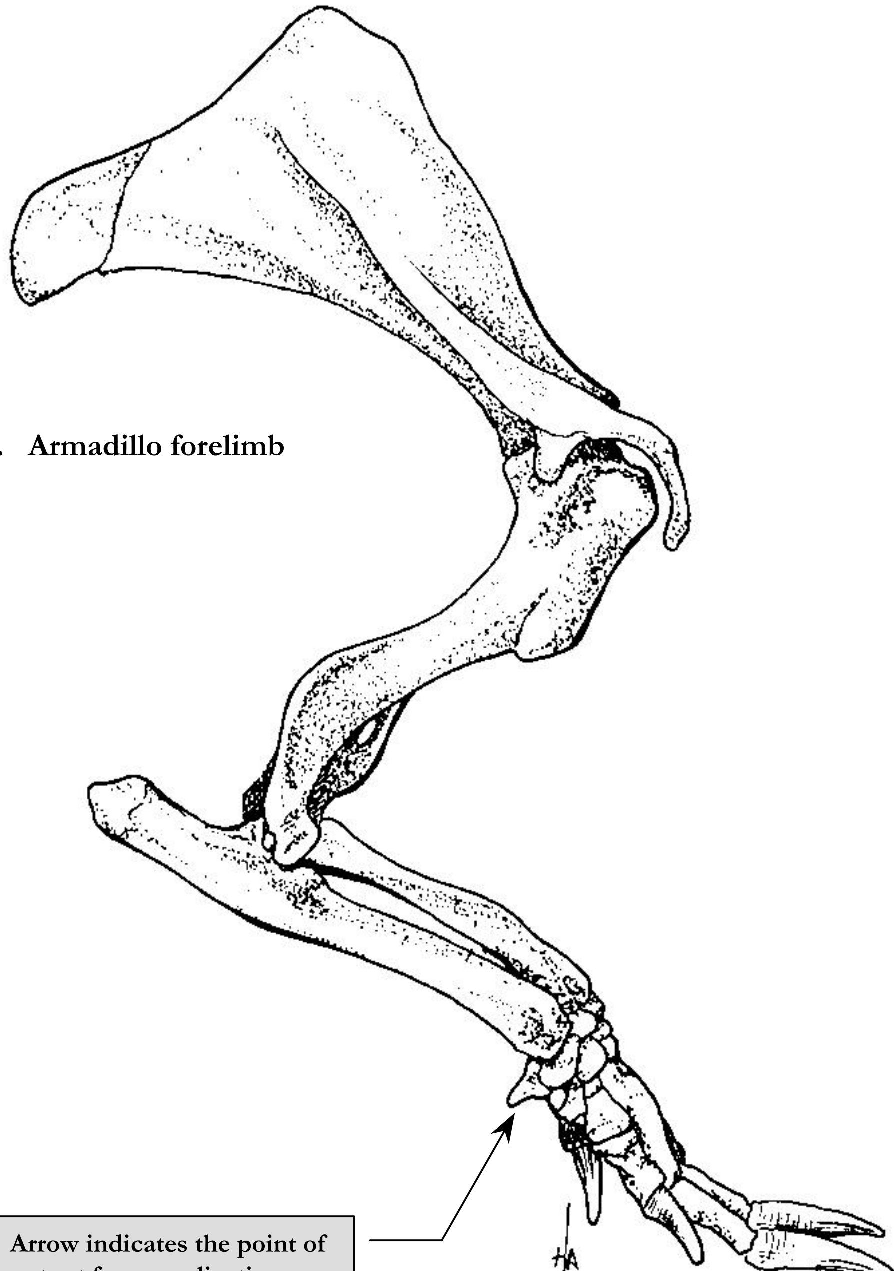

Unguligrade
Digitigrade
Plantigrade

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

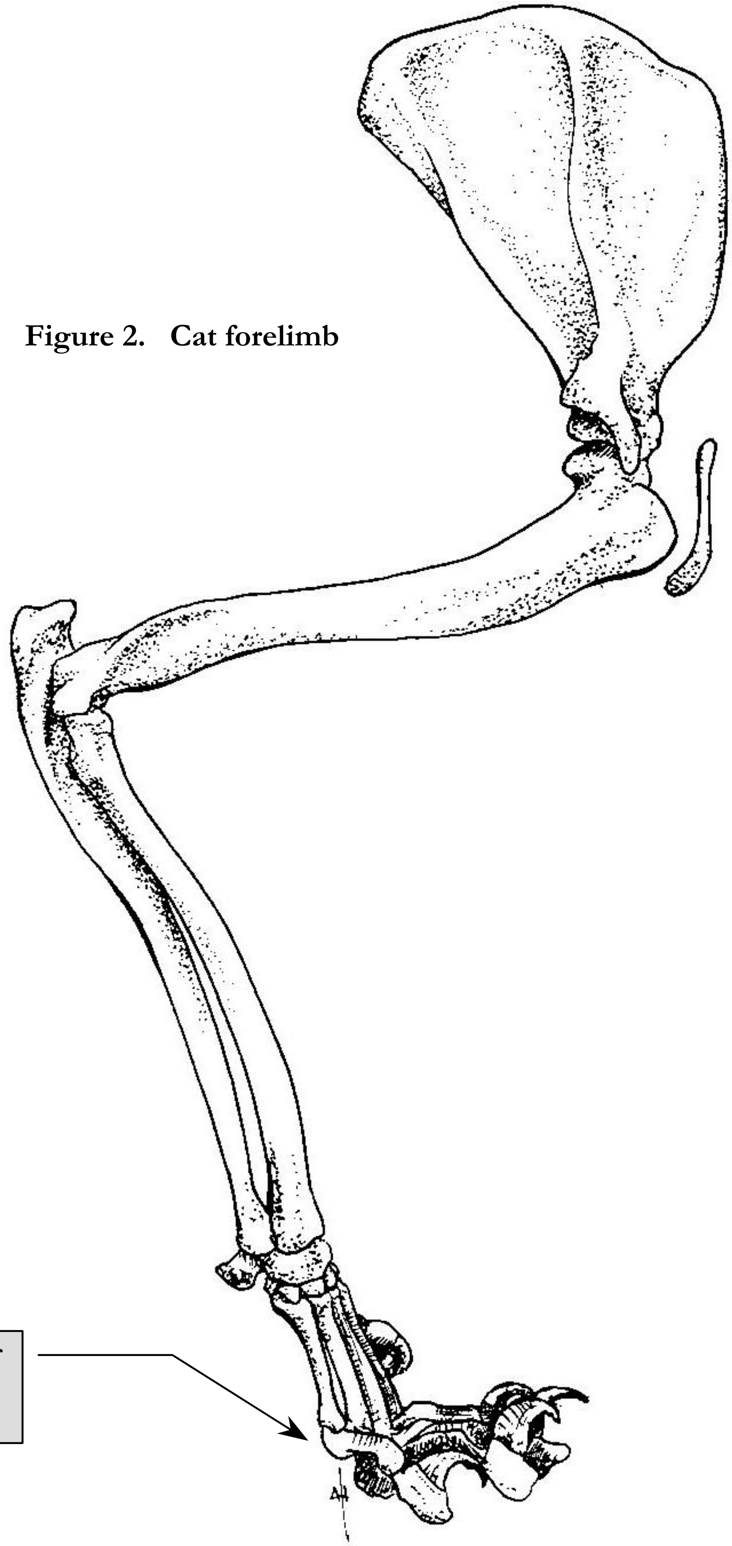
Organism	Foot posture	Humerus length (meters)	l_i (meters)	l_o (meters)	$F_2=F_1 li/lo$	Mech. Adv. l_i / l_o	Vel. Ratio 1 / MA	Actual Vel. VR x 1/3 humerus length (meters)
Armadillo Figure 1	Plantigrade							
Cat Figure 2	Digitigrade							
Deer Figure 3	Unguligrade							
Horse *if available	Unguligrade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

Figure 1. Armadillo forelimb



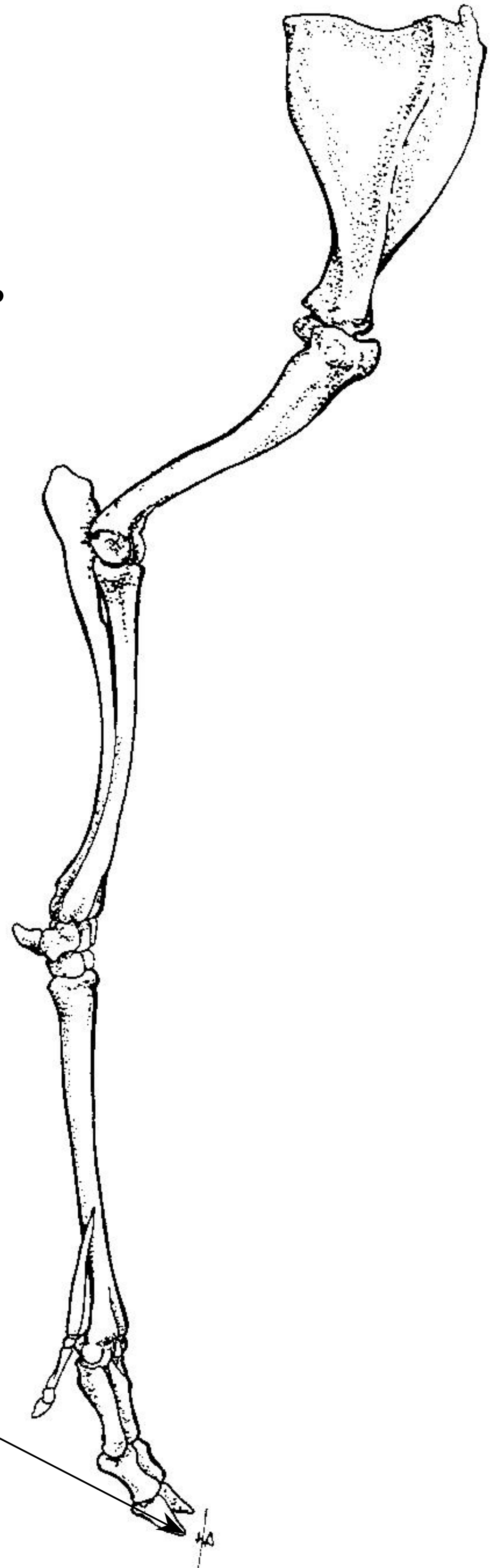
Arrow indicates the point of output force application.

Figure 2. Cat forelimb



Arrow indicates the point of output force application.

Figure 3. Deer forelimb



Arrow indicates the point of output force application.

D. Preparation & Procedures (cont.)

Exercise 2. Mechanical Advantage

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

The ratio $\mathbf{F_2/F_1}$ is called the **mechanical advantage** (or **force advantage**). But since $\mathbf{F_2}\boldsymbol{l_o} = \mathbf{F_1}\boldsymbol{l_i}$,one can determine the relative mechanical advantage (MA) without knowing anything about the forces: **MA =** $\mathbf{F_2/F_1 = l_i / l_o}$. 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

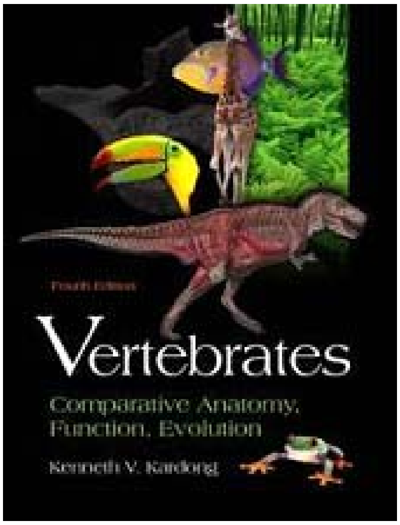
A second item of interest is how fast the foot moves with relation to the velocity of contraction of the muscle. This can be determined from the velocity ratio (VR). In an ideal machine without any friction, the velocity ratio **(VR) = 1/MA**.

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.

E. Synthesis:

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.



Instructor's Guide

Torques and Levers: Burrowers and Runners

Follow up in Textbook: 139-141; 378-381

A. Background

1. Consider using this exercise to accompany:
    - Chapter 4 (Textbook) assignments,
    - lectures on animal locomotion (Chapter 9, Textbook), and/or
    - laboratories on skeletal appendages.

2. Students with little mechanics or physics backgrounds may be more likely to struggle with some of the calculations in this exercise. Consider teaming such students up with other students with stronger physical science backgrounds.

B. Materials Preparation

1. This exercise is designed for all classes, regardless of the availability of specimens. For instructors with limited specimens, the exercise can be completed using only the information in figures 1-3. For instructors with skeletal preparations, students can be directed to make direct measurements on specimens. If there are several specimens to measure, consider moving teams of students through the laboratory in an orderly fashion, shifting past the skeletons in sequence
2. Rulers suitable for measuring the figures and/or actual specimens will need to be supplied.
3. Calculators may be supplied to facilitate the calculations.

C. Facilitating Tips

1. Be sure that the students gather the data from each animal, enter it, and then work through the questions.
2. When measuring the out-lever (lo), be sure that students measure to the point of force application on the foot which may be near the wrist or palm (see the arrows on Figures 1-3 for suggestions). This is a good time to draw their attention to plantigrade, digitigrade, and unguligrade foot postures.
3. Be sure that they work from their observation of the skeleton, NOT from the textbook.

D. Assessment - Advice for Evaluating Responses

Note that the question is two parts, so the students must supply an answer that addresses BOTH parts of the question.

Part 1.— What is the correlation between lifestyles of animals and their mechanical advantage and velocity ratios?

Students should comment on the interrelationships between mechanics and biological roles. In general, higher mechanical advantages are found in fossorial animals while lower mechanical advantages are associated with adaptations for speed.

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

The lever systems of an animal set the relationships between force and speed (or distance). But, a high mechanical advantage and a high velocity ratio cannot occur simultaneously because the velocity ratio is the inverse of the MA. Thus, a high mechanical advantage and a high velocity ratio require just the opposite lever arm ratios. Stated another way, the biomechanics of a lever system that produces a high output force advantage (high mechanical advantage) does not also produce high velocity (or distance) advantage. For an organism to enjoy some of both, the overall system must be designed to compensate, as for example happens in high and low gear muscles moving the same bony elements of the lever system but with different MA ratios (textbook figure 4.26). The two muscles of the deer limb swing it in the same direction. But each muscle acts with a different lever advantage. One is suited to produce large forces, the other for speed. This represents one way biological design may incorporate the mechanics of torques and levers to provide the limb of a running animal with some degree of both force and speed output.