Bio 112 Handout for Themes 3

This handout contains:
• Today's iClicker Questions
• an interesting article

iClicker Question #9A - <u>before</u> lecture

In the classic 1954 science fiction movie "Them", Los Angeles is terrorized by giant ants. These ants are roughly 1000-times larger than regular ants. Which of the following statements is correct?

A. The giant ants will have the same "skin" surface area as regular ants.
B. The giant ants will have roughly 1,000-times more "skin" surface area than regular ants.
C. The giant ants will have roughly 1,000,000-times more "skin" surface area than regular ants.
D. The giant ants will have roughly 1,000,000,000-times more "skin" surface area than regular ants.
E. None of the above.

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iClicker Question #9B - <u>after</u> lecture

As they develop, the birds growing in all bird eggs "breathe" through the shell; O_2 diffuses in and CO_2 diffuses out through many tiny holes in the surface of the shell.

An ostrich egg is roughly 10 inches in diameter; a chicken egg is roughly 2 inches in diameter. Based on this, assuming that the holes are the same size in all eggs:

A. You would expect more holes per square inch on the surface of an ostrich egg than on the surface of a chicken egg.
B. You would expect more holes per square inch on the surface of a chicken egg than on the surface of an ostrich egg.
C. You would expect the same number of holes per square inch on the surface of both eggs.
D. I don't know.

<u>Beaming in your answers</u>

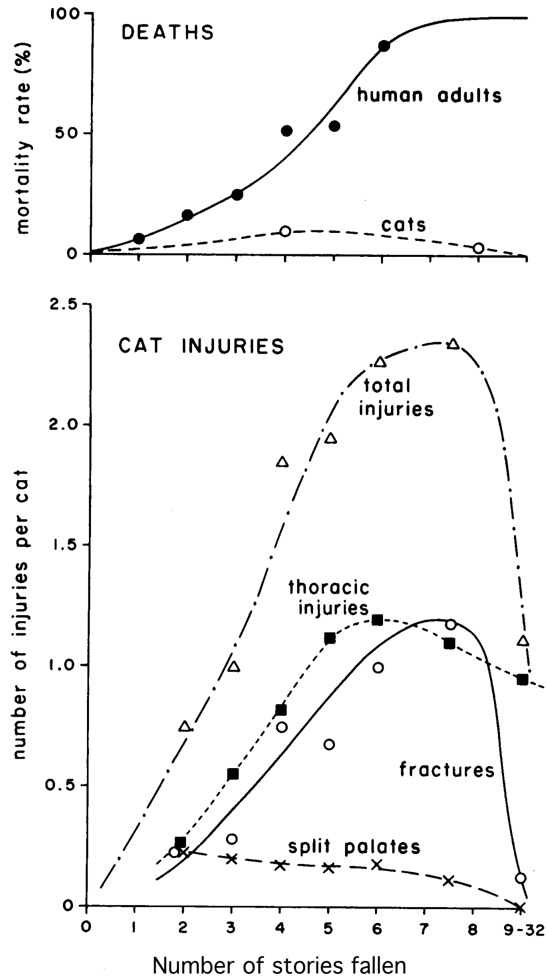
1. Figure out your answer and select the appropriate letter (A-E).
2. Turn on your iCliker by pressing the "ON/OFF" button; the blue "POWER" light should come on. If the red "LOW BATTERY" light comes on, you should replace your batteries soon.
3. Transmit your answer as follows:
   a. Press the button corresponding to the answer you've selected (A thru E).
   b. The "STATUS" light will flash green to indicate that your answer has been received. If the "STATUS" light flashed red, your answer was not received; you should re-send it until you get a green "STATUS" light.

Bio 112:
Why cats have nine lives

Jared M. Diamond
[From *Nature* vol 332, pp. 586-587; April 14, 1988]

The famous adage that cats have nine lives stems in part from their ability to survive falls lethal to most people. This phenomenon has not received the scientific attention that it deserves. Filling this lacuna, a new study by W. O. Whitney and C.J. Mehlhoff (*J. Am. Vet. Med. Assoc.* 191, 1399-1403; 1987) applies principles of anatomy, physics and evolutionary biology to falling cats.

The authors were veterinarians at an animal hospital in New York City, where skyscrapers, open windows and paved ground combined to generate a database of 132 cats injured by falls of 2 or more stories, with a maximum of 32 stories and a mean of 5.5 + 0.3 (s.e.m.) (1 storey = 15 feet). Most victims landed on concrete after a free-fall. Omitting 17 cats that were euthanized by owners unable to afford treatment, 90 per cent of the cats (104 of 115) survived, whereas 11 died (mainly because of thoracic injuries and shock). The most remarkable feature of the results (see figure) is that incidence both of injuries and of mortality peaked for falls of around seven stories and decreased for falls from greater heights. For instance, the cat that free-fell 32 stories onto concrete was released after 2 days of observation in the hospital, having suffered nothing worse than a chipped tooth and mild pneumothorax.



Mortality rates for falling adult humans and cats (above), and number of total injuries and various types of injury per falling cat (below), as a function of number of stories fallen. (Based on the work by Waring and Demling and by Whitney and Mehlhoff.)

Falling adult humans differ from falling cats in their much higher mortality rate, monotonic mortality/height relation, different causes of death, and different sublethal injuries (Warner, K.G. & Demling, R.H. *Ann. emerg. Med.* 15, 1088-1093; 1986). As illustrated in the figure, higher falls are increasingly lethal for humans, and few adults survive falls of more than six stories onto concrete. The principal causes of death are head injuries and hemorrhage from visceral injuries. Although forelimb fractures are slightly commoner than hindlimb fractures in falling cats, falling adult humans most often break their legs, and falling children their arms (Smith, M.D. et al. *J. Trauma* 15, 987-991; 1975).

Straightforward theory relates injuries from falls to three sets of variables, as shown by Warner and Demling. First, the height of the fall determines the impact velocity. Second, the softness of the surface of impact affects the stopping distance and hence the impact force. Those people surviving falls from airplanes have landed on mud or snow, not concrete. And third, at least five properties of the falling body itself are relevant: its mass, which determines impact force (F) and energy; its cross-sectional area A, determining frictional drag during fall and also stress on impact (F/A); cross-sectional areas of bone, determining bone strength; cushioning of vital parts by fat and other soft tissue; and dissipation of impact forces through flexing of muscles and use of joints.

These theoretical considerations provide several reasons why cats survive falls that kill adult humans. First, because mass increases as the cube but surface area as the square of linear dimensions, falling large animals are in general more injury-prone than small ones, as they suffer greater impact stress, their bones experience greater stress, and they reach higher terminal velocities in free-fall because of a less favorable area/mass ratio. Even a small drop breaks an elephant's leg, but falling mice reach terminal velocity in the atmosphere much sooner and at a much lower value than do falling elephants.

Second, falling cats have a superb vestibular system and make gyroscopic turns such that all four feet are soon pointing downwards, regardless of the cat's orientation at the start of the fall. Hence cats dissipate the impact force over all four limbs. Falling human adults tend to tumble uncontrollably but land most often on two feet, next most often on their heads. Falling babies, because their relatively large heads shift their center of gravity towards the head, tend to land head-first with arms reflexively extended to break the fall. These facts contribute not only to the lower mortality of falling cats but also to the tendencies of falling babies adults and cats to broken arms, broken legs and breaks distributed over all four limbs, respectively.

Third, a cat falling in the atmosphere reaches a terminal velocity of about 60 m.p.h. (compared with 120 m.p.h. for adult humans) after only about 100 feet. As long as it experiences acceleration, the cat probably extends its limbs reflexively, but on reaching terminal velocity it may relax and extend the limbs more horizontally in flying-squirrel fashion, thus not only reducing the velocity of fall but also absorbing the impact over a greater area of its body. This may explain the paradoxical decrease of mortality and injury in cats that fall more than 100 feet.

Finally, cats that land with their limbs flexed dissipate much of the impact force through soft tissue. Parachutists are trained to dissipate impact forces by landing with knees and hips flexed, then rolling.

Evidently, falling cats have some advantages shared with any small animal of similar mass and shape but also have unique advantages of their own, notably their gyroscopic righting reflex and their limb flexing on landing. Small dogs that fall from buildings are prone to more serious injuries than cats. The cat-specific advantages have undoubtedly evolved through natural selection: most felid but few canid species are arboreal, so that millions of years of springing or falling from trees have favored those felids with the best vestibular systems. Thus, the nine lives of cats are a product of their evolutionary history.

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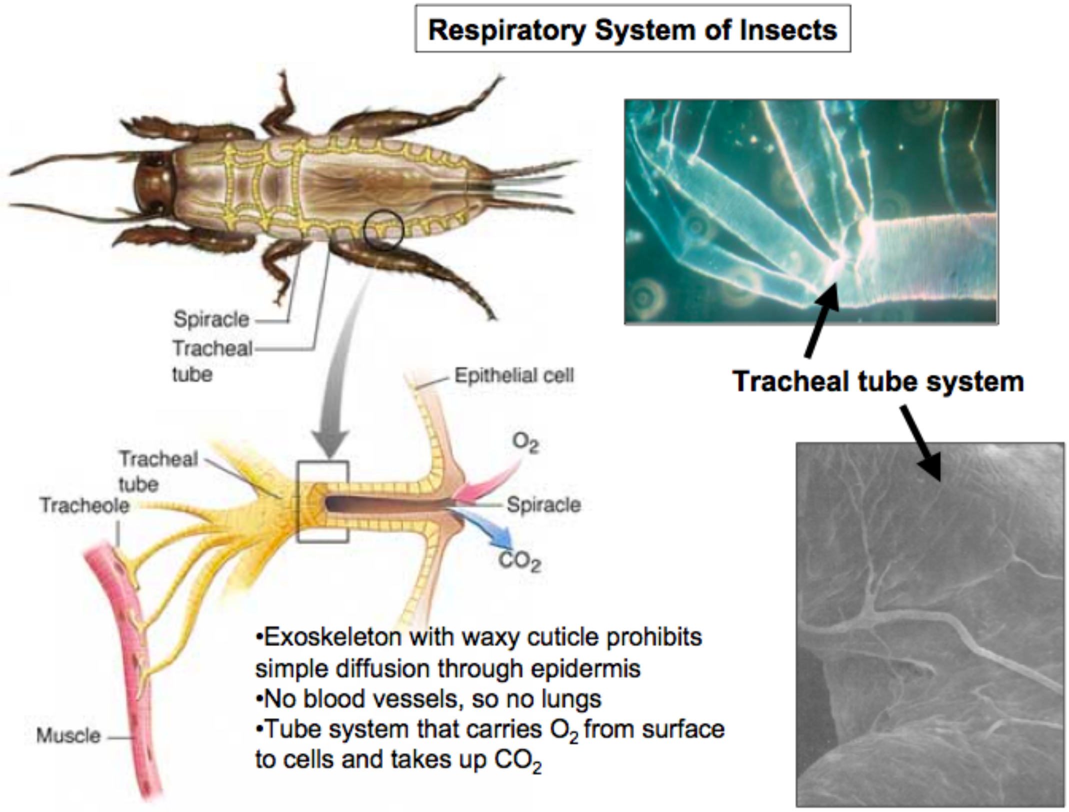
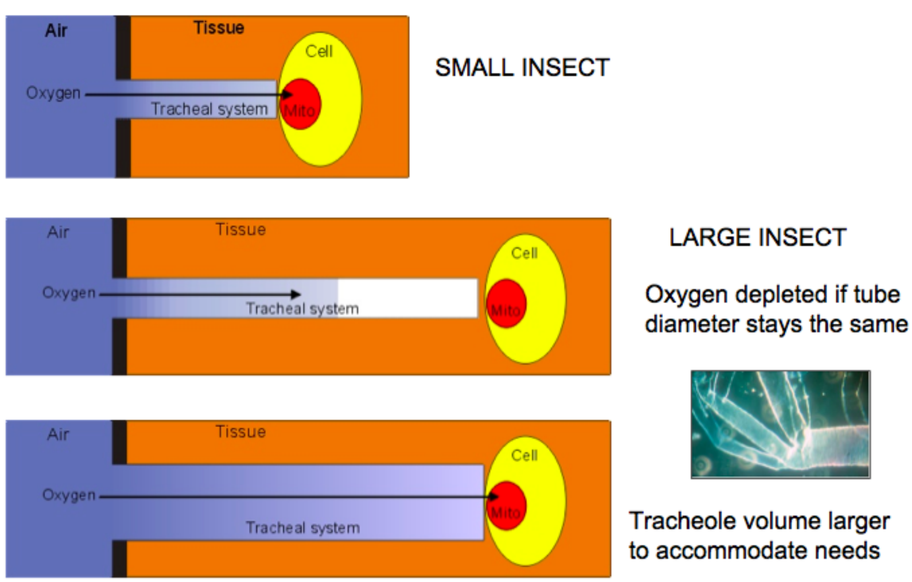
Size and Scale and Giant Insects

In the 1950's there were many science fiction horror movies about giant insects produced by nuclear radiation. For a variety of reasons, giant insects are impossible.

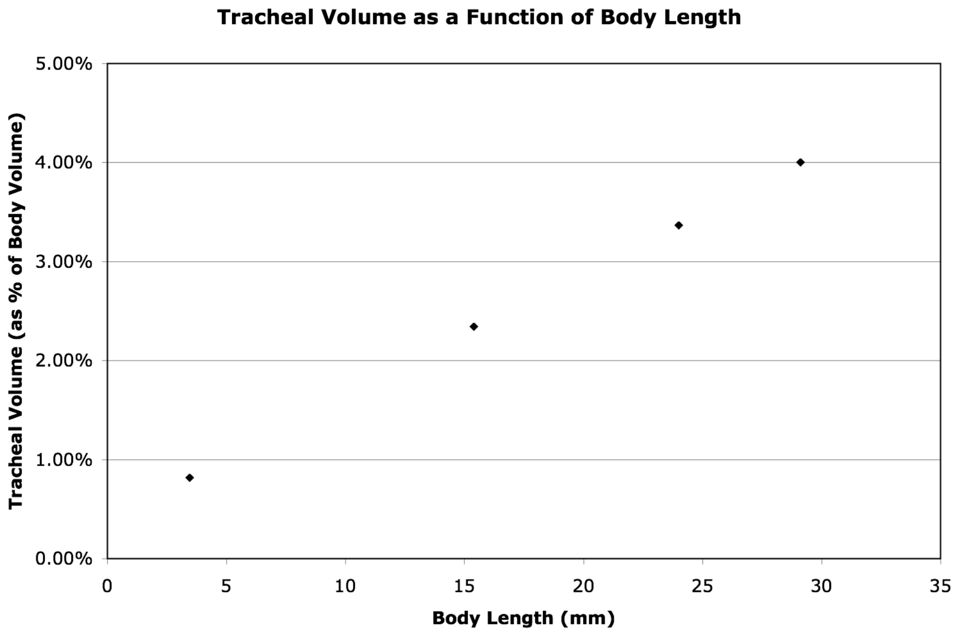
One important factor that likely limits insect size is respiratory capacity. As we will discuss in detail during the animal diversity lectures, insects breathe through pores in their skin using a system of tracheoles. This is shown below:



Larger insects require longer tracheal tubes to reach into their insides. In order to function properly, longer tracheal tubes must also be larger in diameter. This is illustrated below:



In a recent paper (*Increase in tracheal investment with beetle size supports hypothesis of oxygen limitation on insect gigantism.* Proceedings of the National Academy of Sciences 104(32): 13,198 – 13,203; this paper is available free online; you don't have to read it, but you can if you want), Alex Kaiser *et al.* collected looked at four related beetle species of very different size and measured the percent of their body volume that was taken up by their tracheal system. Their data are shown below:



1) Would you expect the % of body volume devoted to the tracheal system to increase, decrease, or stay the same if larger beetles were simply scaled-up smaller ones?

2) Why does the % of body volume devoted to the tracheal system increase in the larger beetles?

3) Using these data, roughly how big could a beetle be?

Note: it is important to keep in mind the dangers of extrapolation. As Mark Twain wrote, in *Life on the Mississippi* (1883; Ch 17), "In the space of one hundred and seventy-six years the Lower Mississippi has shortened itself two hundred and forty-two miles. That is an average of a trifle over one mile and a third per year. Therefore, any calm person, who is not blind or idiotic, can see that in the Old Oolitic Silurian Period,' just a million years ago next November, the Lower Mississippi River was upwards of one million three hundred thousand miles long, and stuck out over the Gulf of Mexico like a fishing-rod. And by the same token any person can see that seven hundred and forty-two years from now the Lower Mississippi will be only a mile and three-quarters long, and Cairo and New Orleans will have joined their streets together, and be plodding comfortably along under a single mayor and a mutual board of aldermen. There is something fascinating about science. One gets such wholesale returns of conjecture out of such a trifling investment of fact."