THE MECHANICS OF JUMPING VERSUS STEADY HOPPING IN YELLOW-FOOTED ROCK WALLABIES

[1] Craig P. McGowan*, [2]R. V. Baudinette and [1]A. A. Biewener
[1]Concord Field Station, Harvard University, Bedford, Massachusetts, USA
[2]Department of Zoology, University of Adelaide, Adelaide, South Australia, AU
*e-mail: cmcgowan@oeb.harvard.edu

INTRODUCTION

Previous work has suggested that a musculoskeletal design that favors elastic energy recovery, like that found in wallabies and kangaroos, may be constrained in the ability to generate mechanical power [1]. Yet rock wallabies regularly make large jumps while maneuvering through their environment. The goal of our study was to explore the mechanical power requirements associated with jumping in yellow-footed rock wallabies and to determine how these requirements are achieved relative to steady speed hopping mechanics. As jumping can be a high power activity, we hypothesized that yellow-footed rock wallabies would be able generate substantial amounts of mechanical power.

METHODS

Four adult yellow-footed rock wallabies, *Petrogale xanthopus* (one male and three female, ranging from 5.10 to 5.50 kg body mass) were trained to hop through a straight runway with no obstacles and through a runway containing a jump 1.10m high. High-speed video recordings (Photron Fastcam-X 1280 PCI) and ground reaction force measurements from a runway mounted force platform (Kistler type 9286AA) were used to calculate whole body power output and to construct a simple mass-spring type model to determine whole limb mechanics. The combined mass of the hind limb extensor muscles was used to estimate muscle mass-specific power output.

Changes in mechanical energy and whole body power outputs were calculated via integration of the vertical and horizontal ground reaction forces [2]. The legs were modeled as a spring in series with a linear actuator and the body was considered to be a point mass located at the ilium point, which was a proxy for the position of the CoM. The actuator in this model can only produce positive work, and it is assumed that all of the negative energy associated with leg spring compression is recovered elastically. Leg stiffness was determined at the point of maximum leg compression.

RESULTS AND DISCUSSION

Net extensor muscle power outputs averaged 155 W kg^{-1} during steady hopping and 495 W kg^{-1} during jumping (Figure 1). The highest net power measured reaching nearly 640 W kg^{-1}. As these values exceeded the maximum power producing capability of vertebrate skeletal muscle [3], it was determined that back, trunk and tail musculature likely played a substantial role in contributing power during jumping. Inclusion of this musculature produced a maximum power output of 452 Wkg^{-1} muscle.

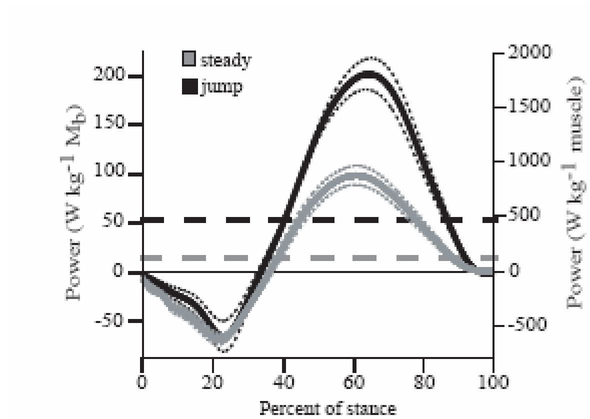

Figure 1. Mean power output during stance normalized to body mass (M_b, left axis) and hind limb extensor muscle mass (right axis). Horizontal dashed lines represent the net power produced during stance.

Similar to human high-jumping, rock wallabies used a moderate approach speed (not significantly different than steady hopping) and a relatively shallow leg angle of attack (45-55º) during jumps [4]. Leg stiffness increased nearly twofold in jumping (steady: 2.98 kN m^{-1} vs. jumping: 5.50 kN m^{-1}), which facilitated the transfer of horizontal kinetic energy into vertical kinetic energy. Time of contact was maintained during jumping despite greater leg stiffness and smaller leg excursions by a substantial extension of the leg, which kept the foot in contact with the ground. Additionally, rock wallabies appeared to minimize potential pitching moments by adjusting their leg angle to match the angle of ground reaction force vector.

CONCLUSIONS

Our results clearly show that rock wallabies are capable of producing very high power outputs. For the jumps recorded in this study, estimates of muscle mass-specific power output (450 W kg^{-1} muscle) suggest that all of the musculature of the legs, back and tail were recruited to produce jumps and that power output is near the maximum expected for vertebrate skeletal muscle. However, whether this comes at the expense of tendon and aponeurosis strain energy savings by rock wallabies during steady level hopping requires a more detailed kinetic analysis of their level hopping mechanics.

REFERENCES

1. Biewener, A. A. *Amer. Zool.* **38**, 703-717, 1998.
2. Cavagna, G. A. *J. Applied Physiol.* 39,174 -179, 1975.
3. Weis-Fogh, T. and Alexander, R. McN. *Scale Effects in Animal Locomotion.* ed. Pedley, T. J. Chapter 30. New York: Academic Press, 1977.
4. Alexander, R. McN. *Phil. Trans. R. Soc. Lond.* B **329**, 3-10, 1990.