Fossil Footprints

How Fast Was That Dinosaur Moving?

Randall Caton Charlotte Otts

Students are fascinated by dinosaurs. We have developed an activity for middle and high school students that uses dinosaur tracks to estimate the speed of the animal making the track to capitalize on this interest. The activity begins with a discussion of dinosaurs and how paleontologists study their preserved bones and footprints to learn how these animals could have moved. After an introduction using videos, models, slides and overheads explaining how footprints are made and what can be measured from a footprint sequence, the students are ready to begin the activity.

Students measure their leg lengths, count their steps, and time themselves while walking and running a measured course. After averaging data from three trials of walking and of running, the students calculate their stride lengths and normalize these stride lengths and their speeds using leg lengths and gravity.

Through this experience students learn how science works, how normalized stride length and speed are correlated, and how these values compare with those of other bipeds and quadrupeds. They also see how the linear relationship between normalized stride lengths and speeds in living animals can be used along with leg lengths to estimate the actual speeds of extinct animals, such as dinosaurs, from their preserved footprint sequences.

Dinosaur Paleobiology

Current paleontological research in dinosaurs is multifaceted. Paleontologists are finding more dinosaur skeletons and partial skeletons, including those of previously unknown species, in more parts of the world than ever before. In fact, Gore (1993) points out that at least half of the species of dinosaurs known today have been found in the past 20 years. The rate of discovery does not seem to be slowing.

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Paleontologists also have revised their ideas on what dinosaurs were like. Initially, we thought of dinosaurs as being slow, completely dependent on ambient temperature for their level of activity, and too large, too sprawled, and too stupid to move very quickly. In the past few decades, based upon closer study of bone and joint anatomy, bone histology, footprint sequences, nest sites, and discoveries of dinosaurs in (what should have been, at least seasonally) colder, darker climates, we are beginning to appreciate dinosaur diversity in terms of activity level, intelligence, speed, parental behavior, and herding behavior. At least some dinosaurs apparently were active, intelligent, and capable of running as well as walking. Some dinosaurs seem to have taken good care of their offspring and, at least seasonally, lived in migrating herds.

Detailed studies of dinosaur footprint sequences have been very important in our reexamination of dinosaur paleobiology. Although the chances are very small that a given set of dinosaur footprints would be preserved and then discovered, given the millions of years in which dinosaurs lived and the numbers of dinosaurs worldwide at any particular time, it is not surprising that some dinosaur footprints and even some very good footprint sequences have been found.

What can be learned about dinosaurs from a study of their footprints? Several things can be measured directly from a well-preserved footprint sequence. First, the length of the entire footprint sequence made by one animal can be measured. This measurement is more easily accomplished if the sequence is fairly straight and if prints from only one dinosaur are included. Second, stride lengths can be measured and the average stride length for that sequence determined. The stride length is the distance between prints made by the same foot, for example, from the front of a right hind foot print to the front of the next right hind foot print. For a bipedal dinosaur, one stride length equals two steps. Third, the length of the individual prints can be measured. Fourth, we can measure the lateral distance of each print from the midline. If other dinosaur prints are part of the sequence, paleontologists measure all of them and try to determine whether the prints were made by a group of dinosaurs at the same time or by a series of individual dinosaurs that passed the same way at different times.

From these measurements paleontologists can determine whether the dinosaur was upright or sprawled in posture and can estimate the walking or running speed of the animal. R. McNeill Alexander (1991, 1992, 1995) from the University of Leeds has studied the relationship between stride length and walking or running speed in a variety of extant bipedal and quadrupedal birds and mammals, including humans. He has found that within a given group of animals there is a direct relationship between stride length and speed (the longer the stride length, the greater the speed). We present data in Figure 1 taken by middle students in the Science of Living Spaces (SLS) program at Christopher Newport University and data from the dog of one of the authors. Notice that the two types of animals follow different curves and that there is considerable scatter in the human data.

Alexander found that if he took gravity and animal size into account, he found the same relationship across

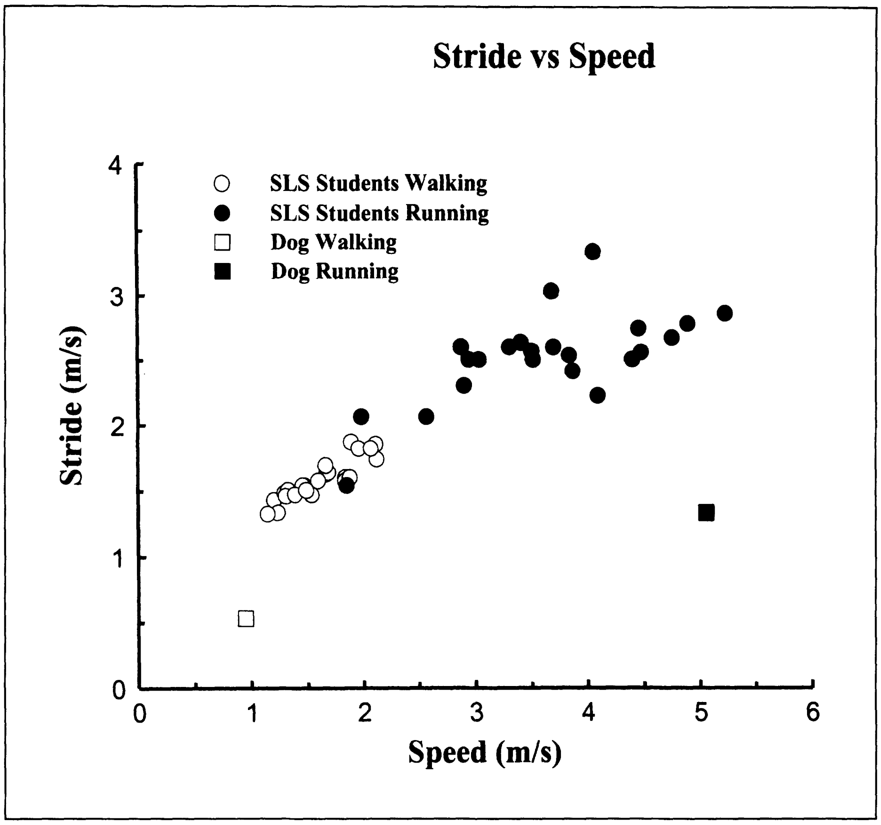

Figure 1. Stride vs. speed for SLS students and dog.

different sizes and in both bipeds and quadrupeds of different groups. He compared relative stride length, or stride length taking leg length into account, with dimensionless speed, or speed taking both leg length and the gravitational acceleration at the Earth's surface into account.

relative stride length = stride length/leg length
dimensionless speed = speed/(leg length x gravitational acceleration)$^{1/2}$

Dimensionless speed is used by naval architects and engineers to make meaningful comparisons between scale models and real ships during the design process. Alexander found a relationship between relative stride length and dimensionless speed in a variety of bipedal and quadrupedal birds and mammals. As relative stride length increases, dimensionless speed also increases. In Figure 2 we show the same data from the Science of Living Spaces students and dog replotted as relative stride vs. dimensionless speed. Notice that both animals now follow the same curve.

Alexander reasoned that bipedal and quadrupedal dinosaurs of different sizes should be similar to other animals in this respect, and that the well-established relationship for modern birds and mammals could be used to estimate dinosaur speed from a footprint sequence in which stride length could be measured directly.

Thus, if we know which dinosaur made the footprint sequence and the posture of the animal (so that leg length from the hip joint to the ground can be measured), then relative stride length can be determined. Next that dinosaur's dimensionless speed could be estimated from comparison with the graph of relative stride length and dimensionless speed in birds and mammals. Then the estimated actual speed could be calculated from the equation for dimensionless speed, since the acceleration of gravity at the Earth's surface is the same today as during the time of the dinosaurs.

In some cases, we do know which dinosaur species, or at least which dinosaur family, made the prints and can use the average leg length for those dinosaurs to estimate speed. But what if we do not know which dinosaur made the prints? Is there another way to estimate leg length so we still can estimate speed?

Alexander measured the height at the hip joint and length of the part of the foot that makes the print in the skeletons of many dinosaurs. He found that leg length is approximately four times foot length in a variety of bipedal and quadrupedal dinosaurs. So we can estimate leg length from the length of the footprint and estimate speed even if we do not know which dinosaur made the prints.

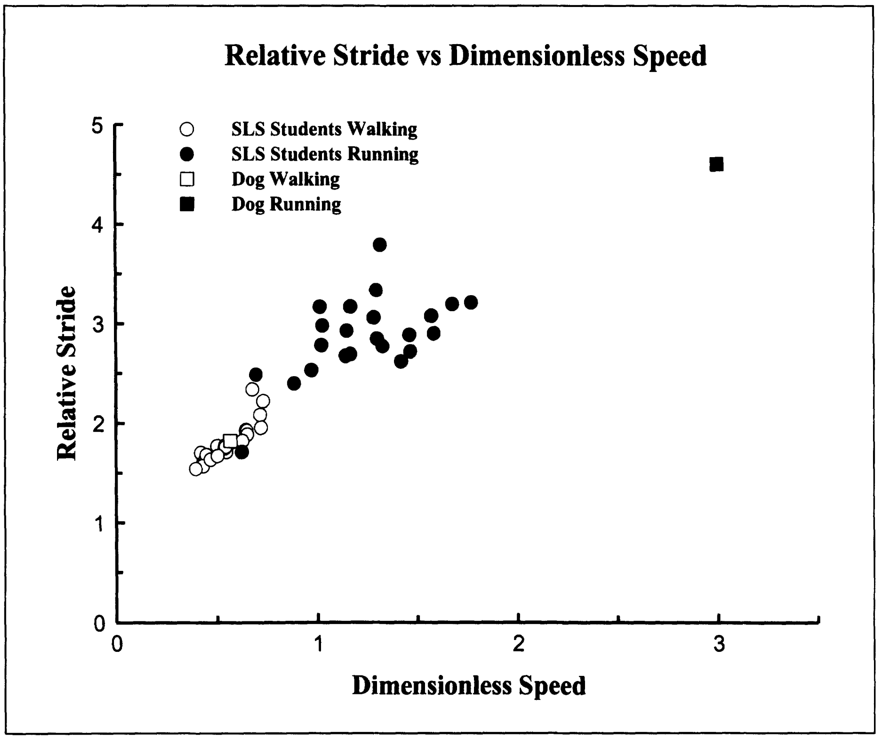

Figure 2. Relative stride vs. dimensionless speed for SLS students and dog.

How fast were the dinosaurs moving? In most footprint sequences the dinosaurs apparently were walking. Some sequences indicate, however, that the dinosaur was running. The top speed made by two theropods (Alexander 1989) in different localities, one with 29-cm prints and the other with 38-cm prints, is 12 m/s. This speed compares very favorably with racehorse (speeds up to 17 m/s), greyhound (speeds up to 16 m/s), and human sprinting (speeds up to 10 m/s) (Farlow et al. 1989).

Dinosaur Activity

Students can calculate how closely their relative stride lengths and dimensionless walking and running speeds compare to those of birds and other mammals by measuring their leg lengths and times when walking and running. Students measure their leg length and walk and run, counting their steps and measuring their times with a stopwatch. The students analyze their data by calculating their average stride lengths, relative stride lengths, average speeds, and dimensionless speeds. Students see how science works as they graph their relative stride lengths against their dimensionless speeds and compare their positions on the graph with those of other walking and running animals. They see that their results fall on the same curve with all animals and that this curve can be used to estimate speeds of dinosaurs from the tracks that they left. The fascination with dinosaurs coupled with measurements of their own motion should make the learning more memorable and meaningful to the students.

We introduced the activity to the students by showing them video clips and pictures from the CD-ROM Prehistoria (Devoney 1994) and overhead transparencies (e.g. of dinosaur footprints). Data sheets for the students were developed and used, but having the students create their own data sheets would be better if time permits. Of course, it is important to have the students use metric units throughout.

Since the leg length is needed for later analysis we have the students help each other measure leg length (from the center of the hip joint to the ground). It is necessary to demonstrate the position of the hip joint (on a skeleton if possible). The hip joint is located at the "x" in Figure 3. Students often try to measure from the top of the pelvis, which will give them an incorrect leg length. Suggesting that they swing the leg back and forth from the hip joint may help them determine the center of the hip joint by feeling its slight movement. The leg length should include the shoe thickness, because the effective leg length is increased by wearing shoes.

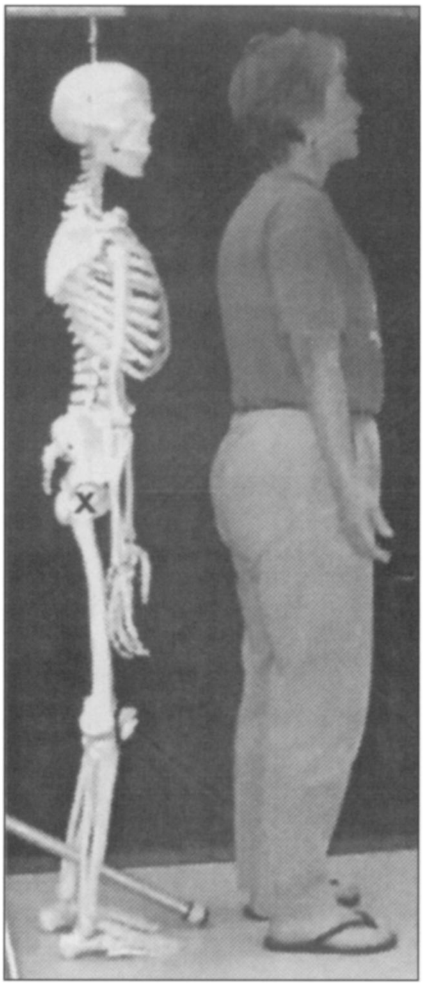

Figure 3. Leg length is measured from the hip joint (x on diagram) to the floor.

The students should hypothesize whether their stride lengths will be greater when walking or when running. They should test their hypotheses by counting steps during one walk and one run for an approximately 10-meter course. We had students count steps (to the nearest ¼ step) for a fixed course length to save time. It would be more accurate to count a fixed number of steps and measure the resulting distance. In walking and running, students should be sure their toes touch down on the start line. With the very next step they should begin counting footfalls. After collecting their data they then convert the number of steps to the number of strides (or fractions of strides) by dividing the number of steps by two. Their stride lengths in meters are obtained by dividing the course length by the number of strides. This preliminary part of the experiment should get them used to walking and running the course in a natural style. They could also time their walks and runs, even though they do not need the times yet, to get them used to coordinating the counting with turning the stopwatch on and off. Individuals may have to repeat trials if they got a slow start, did not gauge the start position accurately, or if they walked or ran in an artificial manner. Depending on time available and student preparation, the activity leader should decide if he/she prefers to tell the students how to design the experiment, take the data, determine the number of strides from the number of steps, or calculate stride length from course length and number of strides, or if he/she should leave some of these things to the students to figure out.

After practicing as described above, the students are ready to perform the experiments that will allow them to determine the relationship between their relative stride lengths and dimensionless speeds. Each student should record the time in seconds and the number of steps for several trials (three is reasonable). It is important to emphasize that it is necessary to repeat experiments to check reproducibility and to get a more reliable value by averaging the trial values. After averaging the results, the students should calculate the average number of strides, the average stride length in meters, and the average speed in meters per second. Using measured leg length (in meters) and the acceleration of gravity (9.8 meters per second squared), the students finally can calculate average relative stride length and average dimensionless speed according to the formulas given above. When the average relative stride length and dimensionless speed for walking and for running are graphed by the students on a plot containing data for a variety of bipeds and quadrupeds, they see that their results for a human animal fall near the curve for many different kinds of animals.

The "how science is done" part of the exercise can be brought home by having the students estimate the speed of a dinosaur from sample dinosaur footprint sequence data [e.g. a leg length of 3.0 meters and average stride length of 2.6 meters for a sauropod track discovered near the Paluxy River in Texas (Farlow et al. 1989)]. The scientist gathers data on a variety of animals that fall convincingly on the same curve. Then, to estimate how fast dinosaurs walked or ran, the scientist makes the reasonable hypothesis that the dinosaurs also would fall on this same curve.

In Figure 4 we show data for middle school students in Project Excel: Focused on Physics plotted along with other animals measured by Alexander (1992). Note the scatter in the student data. The scatter could be improved by having the students perfect their technique of data taking. From this chart and the data for dinosaur tracks given above, we would estimate that the above dinosaur was walking at a speed of about 3 meters per second.

Extensions of the Activity

This activity could easily be turned into an extended research project. We list some possible areas for research below:

1. Just how do you measure *hip height*? What would be the effect on the measurements if you measured from the top of your pelvis to your heel?
2. Do smaller mammals or non-mammals fit on the same curve as the larger mammals like the kangaroo, camel or rhinoceros? You could take data on your pets or insects.
3. When does walking stop and running start for humans? For other animals? Does this occur at the same dimensionless speed for different animals?
4. Is there a curve relating foot length to hip height for humans? Other animals?
5. Do the data still follow the same curve for different walking or running surfaces? On wet beach sand, dry beach sand, mud, wet hard surface, etc.? Using different footwear? For other animals?
6. Try walking and running with weights attached to legs and/or arms, etc. to see if the curve of stride vs speed changes.
7. Challenge: How precisely can you make measurements? Can you reduce the scatter in your data by improving data taking and measuring techniques?
8. Students may prefer to set up the course in wet sediment where they can leave footprints. Then stride lengths can be measured directly as they are in fossilized footprint sequences.
9. Using better procedures developed in #7, repeat #2, #3, #5, #6 and/or #8.

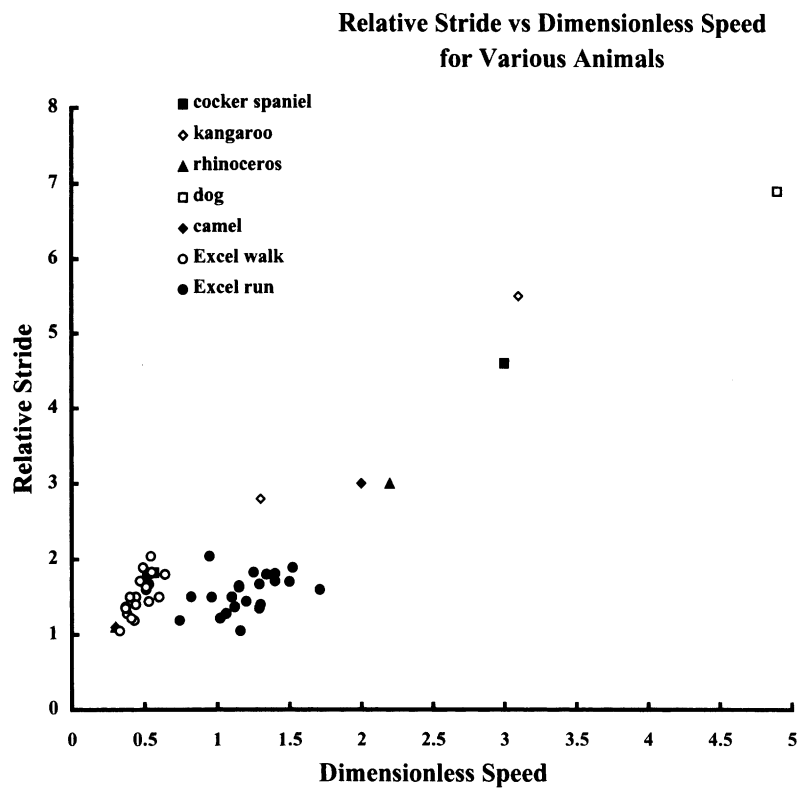

Figure 4. Relative stride vs. dimensionless speed for various animals (Alexander 1992) and Excel students.

Conclusion

The activity we describe has been done successfully with six groups of middle school students and two groups of teachers. It could easily be used with any students with suitable modification. The allure of dinosaurs and relevance of analysis of data from the student's own walking and running make this an attractive and meaningful exercise for students to learn how science works, to study motion, and to apply mathematics for data analysis. Handouts and worksheets (Microsoft® Word™ 6.0 or text) and the multimedia introduction (Microsoft® PowerPoint™ 4.0) are available for downloading (at the URL: http://www.pcs.cnu/~rcaton/). For other interesting activities related to dinosaur paleobiology, see Evans (1990).

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