Speed potential of giant tyrannosaurs

The locomotive capabilities of giant tyrannosaurs have been the source of much debate over the past several decades: some authors describe the animal as a slow scavenger, whilst others attribute to it an ostrich-like swiftness.[1] Recent work using biomechanical scaling from small bipedal birds suggested that at best an animal of this size could only manage a slow run.[2] To further investigate this problem we have been using evolutionary robotics to create biorealistic simulations and directly assessing their locomotive performance.

The field of evolutionary robotics was developed for the automatic creation of autonomous robots.[3] Researchers have primarily concentrated on navigation and learning issues. However, the evolutionary technique also enables the spontaneous generation of locomotion in legged robots: it is therefore an excellent tool for investigating the locomotion of extinct animals. In this situation, the basic mechanics (limb segments, joints, muscles) of the model are based directly on fossil evidence, and a central pattern generator is used to activate the muscles and produce the required locomotion. The activation pattern is produced using a genetic algorithm optimisation procedure so that the locomotive performance achieved maximises some fundamental parameter such as locomotive economy or top speed. This technique was previously used to investigate bipedal walking in early hominids,[4] where it accurately predicted the cost of locomotion: by altering the optimization to maximise distance travelled in a given time, rather than for a given amount of energy, it could be used to predict maximum speeds.

Our model is based on the reconstruction of *Tyrannosaurus (T.) rex* using an estimated body mass of 5700kg.[1] The linear dimensions are based directly on the reconstruction and inertial properties derived from a 3D extrusion CAD model. Muscle groups are modelled as point-to-point force generators acting around the hip, knee and ankle joints with physiological parameters derived from their estimated masses (see Figure 1). However, as soft-tissues are only very rarely preserved in fossils, we use a range varying from 25 to 40% of body mass. Similarly, muscles vary in internal geometry depending on force and velocity requirements. To accommodate this uncertainty, the simulation was repeated using different assumptions of fibre length and force generation capability to identify a range of possible speeds for a given limb mass.

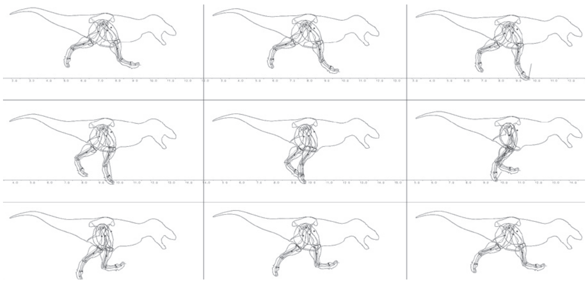


Figure 1. *Still frames taken from the animation sequence at 60ms intervals. These are from a run with a forward velocity of 10.7ms^{-1}.*

The model was able to produce stable running after a few thousand iterations of the optimisation procedure (see Figure 1) with speeds from 6ms^{-1} to over 15ms^{-1} (see Figure 2). To check the validity of the reconstruction, the average muscle power output was calculated (see Figure 3). For comparison, the maximum power output of horse muscle is about 90Wkg^{-1} but, by using elastic energy stored in tendons, an instantaneous power output of 4400Wkg^{-1} can be achieved.[5] If *T. rex* could also use such a mechanism, even the highest values are entirely plausible: this suggests that *T. rex* was indeed a fast-moving animal.

This approach to fossil reconstruction is still in its infancy and considerably more work needs to be done to validate its predictions based on experimental work with living animals. However, with more sophisticated simulations, we should be able to calculate the biomechanical performance limits (and produce realistic animated output) for a whole range of fossil animals.

Further information about this and other simulations can be found on the Animal Simulation Laboratory website.[6]

W. I. Sellers and G. S. Paul*
Department of Human Sciences,
Loughborough University, UK.
E-mail: W.I.Sellers@lboro.ac.uk
*Baltimore, MD, USA

Figure 2. *Graph showing the maximum forward velocity achieved by the model as the proportion of body mass in the legs is increased. The two lines represent different assumptions of the maximum contraction velocity of the muscle.*

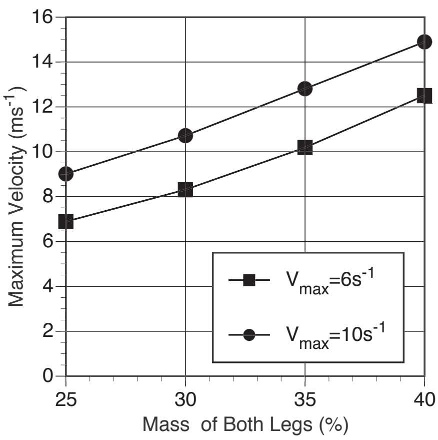
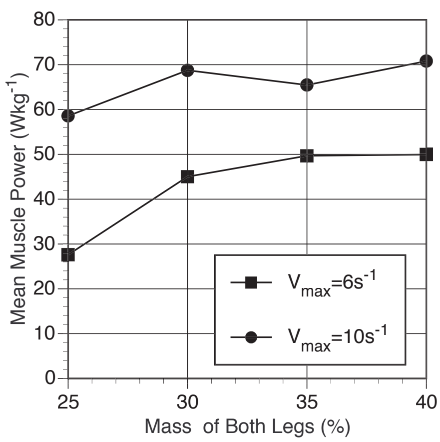


Figure 3. *Graph showing the mean power output per kilogram of muscle for the model as the proportion of body mass in the legs is increased. The two lines represent different assumptions about the maximum contraction velocity of the muscle.*



References

1. G. S. Paul, *Limb design, function and running performance in ostrich-mimics and tyrannosaurs*, **Gaia 15,** pp. 257-270, 1998.
2. J. R Hutchinson and M. Garcia, *Tyrannosaurus was not a fast runner,* **Nature 415,** pp.1018-1021, 2002.
3. S. Nolfi and D. Floreano, **Evolutionary Robotics,** MIT Press, Cambridge MA, 2000.
4. W. I. Sellers, L. A. Dennis, W. Wang and R. H. Crompton, *Evaluating alternative gait strategies using evolutionary robotics*, **J. Anat. 204,** pp. 343-351, 2004.
5. S. W. Wilson and J. C. Watson, *A catapult action for rapid limb protraction*, **Nature 421,** pp. 35-36, 2003.
6. http://mac-huwis.lut.ac.uk/ASL/