MECHANICAL EFFICIENCY DURING WALKING AT DIFFERENT STRIDE RATES

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INTRODUCTION

At any particular walking speed, the rate of metabolic energy expenditure in humans is minimized at the preferred, or self-selected, stride rate [6]. However, our understanding of the underlying factors that determine the global energy rate response, and that ultimately influence the preferred walking pattern, remains incomplete. Mechanical efficiency is a factor that is believed to be important in human locomotion [e.g., 5], but has not received much direct attention in regards to walking stride rate selection. The purpose of this study was to test the hypothesis that maximization of the mechanical efficiency of walking occurs at the preferred stride rate.

METHODS

Six male and four female subjects (M_{age} = 26.7 ± 3.6 yr; M_{ht} = 173.9 ± 9.6 cm; M_{mass} = 67.9 ± 11.9 kg) walked at 1.3 m/s using five different stride rates (preferred, ± 10% of preferred, and ± 20% of preferred). Preferred stride rate was determined as subjects walked on a motorized treadmill, after which the subjects practiced walking at the experimental stride rates for at least 10 min. Following familiarization with the protocol, and after resting for at least 20 min, measurements were made of pulmonary gas exchange while subjects walked on the treadmill at the different stride rates. In a separate trial, ground reaction forces and body segment positions were monitored as subjects walked along a 12 m walkway across a force platform. Subjects matched their stride rates to a metronome for treadmill trials, and to marks placed on the floor for overground trials. For both trials subjects walked with arms folded across their chest, to minimize any influences from outside the lower limbs.

The net (walking minus resting) rate of metabolic energy expenditure (E_{DOT}) was estimated from pulmonary gas exchange [3], and sagittal plane hip, knee, and ankle joint moments were calculated using inverse dynamics [4]. Joint powers were calculated from the net moments and joint angular velocities. Average positive (P_{POS}) and negative (P_{NEG}) power, summed over all three joints, was determined by integrating the instantaneous positive and negative powers over the gait cycle, and dividing by the cycle period. P_{POS} and P_{NEG} were doubled to approximate the power output of both legs. The mechanical efficiency of walking (ε_W) was estimated from P_{POS}, P_{NEG}, and E_{DOT} as $\varepsilon_W = P_{POS} / (E_{DOT} + P_{NEG})$ [1].

Metabolic energy rate and mechanical efficiency data were fit with quadratic polynomials, and the stride rates corresponding to the respective minima and maxima were determined from the resulting equations. Differences between preferred stride rate and the stride rates optimizing energy expenditure and mechanical efficiency were detected using paired t-tests.

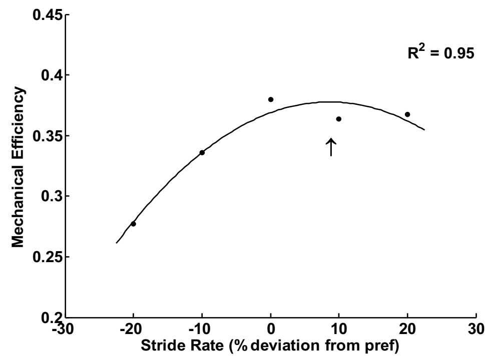

Figure 1: Mechanical efficiency of walking was predicted to be maximized at a stride rate 8.3% above the preferred.

RESULTS AND DISCUSSION

Preferred stride rate (54.3 str/min) and the stride rate minimizing gross metabolic energy expenditure (55.6 str/min) were both similar to previous reports [6], and did not differ significantly ($p > .05$). Mechanical efficiency (Figure 1) was maximized at a stride rate 8.3% higher than preferred (58.8 str/min; $p < .01$). While this difference was statistically significant, the absolute deviation from preferred was modest (4.5 str/min). The present results, combined with earlier work [2] showing that mechanical demand (estimated from net joint moments) was minimized approximately 8.5% below the preferred rate, suggests that these two factor may combine to constrain normal walking stride rates to a narrow range centered around a stride rate of approximately 55 str/min.

CONCLUSIONS

At a single speed, walking with stride rates lower than preferred results in decreased mechanical efficiency, while using stride rates higher than preferred leads to increased loading on the lower limb muscles. The self-selected stride rate in walking appears to represent the best compromise between these two competing factors.

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