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How fast could Tyrannosaurus rex run?

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pant in the experiment claiming fusion, said he's very sure they've achieved d–d fusion. Instead of offering opinions, he says, critics need to try to reproduce their results.

Barbara Goss Levi

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How Fast Could *Tyrannosaurus rex* Run?

A new biomechanics model finds that *T. rex* lacked large enough leg muscles to run fast.

From Saturday-morning television shows to Hollywood blockbusters, dinosaurs are perennial favorites for inspiring people's curiosity. And topping the fascination list is usually *Tyrannosaurus rex*, the six-ton giant that reigned over the Upper Cretaceous Period 65 million years ago, moving around on hind legs more than 2.5 meters long and devouring less fortunate creatures with its powerful jaws.

Although the fossil record provides clues about some aspects of dinosaur existence, insights into many others must be tortuously teased out of uncovered bones and footprints. Many questions lack direct answers. For example, how fast could dinosaurs move?

That question has proved easier to answer for smaller dinosaurs, whose fossilized footprints contain speed information. In the mid-1970s, McNeill Alexander (University of Leeds) derived a method for estimating speed from the ratio of the stride length to the leg length (which can be determined from recovered bones or estimated from the footprint size).[1] So-called trackways containing stride records have provided evidence for running (having a suspended, aerial phase) for many bipedal dinosaurs.

No trackway evidence of running by larger animals such as *T. rex* has been found, which is not unexpected. It's rare to find fossil beds large enough to span the stride of a running *T. rex*. In addition, most creatures spend much more time walking than running, so any running trackways are rare.

Most estimates of the speed of *Tyrannosaurus* and other large dinosaurs have instead come from various comparisons to other vertebrates. Noting the similarity of *T. rex* skeletal anatomy to that of extant birds and other fast runners, Gregory Paul and Robert Bakker have suggested that *T. rex* would have been able to run at least 20 m/s (45 mph).[2]

Applying more physics-based arguments, others have proposed slower maximum speeds. Based on the maximum transverse forces that *T. rex* bones could have withstood, Alexander has argued that it was capable of a modest run at best.[3] Per Christiansen (University of Copenhagen), quantifing such arguments, estimated that *T. rex* could walk at 10 m/s (22 mph)—still far from slow.[4] James Farlow (Indiana–Purdue University) and colleagues[5] have suggested that a fast-running *T. rex* would have experienced fatally large forces if it had tripped, so they concluded it likely moved no faster than 10 m/s.

Working at the University of California, Berkeley, John Hutchinson (now at Stanford University) and Mariano Garcia (now at Borg Warner Automotive in New York) recently offered a new approach for analyzing possible speeds of *T. rex* and other bipeds, based on a biomechanical model for determining the minimum mass of leg extensor muscle required for an animal to run.[6] With this model, the pair found that *T. rex* could not have had strong enough legs to be a fast runner.

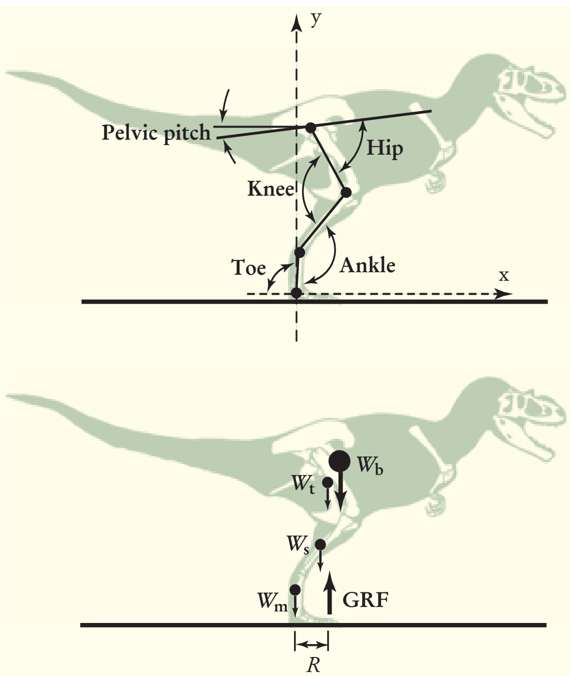

Figure 1. In a free-body diagram for a running tyrannosaur, the angles of the leg joints (top) are critical parameters. In addition to the forces and torques produced by leg muscles, external forces (bottom) including the weights of the body (W_b), thigh (W_t), shank (W_s), and metatarsus (W_m), as well as the ground reaction force (GRF) that acts a distance R from the toe joint must be incorporated. (Adapted from ref. 6.)

Scaling muscles

Underlying this new model is the observation that muscles in vertebrate animals generate remarkably uniform maximum force per unit cross section, about 300 kN/m^2. Given that evolution has conserved this muscle property, Hutchinson and Garcia argue it's reasonable to assume that the muscles of dinosaurs such as *T. rex* had similar force-generating capability.

One consequence of this uniformity is that muscle strength increases more slowly than muscle mass as body size increases, as roughly the $^2/_3$ power rather than linearly. Thus, as body size increases, the muscle mass needed to support and move it increases even faster. This scaling difference, well-known for decades, is at the core of the researchers' conclusion that *T. rex* was not a fast runner.

Hutchinson and Garcia use a two-dimensional free-body diagram to determine the minimum muscle mass per leg that's needed at midstride to maintain quasistatic equilibrium, factoring in the forces and torques from various muscles, limb segment weights, and the ground (see figure 1).

At the midpoint of the running stride, the body is at its lowest point, accelerating upward. The necessary upward force comes from the ground. For extant bipeds at a fast run, this ground reaction force (GRF) is about 2.5 times the body weight, relatively independent of species or mass. Hutchinson and Garcia therefore adopted this relation for their calculations.

To translate this GRF into a forward velocity, the researchers applied the notion of dynamic similarity. Originally proposed by Alexander,[3] this concept considers the ratio between an animal's kinetic and potential energy as expressed in the Froude number, $\mathrm{Fr} = v^2/gh$, where v is the forward velocity, g the acceleration due to gravity, and h the hip height. Animals moving with the same Froude number should have similar gaits and exert similar relative forces. A fast-running ostrich experiences a GRF of 2.7 times its body weight at $\mathrm{Fr} = 16$; a *T. rex* with a similar relative GRF should have a similar Froude number, which corresponds to about 20 m/s—in line with the faster speed estimates.

Hutchinson and Garcia tested their running model with living species: a chicken (a fast runner) and an alligator (unable to run on two legs). The model predicted that a chicken must have at least 5% of its body weight as extensor muscles in each leg to run fast, almost a factor of two below the actual fraction of 9%. But for an alligator to run on its hind legs, the model predicted it would have to have a leg muscle fraction of 8%, and indeed alligators have much less than that. Thus in both cases, the model gave results consistent with observations.

For chickens and alligators, both distant relatives of extinct dinosaurs, the anatomical details the model required—joint angles, limb lengths, and weight distribution—were available from dissection. But for dinosaurs, only limb lengths are readily available from fossils. Weights can be estimated with various methods such as scaling, and by normalizing variables to total body mass, the researchers could reduce the effects of weight uncertainty. That left posture as the largest unknown.

In what Andrew Biewener (Harvard University) calls a nice quantitative addition to their study, Hutchinson and Garcia examined various values for *T. rex*'s posture parameters, thereby getting a sense of the model's sensitivity and uncertainty. The results for the different sets of values are shown as the solid red circles in figure 2.

The color bands of figure 2 follow from anatomical constraints and current knowledge of living animals. Having a leg muscle mass greater than 50% of the total body mass is impossible, because then the two legs combined would be more massive than the whole. For consistency with extant vertebrates, which have a total muscle mass that's half their total body mass or less, the researchers also rule out running when the required leg muscle mass fraction is more than 25%. For required fractional muscle masses below 25%, running ability depends on the actual leg muscle mass, as for the alligator. Empirically, the most agile running bipeds don't require more than 5% of their body weight to be leg extensor muscle.

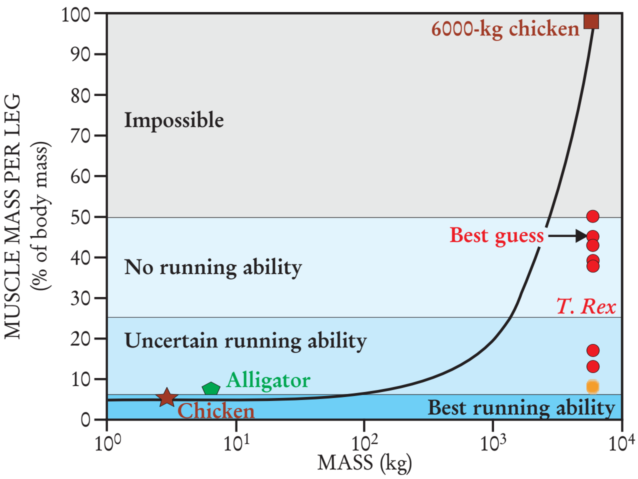

Figure 2. Estimated extensor muscle mass per leg needed to run fast, as a fraction of total body mass. Larger animals need relatively more leg muscle to run. This dependence is illustrated by the solid line, calculated for a chicken scaled up to the size of *T. rex*. For several models of *T. rex* anatomy, the estimates (red) all require more leg muscle for running fast than the creature was likely to have had (orange dot). (Adapted from ref. 6.)

"Despite fairly generous assumptions," says Garcia, "muscle masses would need to be unreasonably high for *T. rex* to be a fast runner." Even with the most favorable posture parameters, the researchers report that required extensor muscle is larger than the actual muscle mass of 7–10% they estimate based on scaling models.

Given the extensive unknowns, the pair hesitate to put a specific upper bound on the maximum speed of *T. rex*. "Speeds of 11 m/s [25 mph] would be pushing it," says Hutchinson, "but 20 m/s [45 mph] is not reasonable."

This work hasn't settled the debate over *T. rex* speed. Hutchinson is working on applying the model to other, larger living animals such as ostriches and rhinoceroses to test the conclusions, something many critics are eager to see.

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Sodium Detected in the Atmosphere of an Extrasolar Planet

> As predicted by models, sodium atoms in the atmosphere of a remote planet are abundant enough that researchers have been able to see them. But they're also scarce enough to prompt some rethinking of the models.

For years, planetary scientists have been scouring the heavens in search of planets outside our own solar system. One very long-term goal is to discover a twin to our planet Earth and to search for biological features in its atmospheric spectrum. A shorter-term goal is to understand planetary formation processes more generally.

Since the first sighting of an extrasolar planet in 1995, the search has netted nearly 80 planets, but we know little more about them than their minimum masses and their orbital parameters.[1] It's been tough enough to glean that much information, which in most cases has been inferred from the tiny, periodic wobble that the planet's orbital motion produces in the Doppler shift of its parent star. It's far tougher to detect the planet's atmospheric