REDISTRIBUTION OF JOINT WORK DURING ACCELERATION AND DECELERATION IN AN AVIAN BIPED

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INTRODUCTION

The nature of muscle force generation in relation to length change (muscle work) is key to understanding the roles of different muscles within the limb. Recent research has shown that the gastrocnemius muscle in the turkey is able to produce force economically during steady running by contracting with little length change, but can contribute significantly to positive work by shortening during incline running (Roberts et al., 1997). Direct measurement of *in vivo* muscular work however is only possible in a few muscles for which direct recordings of muscle force and length change are possible. Moreover, the role of more proximal muscle groups at the hip and knee, which have been shown to be important for power generation or absorption in human jumping and running (e.g., Bobbert et al., 1986; Pandy & Zajac, 1991; Winter, 1983), raises the question of how different muscle groups contribute to mechanical work versus economical force transmission during steady versus non-steady locomotion.

In order to assess more broadly how muscle work versus isometric force transmission is distributed within the limb of a running animal, we examine the external work performed at each joint in the hindlimb of the guinea fowl (*Numida meleagris*) during steady running, acceleration and deceleration. By comparing the external joint work performed under these different locomotor conditions, we seek to evaluate how various muscle groups within a limb contribute to weight support and mechanical work, and how these roles may vary to accommodate variable conditions of locomotor movement.

METHODS

We obtained horizontal fore-aft, vertical, and center of pressure ground reaction force (G_{RF}) recordings from four guinea fowl (1.58 $\pm$ 0.11 kg) as they ran across a Kistler 9203 force platform over a range of speeds. A Redlake high-speed digital video system was used to track skin-marked limb joint positions at 250Hz. Coordinate data were then smoothed using a fourth-order digital Butterworth filter with a 35 Hz 3db cutoff before calculating joint angular velocities (ω) and external moments (M). All calculations were carried out in Matlab. [Ongoing work will incorporate segmental and gravitational moments in our analysis.] Measurements of joint power ($M \times \omega$) were integrated over the stance phase of the step cycle to obtain the net external joint work performed during support.

External power and net work at each joint were compared under three conditions: steady running, acceleration, and deceleration. Trials were considered steady if the change in velocity during the single step was less than 3% of the animal's initial velocity as it reached the force plate.

RESULTS AND DISCUSSION

We found that each joint contributes differently to mechanical work under steady running conditions (Fig. 1). The hip performs net positive work, the ankle and knee perform nearly equal amounts of positive and negative work, resulting in little net work, and the tarsometatarsophalangeal (TMP) joint absorbs energy.

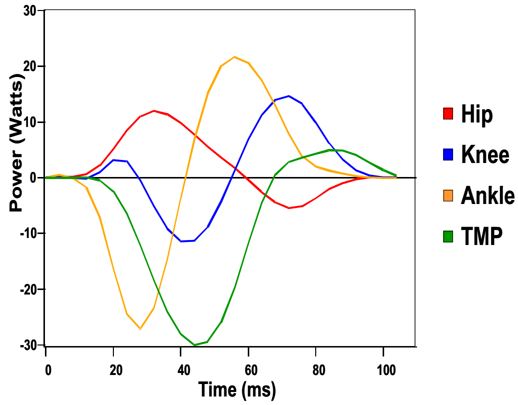

Figure 1. External joint power at each joint in the hindlimb during the support phase of a single steady run.

During acceleration (+5.1 $\pm$ 2.8 % Δvel) and deceleration (-5.0$\pm$1.3% Δvel) the net mechanical work for the limb as a whole shifts as expected to being more positive or negative, respectively. However, the shift in mechanical work is not the same at each joint (Fig. 2). In particular, we found that the increase in whole limb positive work during acceleration was achieved primarily by a decrease (p=0.028) in the net energy absorbed by the TMP joint, together with an increase (p=0.07) in positive work performed by the ankle.

In contrast, the increase in energy absorption during deceleration was mainly achieved by negative joint work performed at the knee and ankle, for which energy absorption was significantly greater than during steady running (p<0.0001) (Fig. 2). The hip also contributed by reducing its net positive work during deceleration (p=0.07). Finally, the TMP joint actually absorbed less energy during deceleration than during steady running (Fig. 2).

These results indicate that changes in whole limb external joint power and work are achieved by differing contributions from individual limb joints for steady versus non-steady locomotor movement. Although the relatively low values of external work observed at the knee and ankle joints during steady running are consistent with isometric contraction and economical force transmission of the quadriceps and ankle extensors, the positive work performed at the hip and negative work at the TMP joint, indicate that substantial modulation of recruitment to control fascicle shortening or lengthening is important to the mechanics of steady, as well as non-steady running.

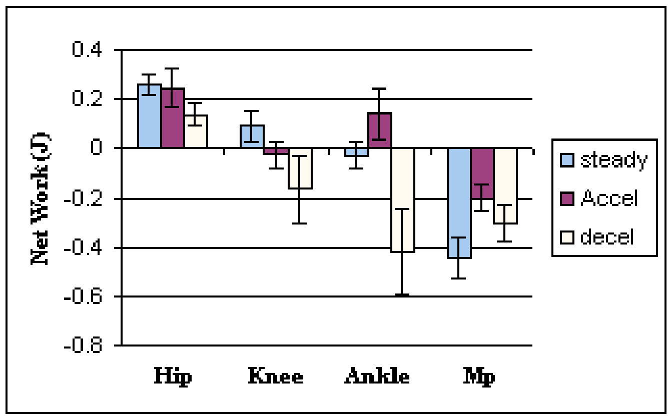

Figure 2. Mean net joint work during the support period for all trials for the four birds ($\pm$SEM).

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