Muscle Contributions to Forward Progression During Walking

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INTRODUCTION

Knowing how muscles influence the forward acceleration of the body is of interest to human movement scientists and clinicians who try to improve the walking ability of patients with neuromuscular disorders.

Previous studies concluded that the soleus and gastrocnemius provide nearly all of the propulsive effort during walking (e.g., Kepple et al. 1997, Neptune et al. 2001). Neptune et al. (2004) reported that additional muscles, such as flexors and extensors of the hip and knee, may influence forward progression. However, these studies analyzed two-dimensional simulations of walking, excluding non-sagittal plane muscles that may be active during walking (e.g., gluteus medius, Lyons et al. 1983).

OBJECTIVE

The objective of this study is to identify the key muscles that contribute to forward acceleration of the body mass center during normal walking.

METHODS

We used an existing dynamic optimization solution for normal gait as the basis of our analysis (Anderson and Pandy 2001). The solution predicts joint angles, ground reaction forces, and muscle excitations that are similar to experimental data. The body was modeled as an articulated linkage actuated by muscles (Fig. 1).

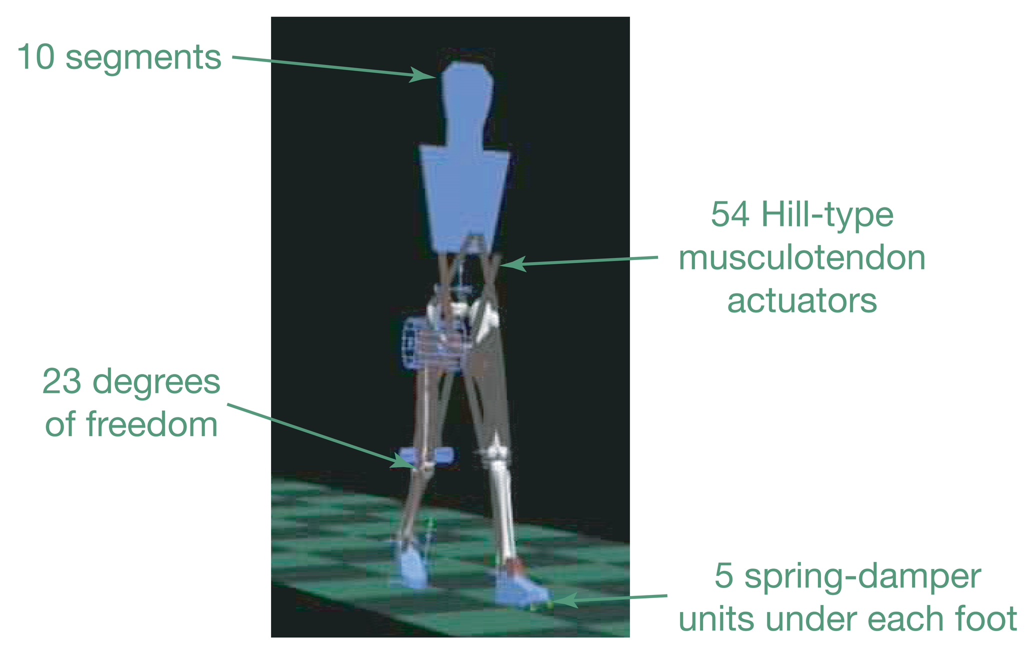

Figure 1: Musculoskeletal model used in simulation (Anderson and Pandy 2001).

We computed each muscle's influence on the forward acceleration of the body mass center ($\ddot{x}_m^{com}$) by performing a perturbation analysis of the muscle forces (Eqn. 1) every 0.02 s during the simulation for each muscle *m* and for gravity.

$$\ddot{x}_m^{com}\Big|_t \approx \frac{2F_m\left[x(F_m + dF_m)\big|_{t+\Delta t} - x(F_m)\big|_{t+\Delta t}\right]}{\Delta t^2\, dF_m} \qquad (1)$$

F_m : muscle's unperturbed force

dF_m : magnitude of the force perturbation (1.0 N)

$x(F_m)$: position of the body mass center in direction of progression

Δt : duration of perturbation (0.03 s)

The accuracy of this method was validated by comparing the simulated unperturbed acceleration of the body mass center to the total acceleration computed for all muscles and gravity (Fig. 2).

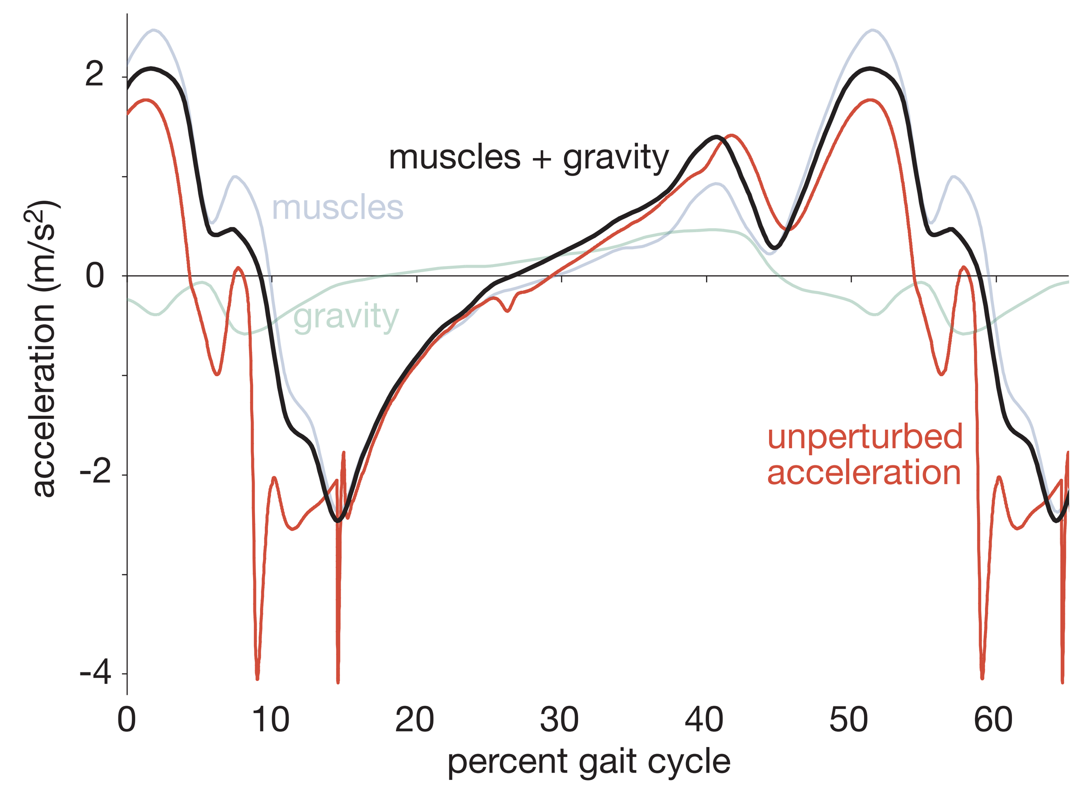

Figure 2: The combined influences from all muscles and gravity compared favorably to the simulated unperturbed forward acceleration of body mass center.

RESULTS

The stance-side muscles that generated the greatest peak influences in each half of the stance phase were identified (Fig. 3):

- Vasti caused most of the body's deceleration, assisted by gluteus maximus.
- Dorsiflexors decelerated the body during early stance, but accelerated it forward after foot-flat (~9% of the gait cycle).
- Anterior and posterior gluteus medius provided forward acceleration early in the acceleration phase (~32-50% of the gait cycle).
- Gastrocnemius and soleus generated most of the propulsion during the acceleration phase.

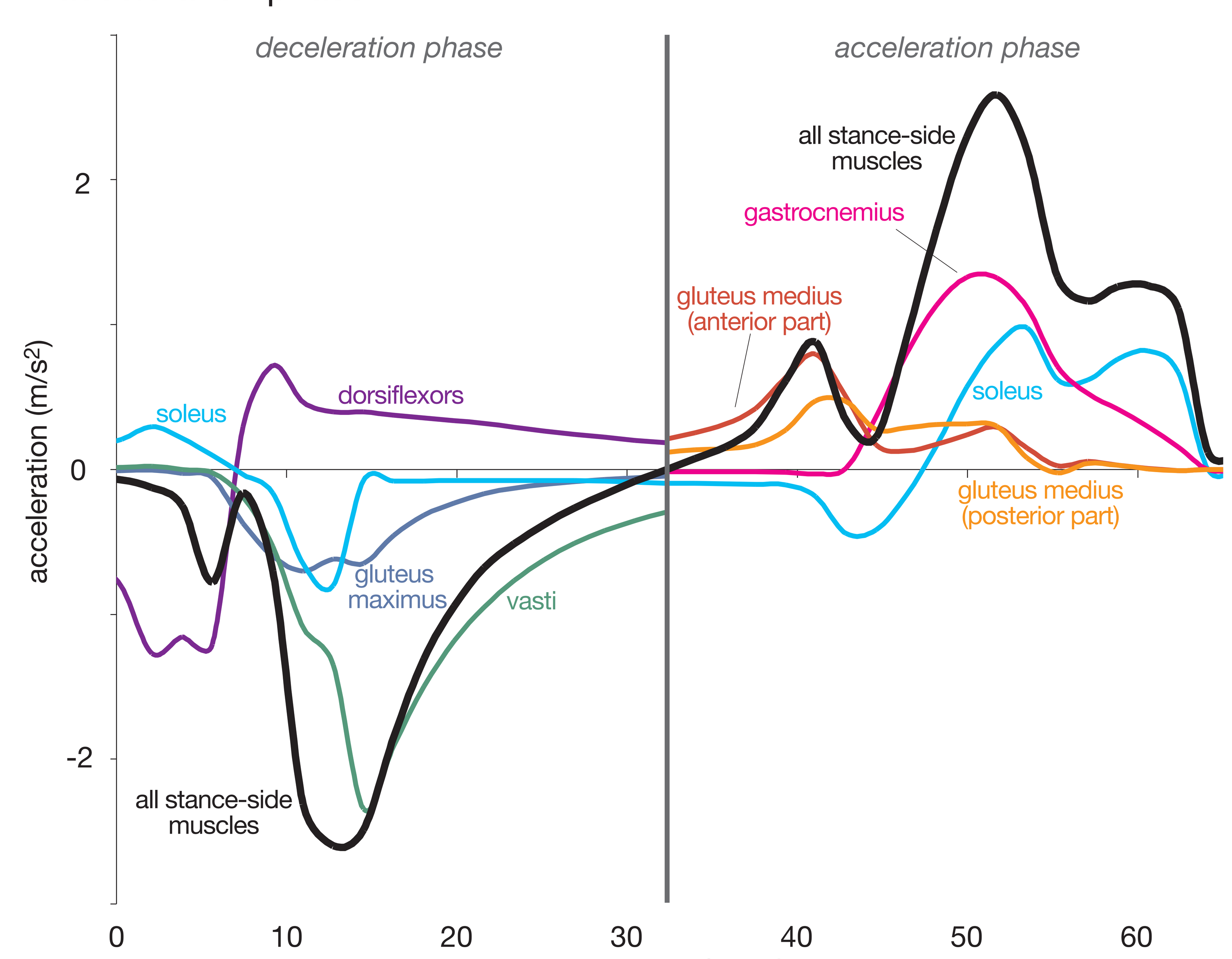

Figure 3: Influences on forward acceleration of body mass center for stance-side muscles with the greatest peak influences during the deceleration (0-32% of the gait cycle) and acceleration (32-65% of the gait cycle) phases of stance.

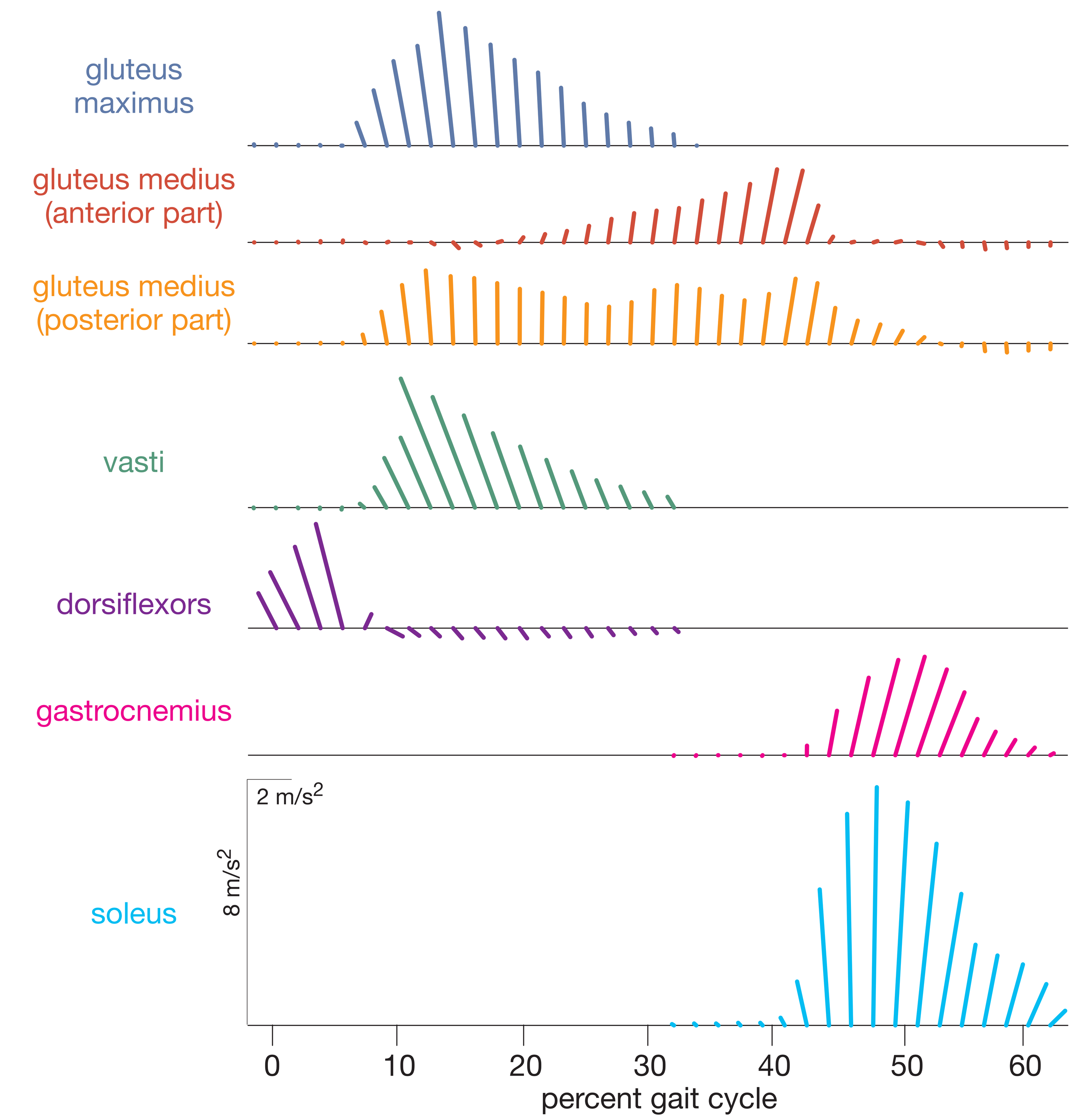

Figure 4: Relative influences on forward and vertical acceleration for muscles with the largest contributions to both during stance. Data for gluteus maximus, vasti, and dorsiflexors shown only for deceleration phase. Data for soleus and gastrocnemius shown only for acceleration phase.

CONCLUSIONS

- Most of the body's fore-aft acceleration was generated by relatively few muscles.
- In this simulation, both gastrocnemius and soleus made large contributions to forward acceleration.
- It is important to consider non-sagittal muscles, such as the gluteus medius, when analyzing human walking.
- The same muscles that influence forward acceleration of the body also make large contributions to its vertical acceleration (Anderson and Pandy 2003). Combining data on forward and vertical acceleration provides a more complete explanation of muscle function during normal walking (Fig. 4).

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