Metabolic Cost and Muscle Contraction during Human Leg Swing

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INTRODUCTION

Leg swing is an important part of human locomotion. Evidence suggests that pendular dynamics may be responsible for much of the swing phase of gait (Mochon, McMahon, 1980). As it would require mechanical energy to swing a pendulum fast, it may require metabolic energy to swing a leg at a high frequency. Studies have shown that short, intermittent contraction of muscles cost more energy than long, sustained contractions (Hogan et al. 1998). We hypothesize that the increase in metabolic cost of leg swinging at high frequencies may be linked to short bursts of muscle contractions. In this study, we measured the metabolic cost of swinging the leg, isolated from walking.

We constructed an ergometer that measured metabolic, kinematics, and kinetics data as subjects stood on one leg and swung their other leg at various frequencies. Metabolic cost increased sharply as swing frequency increased, while muscle contraction time decreased with swing frequency.

METHODS

Twelve healthy young adults (6 males, 6 females; body mass = 64.8 ± 8.3 kg, leg length = 0.88 ± 0.07 m, mean ± SD) consented to participate in this study. Seven different swing frequencies, ranging from approximately 0.5 to 1.1 Hz, were tested on each subject's left leg. For each frequency, metabolic, kinematics, and kinetics data were collected. At a later session, electromyographic (EMG) data were collected on the same 6 male subjects during the leg swing conditions.

The leg swing apparatus consisted of a metal frame that supported the upper body of the subject, and was placed on a force plate to measure the kinetics (Figure 1). An optical encoder was attached to the swing leg to record the kinematics of the leg. The subjects wore a mouthpiece connected to an open circuit respirometry system for measuring metabolic data.

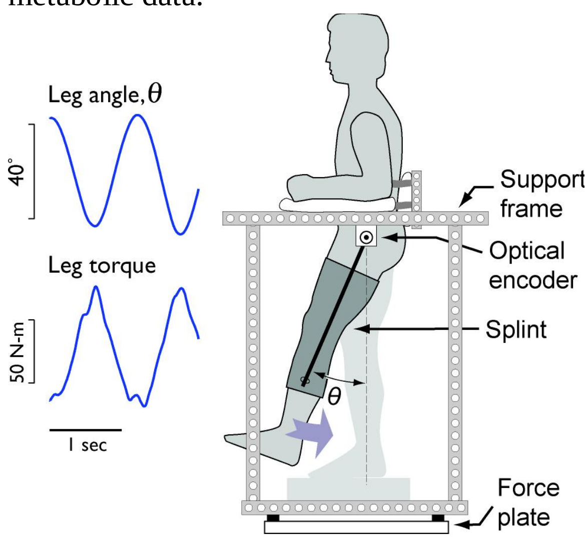

Figure 1: Leg Swing Apparatus. The graphs show sample of leg angle and computed leg torque data.

Subjects received visual feedback of their leg angle against a constant target amplitude, with frequency enforced by a metronome. Each trial ran for six minutes to allow oxygen consumption to reach steady state, with the last three minutes used for analysis. For EMG measurements, we recorded muscle activity from one hip flexor (Rectus Femoris) and two extensors (Medial Hamstring and Gluteus Maximus) using surface EMG electrodes, as subjects swung their leg at the same range of frequencies for 1 minute each.

RESULTS AND DISCUSSION

One possible cause for an increase in metabolic cost is the amount of mechanical work done on the leg during leg swing. Assuming constant muscle efficiency, we can expect the metabolic cost to increase in proportion to the mechanical work (*work hypothesis)*. Pendular mechanics suggest that metabolic power would increase roughly with the 3rd power of the swing frequency. Yet another cause for metabolic increase is the cost for the muscle to produce short bursts of force (Roberts et al., 1997), proportional to force divided by burst duration (*force/time hypothesis)*. With this hypothesis, we predict the metabolic power to increase roughly with the 4th power of the swing frequency.

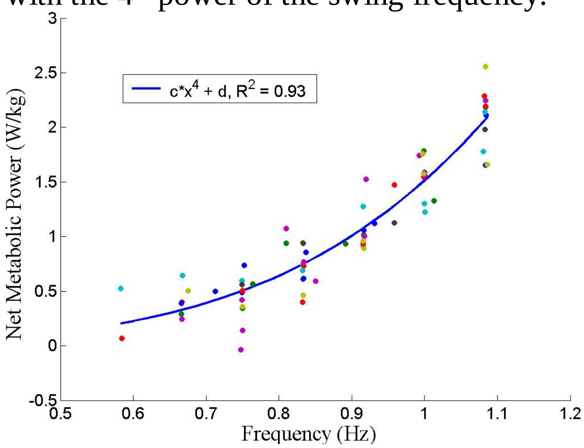

Figure 2: Net metabolic power increased by roughly (freq)^4. Cost of standing quietly was subtracted from overall power to yield net.

We found that the metabolic cost increased sharply with leg swing frequency. Metabolic power also increased to the 4th power of swing frequency ($R^2 = 0.93$; Figure 2). This suggests that the metabolics of leg swinging at high frequencies may be governed by the *force/time hypothesis,* more so than by the cost of producing work.

EMG measurements showed that contraction durations decreased with increasing swing frequency (Figure 3). Burst magnitudes also increased with frequency. Metabolic cost has been shown to increase with force magnitude, and inversely with burst duration (Roberts et al. 1997), and both may be responsible for the metabolic cost increases observed here.

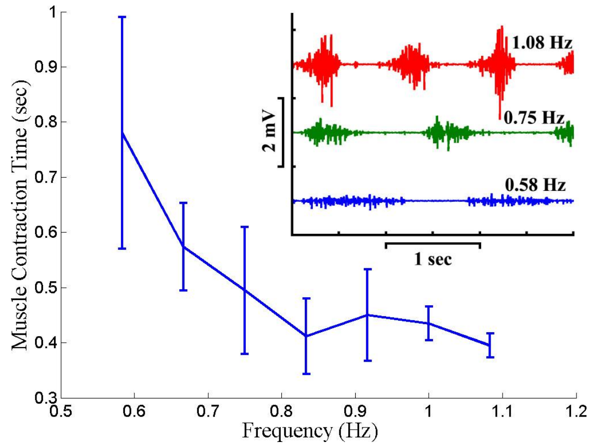

Figure 3: Medial hamstring (MH) contraction duration per cycle. The data is the average of all subjects. The inset displays samples of raw EMG signals from the MH at 3 different frequencies. As the frequency increases, the peak amplitude increases and the contraction time decreases.

These results suggest that much of the metabolic cost of swinging the leg is due to muscles producing high forces for short durations. Some of the mechanical work may be performed by elastic hip tendons, similar to the function of other tendons in running (Roberts et al., 1997). Further comparisons of metabolic cost with the mechanical work performed by muscle will provide more insight as to the relative contributions of muscle work and force to the energetic cost of leg swinging.

REFERENCES

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