BIOMECHANICS

Tyrannosaurus on the run

R. McNeill Alexander

ONE of the characters in *Jurassic Park*[1] tells us that *Tyrannosaurus rex* could easily outrun a Jeep, driven off-road at 30–40 m.p.h. (13–18 m s^{-1}), and the film of the book showed us how alarming that would have been. The suggested speed is similar to that of racehorses (16–17 m s^{-1}, based on race times given in newspapers). In a paper just published in *Journal of Vertebrate Paleontology*, however, Farlow *et al.*[2] argue not only that the top speed of *Tyrannosaurus* was much slower (about 10 m s^{-1}), but that there were reasons why the creature would have found it dangerous to run at the higher speeds.

Old reconstructions of the giant carnivore show an ungainly and presumably slow-moving animal. Bakker's[3] arguments for dinosaurs being warm-blooded, and the stunning pictures he drew to illustrate them, encouraged us to think of dinosaurs as much faster and more athletic, but an analysis of bone strength[4] seemed to show that *Tyrannosaurus* must have been relatively slow. The faster an animal runs or the higher it jumps, the greater the forces on its feet. If similar animals (possibly of very different sizes) move in dynamically similar fashion, the forces on their feet will be equal multiples of body weight. The dimensions of fossil leg bones can be used to estimate the strengths of the living bones, and if these are equal multiples of body weight, for a fossil species and a living one, the fossil species could have been as athletic as the living one. This approach led to the conclusion that *Tyrannosaurus* probably ran only slowly, with a top speed possibly around 8 m s^{-1}. I even claimed (I was younger then) to be able to outrun *Tyrannosaurus*.

Farlow *et al.*[2] have repeated this analysis with better material — a skeleton of *Tyrannosaurus* in the Museum of the Rockies — and have reached the same conclusion. But they also present a new argument for *Tyrannosaurus* being slow. The animal was tall, with the lowest points on its belly and head being 1.5 and 3.5 m, respectively, above the ground. If it tripped it would fall a long way, and its vestigial arms would be useless to break its fall. It could not risk falling, runs the argument, and would have had to have moved carefully.

From simple calculations, Farlow *et al.* estimated impact forces occurring during falls. If the torso falls from 1.5 m and is brought to rest in 0.3 m (an estimate that includes deformation both of the wall of the chest, and of the ground), the mean force during the impact is (1.5 + 0.3)/0.3 = 6 times torso weight. If the animal falls while running at 20 m s^{-1} and skids 3 metres along the ground before coming to a halt, the horizontal force involved is its kinetic energy divided by the skid distance, 7 times body weight. The deformation distance and the skid distance are merely plausible guesses; even so, Farlow *et al.* conclude that the dinosaur would have been unlikely to survive its fall.

There is very little quantitative information about the forces involved in falls and similar accidents either for animals or for people. Indeed, I know of only one sporting accident for which forces could be calculated: a weight lifter broke his patellar ligament in competition, while being filmed by a team of biomechanists who were able to calculate that the force that broke it had been 14,500 newtons (ref. 5). We might be able to learn more by fitting appropriate instruments to footballers and sending them out to play, hoping they would get hurt, but that would seem callous. However, we do know a good deal about the forces that cause injury in car crashes[6]. It proved possible to determine the forces that had acted on seat belts of one particular design, by examining the belts after accidents, and it was found that young adults suffered no chest injuries unless belt force exceeded 7,300 newtons (about 10 times body weight for a typical man). To estimate the force on the chest we must take account of the belt being attached at both ends, and of the angles of its attachments: 15 times body weight seems likely.

The forces that animals of different sizes can withstand are not expected to be proportional to their body weight, but to their areas (to the two-thirds power of weight). If a 70-kg man can tolerate 15 times body weight, a 6,000-kg tyrannosaur can be expected to tolerate $15 \times (70/6{,}000)^{1/3} = 3.4$ times body weight. So according to these calculations it does indeed seem that if a tyrannosaur fell while going full pelt it would cause itself some damage.

However, we need to ask whether animals can be expected to be cautious, or to live dangerously. The underside of a giraffe's belly is about 2.0 m from the ground (compared to 1.5 m for *Tyrannosaurus*), but giraffes gallop moderately fast, up to at least 11 m s^{-1} (ref. 7). Ostriches are bipeds with no arms to break a fall, but run very fast indeed (I have driven alongside one in a Jeep with the speedometer reading 35 m.p.h., 16 m s^{-1}). And the argument that *Tyrannosaurus* must have moved cautiously because of the danger of falling would seem to imply that, for instance, gibbons should move gingerly through the treetops instead of swinging rapidly from their arms.

Whatever the merits of the new argument of Farlow *et al.*, the old one based on leg-bone strength is confirmed. *Tyrannosaurus* was not good at chasing Jeeps. □

R. McNeill Alexander is in the Department of Pure and Applied Biology, University of Leeds, Leeds LS2 9JT, UK.

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PARTICLE PHYSICS

Glueball caught in a lattice

Frank Close

ATOMS of light do not exist, but theory suggests that closely related entities called 'glueballs' should occur on the scale of individual protons and neutrons. For over twenty years no clear evidence for glueballs has emerged, though there have been occasional sightings whose status is still not settled. In the past year this question has come sharply into focus, culminating in the most recent "Numerical evidence for a scalar glueball"[1]. One press report described this as the "first instance of a particle's discovery by computer".

First, what are glueballs and how do they relate to atoms of light?

Many of our daily experiences are governed by the absorption and emission of photons, the quanta of the electromagnetic field and thus the particles that carry electromagnetic forces. An essential rule underpinning the structure of matter is that opposite charges attract, and it is the attraction between electrons and protons that allows atoms to form. Photons carry no electric charge and so do not attract one another, hence the absence of atoms of light.

The relativistic quantum theory of electromagnetic phenomena is known as quantum electrodynamics (QED) and is considered a model for theories of the other fundamental forces, such as those controlling the structure of the atomic nucleus and its constituent particles. Quantum chromodynamics (QCD) is the theory of the strong nuclear force, and as its name suggests, it is tantalizingly similar to QED. The analogues of photons are 'gluons'. Whereas photons carry no electric charge, gluons do possess the 'colour'