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THE EFFECT OF WALKING SPEED ON MUSCLE FUNCTION

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INTRODUCTION

Effectively modulating walking speed over a wide range is important in human gait, yet understanding how the neuromotor patterns adapt to the changing energetic demands of different speeds is not well understood. Recent modeling studies of walking at self-selected speeds have identified how individual muscles function in synergy to satisfy the task demands including body support, forward propulsion and leg swing (e.g. [1,2]). These studies revealed that young adults utilize a distribution of hip and knee extensor muscle force in early stance and plantar flexor and rectus femoris force in late stance to provide body support and forward propulsion [2]. However, how each muscle's contribution to these functional tasks changes with speed is not well understood.

The objective of this study was to identify how individual muscle function changes in response to walking at increasing steady-state speeds using a musculoskeletal model and forward dynamics simulations that emulate experimentally collected kinematic and ground reaction force (GRF) data. Dynamic simulations provide a framework to identify muscle function and how it changes as the task requirements associated with increasing speed change.

METHODS

A 2D musculoskeletal model [2] was used to generate forward dynamics simulations that emulate group averaged body segment kinematic and ground reaction force data collected from 10 young healthy adults walking at 0.4, 0.8, 1.2, 1.6 and 2.0 m/s. The model consisting of a trunk and two legs (femur, tibia, patella and foot per leg) and fifteen individual muscle actuators per leg was developed using SIMM/Dynamics Pipeline (MusculoGraphics, Inc.). The model had nine degrees-of-freedom (trunk anterior-posterior tilt and horizontal and vertical translation, hip, knee and ankle flexion-extension for both legs). Contact between the foot and ground was modeled using 30 visco-elastic elements attached to each foot segment. Muscle excitation patterns at each speed were derived from averaged EMG signals obtained from the 10 subjects. A simulated annealing algorithm [3] was used to fine-tune the onset, duration and magnitude of the excitation patterns such that the simulations emulated the human subject kinematic and GRF data at each speed. To identify the influence of walking speed on muscle function, individual muscle contributions to body support, forward propulsion and leg swing were determined using a segment power analysis [4].

RESULTS

The walking simulations at each of the walking speeds emulated well the group-averaged data and the corresponding muscle excitation patterns systematically increased in magnitude as walking speed increased. Although there were some quantitative differences, all muscles generated consistent contributions to body support and forward propulsion that systematically increased with speed. The hip and knee extensors and the plantar flexors (SOL and GAS) were the primary contributors to trunk support in early and late stance, respectively. SOL and RF (rectus femoris) were the primary contributors to trunk propulsion in late stance (Fig. 1), with their contributions systematically increasing with speed. Leg swing was provided primarily by iliopsoas (IL), as it acted to deliver energy to the leg in early swing. The hamstrings also acted strongly at higher speeds to decelerate the leg in late swing in preparation for heel strike.

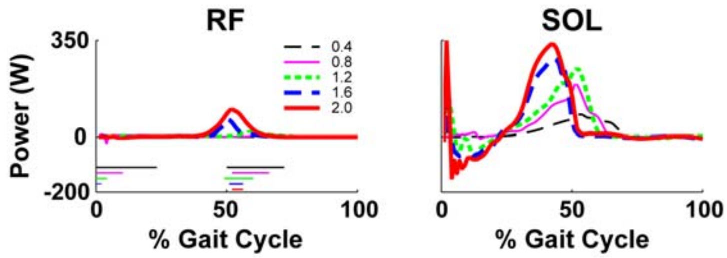

Fig. 1: Mechanical power delivered by RF and SOL to the trunk in the horizontal direction to provide forward propulsion across increasing walking speeds. The horizontal bars indicate the regions of double support, which decreased in duration with increasing speed.

DISCUSSION

The systematic increase in muscle contributions to trunk and leg mechanical power was consistent with previous EMG measurements [5]. Increasing walking speed has been shown to be associated with longer stride lengths, which leads to greater braking by the hip and knee extensors. The increased braking subsequently requires greater propulsion by the plantar flexors and rectus femoris in late stance (Fig. 1). Increased stride lengths also requires increased power generation from those muscles contributing to leg swing, which occurred primarily in the hip flexors (IL). These results provide important insight into the neuromotor mechanisms underlying speed regulation in walking and provide the foundation for future studies in pathological populations.

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