MUSCLE CONTRIBUTIONS TO THE FLIGHT PHASE IN RUNNING

Kotaro Sasaki and Richard R. Neptune
Department of Mechanical Engineering, University of Texas, Austin, TX, USA
Email: rneptune@mail.utexas.edu

INTRODUCTION

One of the most distinctive differences between walking and running is the existence of a flight phase in running rather than the double support phase that occurs in walking. This fundamental difference in gait mechanics indicates the need for muscles to generate greater vertical acceleration of the body's center of mass (COM) in running. Previous modeling studies of normal walking have shown that the uniarticular hip and knee extensors, and the ankle plantar flexors are the primary contributors to vertical acceleration of the COM from early to mid stance, and from mid to late stance, respectively [1, 2]. However, little is known about how individual muscles work in synergy to accelerate the COM upward to produce the flight phase in running. Therefore, the objective of this study was to identify which muscles contribute to the acceleration of the COM vertically and how these contributions differ between walking and running at the same speed.

METHODS

Individual muscle contributions to the vertical acceleration of the COM were obtained by quantifying each muscle's contribution to the vertical ground reaction force (GRF) using forward dynamical simulations of walking and running. A 2D musculoskeletal model with nine degrees-of-freedom (trunk anterior-posterior tilt, trunk horizontal and vertical translation, hip, knee and ankle flexion-extension for both legs) consisting of a trunk and two legs (femur, tibia, patella and foot per leg) and seventeen Hill-type muscle actuators per leg was developed using SIMM [3]. The muscles included in the model were the gluteus maximus, anterior and posterior gluteus medius, adductor magnus, iliacus, psoas, biceps femoris long head, medial hamstrings, biceps femoris short head, vastii, rectus femoris, tibialis anterior, soleus and medial and lateral gastrocnemius. The equations of motion were derived using SD/FAST (PTC, Needham, MA). Visco-elastic elements were attached to each foot segment to model the foot-ground contact [2]. Muscle excitation patterns were derived from measured group-averaged EMG patterns. A simulated annealing optimization algorithm was used to fine-tune the onset, duration and magnitude of the EMG patterns such that the simulations emulated group averaged experimental kinematic and GRF data collected from 10 young healthy subjects during walking and running at the preferred walk-to-run transition speed (~2 m/s). The contributions of each muscle to the vertical GRF were then quantified using a GRF decomposition [1, 2].

RESULTS AND DISCUSSION

The primary contributors to vertical GRF were the soleus (SOL), vasti (VAS) and gluteus maximus (GMAX) in both walking and running (Fig. 1). In walking, VAS and GMAX contributions occurred primarily in early stance phase (~0-30% stance phase), and then SOL contributed from mid to late stance (~30-100% stance phase, see also [1, 2]). In running,

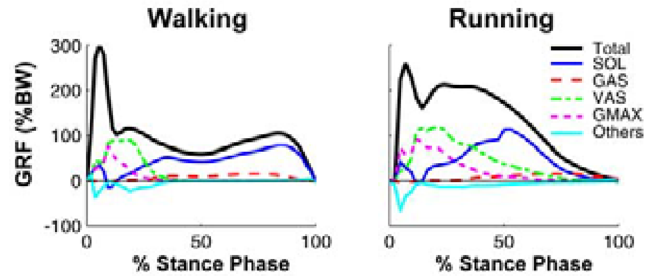

Figure 1: Individual muscle contributions to vertical GRF. Total: the total GRF including muscular and non-muscular components, Others: hamstrings, gluteus medius, tibialis anterior, rectus femoris, biceps femoris short head and iliacus-psoas combined.

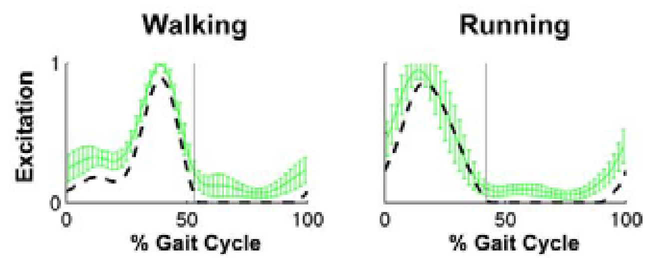

Figure 2: SOL excitation patterns for the walking and running simulations (dashed line) and group average EMG linear envelopes (solid line, average ± S.D.) at the preferred transition speed from heel-strike to heel-strike of the ipsilateral leg. The EMG data were normalized to the maximum value observed over the gait cycle. The vertical lines indicate toe-off.

the magnitude of the VAS and GMAX contribution increased and extended into mid stance (~0-60% stance), while the SOL contribution shifted earlier in the stance phase (~0-70% stance), which corresponded with a shift in SOL muscle activity (Fig. 2, [4]). These results indicate that the flight phase in running is produced by increased and prolonged VAS and GMAX and phase-advanced SOL contributions to the vertical GRF which provides the necessary vertical acceleration of the COM.

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