A Spring in the Dinosaur's Step: Musculoskeletal Modelling Dinosaur Locomotion

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Abstract

Investigating the relative running ability of extinct animals can be approached through the analysis of skeletal (ostelological) adaptations for running, or cursoriality. This approach suits dinosaurs particularly well, since skeletal evidence is what fossils tend to provide best. Soft-tissue aspects of dinosaurs such as metabolism and muscle structure impact heavily upon the animals' potential cursorial ability, but to take these factors into account relies upon many assumptions and a great deal of speculation. In comparison, osteological analysis has the advantage of dealing with hard and quantifiable evidence. Dinosaurs, like many vertebrates, would have had the capability to walk, run and probably even skip! The relative positions of body, limbs, centre of mass, and speed combine to define gait: walking, jogging, trotting, running, and galloping. Each mode of locomotion has its own specific gait pattern. Animals adjust their gait to minimize energy expenditure, whether walking, hopping, or running.

As the use of computer modeling becomes more widespread in palaeontology, and precise laser-scanned models of dinosaur skeletons become more widely available, increases in computing power are making greater and greater use of elaborately fleshed-out digital dinosaurs to investigate movement and locomotion. Software (Gaitsym) has been developed at the University of Manchester that allows the gait of both extant and extinct animal to be derived through using a distributed genetic algorithm optimization system. This approach employs a genome that represents the gait cycle duration and the muscle activation levels at given time periods through a gait cycle. I use the word genome here cautiously, since this suggests an evolutionary or even biological process occurs where the computer 'learns'. This is not the case. The 3D functional space that a limb could potentially move in is quite large, but is unlikely an organism uses much of that potential space. Animals tend to work in the most efficient way to get from A to B for their specific body plan, geometry, the environment they are in, and what they are doing (hunting, breeding, or browsing). Gaitsym searches for the most efficient way from getting from A to B for each musculoskeletal model that we create. After hundreds of thousands of virtual 'runs', more efficient gaits for each model are generated. The software doesn't so much learn from its mistakes, but simply builds upon them.

The optimization of musculoskeletal dinosaur models has taken a curious step forward, a step that relies upon the potential of stored energy in elastic structures. The potential elastic properties of the backs of dinosaurs have fascinated scientists for some time, with vast tendons often preserved along the top and side of vertebrae. The locomotor capabilities of quadrupedal vertebrates are considerably enhanced by the storage and recoil of elastic energy in back tendons, providing energy recovery from step to step. However, elastic recoil in living bipeds, such as running humans, is restricted to the legs and feet due to a vertical orientation of the torso. We used a reverse-engineering approach to demonstrate that the unique body shape of bipedal dinosaurs enabled them to store energy in their horizontally held torso and tail. A rigid musculoskeletal models and one with back tendons inserted was used to see if this 'spring' in the trunk (body+tail) might affect maximum

running speed. The maximum benefit was a staggering 32% increase in speed compared to an un-sprung trunk. The model also showed the metabolic cost of locomotion predicted by the simulation fell by 23%, although these values should be treated with caution since metabolic cost was not included in the fitness criteria and animals may have devised cost solutions with very similar speeds that are appreciably cheaper. This clearly illustrates the fact that in the simulation the natural period of an oscillating trunk was actually a harmonic of the gait cycle frequency, which could also be seen in the animation outputs from Gaitsym. The reduction in mechanical energy requirement allowed both a significantly higher top speed combined with an overall reduction in metabolic energy cost. *T. rex* and other bipedal dinosaurs could literally spring into action!