MUSCLE FORCE NOT WORK DEFINES MUSCLE CONTRIBUTIONS TO FORWARD PROGRESSION

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INTRODUCTION

The uniarticular, and not the biarticular, ankle plantar flexors were previously shown to contribute significantly to trunk forward progression from mid stance into pre-swing (late stance) (Neptune et al., 2001). However, other muscles (specific muscles not identified in that study) also contributed to forward progression both in early stance into single-leg support (beginning of stance) and in late stance. We hypothesized that these other muscles contribute to trunk forward progression by redistributing segmental energy by decelerating the leg and accelerating the trunk through active concentric, isometric and eccentric force generation. That is, it is force generation per se that is critical to segmental energy redistribution, irrespective of whether that muscle performs positive work, no work at all, or even negative work.

METHODS

To assess this hypothesis, a forward dynamical simulation that emulated observed walking kinematics and kinetics of young adult subjects was analyzed to quantify the muscle induced-energetics of the trunk and leg segments. Those muscles contributing to trunk progression (i.e., forward acceleration of the trunk) were identified. The musculoskeletal model and simulation were developed using SIMM/Dynamics Pipeline (MusculoGraphics, Inc.) and consisted of the trunk, right and left legs. Each leg consisted of the thigh, shank, foot and fifteen individual Hill-type musculotendon actuators. The trunk was allowed to translate and rotate in the sagittal plane, while the hip, knee and ankle joints were frictionless revolutes. The model's dynamical equations-of-motion were derived using SD/FAST (PTC, Inc.). The contact between the foot and the ground was modeled with discrete visco-elastic elements located on the bottom of the foot. The individual muscle excitation patterns were modeled as block patterns and an optimization framework systematically varied the muscle controls to replicate the experimental data.

RESULTS AND DISCUSSION

The uniarticular knee extensors (vasti, VAS) contributed to trunk progression in the beginning of stance by redistributing segmental energy between the legs and trunk (Fig. 1A). VAS decelerated the leg segments (Fig. 1A, dashed line is negative), causing them to lose energy, and accelerated the trunk forward (as well as upward) through its contribution to the hip intersegmental force (Fig. 1B), causing the trunk to gain energy (Fig. 1A, dotted line is positive). VAS provided this mechanism for the redistribution of energy from the leg to the trunk even though its activity was eccentric, isometric and then concentric (Fig. 1A, solid line is initially negative, momentarily zero, then positive). The concentric uniarticular hip extensors acted co-functional with VAS in early stance by also decelerating the leg and accelerating the trunk. The eccentric rectus femoris (RF) in late stance also redistributed segmental energy to accelerate the trunk forward by acting to accelerate the knee and hip into extension, made possible through dynamic coupling of the body segments. Other muscular contributions to trunk progression, besides from the previously identified plantar flexors, were negligible (e.g., RF in beginning of stance, biarticular hamstrings, hip flexors).

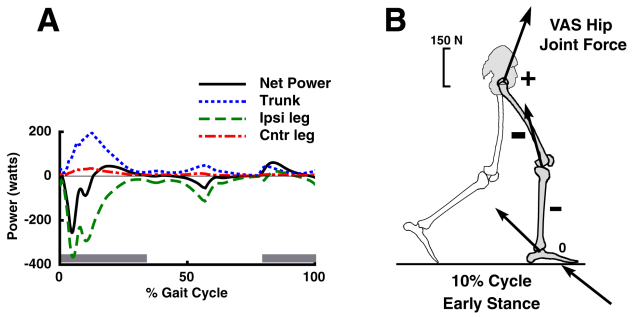

Figure 1: A) Musculotendon mechanical power output by VAS (*Net Power*) and the distribution of this power to the ipsilateral (*Ipsi leg*) and contralateral (*Cntr leg*) leg segments and trunk (*Trunk*) over the gait cycle. Solid horizontal bars indicate muscle excitation timing. B) Contribution by VAS in Early Stance (10% gait cycle) to the intersegmental joint forces and the trunk and leg segmental energetics. The summed hip intersegmental force from both hips accelerates the trunk segment's center-of-mass upwards and forward, causing the trunk to gain energy ("+"). The intersegmental joint forces by VAS decelerate forward motion of the thigh and shank causing them to lose energy ("-").

SUMMARY

The redistribution of segmental energy by the uniarticular hip and knee extensors in the beginning of stance and by RF in late stance contribute significantly to trunk forward progression to complement the late-stance contributions of the ankle plantar flexors. We conclude that muscle force generation is the determining factor in how individual muscles contribute to forward progression, rather than muscle work, since concentric, isometric and eccentric muscle action can all act to accelerate the trunk forward.

REFERENCES

Neptune, R.R. et al. (2001). *J Biomech* **33**:155-64.

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