INTEGRATING THE MECHANICAL AND METABOLIC ENERGETICS OF THE SWING PHASE OF WALKING AND RUNNING

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INTRODUCTION

One of the biggest challenges facing biomechanists and physiologists remains explaining the underlying determinants of the metabolic cost of locomotion. Traditional approaches have been hampered by their inability to partition metabolic energy between individual muscles.

Here we use estimates of muscle-specific metabolic rates from bloodflow measurements (Marsh et al., 2004; Rubenson et al., 2006) to explore the determinants of metabolic energy expenditure in an avian model system (domestic guinea fowl). Specifically, we examine whether the metabolic cost of swinging the leg is determined by mechanical energetics.

Given that a considerable component of the overall energy expenditure occurs during the swing phase (Marsh et al., 2004, Doke et al., 2005), knowledge of its determinants will prove important for our understanding of the energetics of normal and dysfunctional gait.

METHODS

Muscle-specific metabolic rates were estimated from previous studies in our laboratory combining whole body oxygen consumption and muscle bloodflow measurements from guinea fowl (*Numida meleagris*) moving on a motorized treadmill (Marsh et al., 2004; Rubenson et al., 2006). Intramuscular EMG was used to partition the muscles recruited during the swing- and stance-phase.

Using similar size guinea fowl (n = 4; 1.47 ± 0.12 kg; ± S.D.), joint mechanical work was measured using 2-D inverse dynamic modeling as the animals walked and ran on the same treadmill at equivalent speeds. The major joints of the hind limb were identified with reflective markers and videod at 500 Hz (NAC). Center of mass and inertial properties of limb segments from sacrificed animals were determined using a suspension and pendulum method, respectively.

RESULTS AND DISCUSSION

Typical joint angle, moment and power curves for guinea fowl running at 2.5 m s^{-1} are depicted in Fig. 1. Interestingly, both the hip and knee exhibit similar kinematic and kinetic patterns to that of human running (Winter, 1983), whereas the ankle exhibits proportionately greater loading and power generation. The majority of positive work is generated at the hip and ankle and the majority of negative work is generated at the knee.

Metabolic and positive mechanical power of swinging the limb increases with speed, although not proportionately (Table 1). Consequently, the positive mechanical efficiency of swinging the limb during walking remains low (~ 5%), whereas efficiencies during running are greater (~ 12-17%). Interestingly, when the mechanical efficiency is calculated for ankle flexion, in which all of the mechanical and metabolic work is attributed to a single muscle (*tibialis cranialis*), similar values are obtained as that for the entire limb.

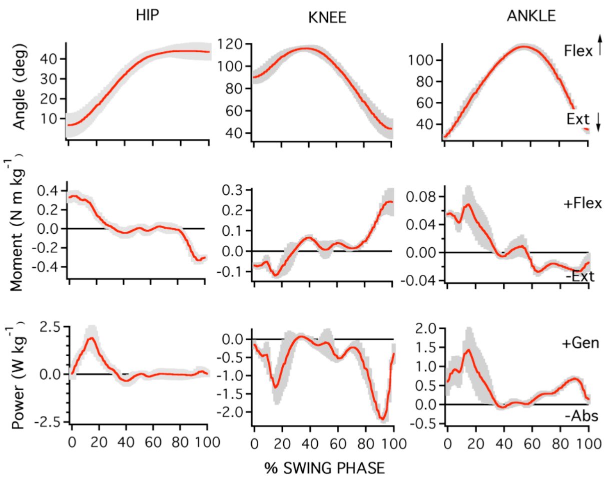

Figure 1: Anglel, moment and power curves for the swing phase (mean ± S.D.) in guinea fowl running at 2.5 m s^{-1}.

SUMMARY/CONCLUSIONS

Given that the maximum positive efficiency of skeletal muscle is ~ 25%, our results indicate that, for running speeds, muscular work may determine a major portion of the metabolic cost of swinging the limb. The situation is, however, complicated due to possible transfer of energy via bi-articular muscles, co-contraction and passive joint moments, which are not accounted for in the present study. These factors are currently being explored and may help to explain the discrepancy between efficiencies during walking and running.

REFERENCES

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Table 1: Metabolic power, positive mechanical power, and positive mechanical efficiency of swinging the limb.

	Walking Speed (m s^{-1})	Running Speed (m s^{-1})	
	0.5	**1.5**	**2.5**
Metabolic Power (W kg^{-1})	1.78	4.34	6.32
+'ve Mechanical Power (W kg^{-1})	0.06 ± 0.02	0.43 ± 0.11	0.88 ± 0.13
+'ve Mechanical Efficiency	5.0 ± 1.0	12.2 ± 3.5	17.0 ± 3.4