Preflex-Mediated Energy Regulation Stabilizes Locomotion on Soft Ground

Brooke A. Christensen[1], Monica A. Daley[1,2]
[1]Neuromechanics Laboratory, Department of Ecology and Evolutionary Biology, University of California, Irvine, USA
[2]Center for Integrative Movement Sciences, University of California, Irvine, USA
Email: brookec1@uci.edu

Summary

Terrestrial locomotion requires precise energy regulation when navigating deformable substrates. Using a novel spring-loaded platform, we investigated how guinea fowl (*Numida meleagris*) regulate muscle-tendon dynamics during unexpected substrate energy loss. *In vivo* muscle recordings revealed that digital flexor muscles maintain force production by rapidly shifting from active stretch (absorbing energy) to near-isometric behavior within the 'preflex' window – before neural feedback occurs. This shift compensates for substrate energy dissipation while also demonstrating how distal limb multiarticular muscle architecture enables rapid mechanical adaptation through intrinsic mechanics, with implications for bio-inspired robotics and prosthetics.

Introduction

Soft substrates pose energetic and stability challenges due to mechanical energy dissipation. Running on sand, for example, increases energy cost in humans by 60% compared to firm ground [1]. Bipeds adjust leg stiffness and contact angle to compensate [2-4], but the mechanisms underlying stability during unexpected energy loss remain unclear.

Preflexes – intrinsic mechanical responses preceding neural feedback – aid stabilization [5,6] but vary depending on limb posture, loading, and activation state [7,8]. Here, we introduce a controlled perturbation system that removes stance-phase energy without altering initial contact dynamics (Figure 1). We hypothesize that reduced limb compression (Figure 2A) enables multiarticular digital flexor muscles to maintain force through isometric behavior, requiring minimal activation changes to compensate for substrate energy removal.

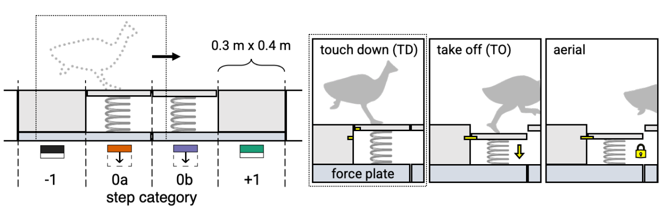

Figure 1: Schematic of runway and energy removal perturbation.

Methods

High-speed video and force plate data were collected from guinea fowl ($N = 10$) running across a runway with either rigid terrain or terrain with energy removal perturbations in the middle two steps (Figure 1). Muscle-tendon dynamics in the digital flexor muscle of digit III were recorded using sonomicrometry crystals (fascicle length), EMG electrodes (activation), and a force buckle transducer (tendon force).

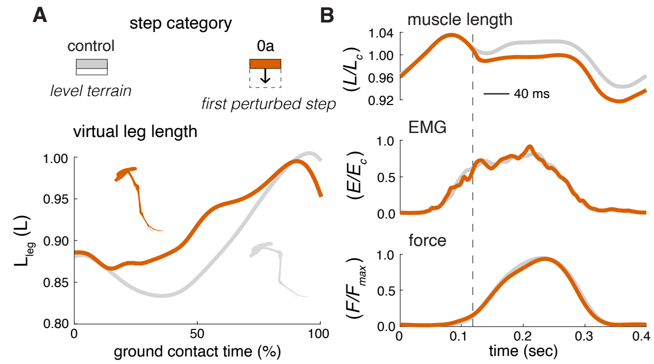

Figure 2: (A) Virtual leg length during stance and (B) digital flexor III muscle measurements across stride; dashed line: ground contact.

Results and Discussion

During the first 40 ms of stance in the initial perturbed step (0a), representing the reflex latency period [9], the digital flexor muscle absorbed less energy relative to control steps (P=0.004). Consistent with our hypothesis, force production remained unchanged (P=0.997) while undergoing reduced stretch velocity (P=0.013), facilitating a shift from energy absorption to near-isometric strut-like behavior (Figure 2B). Subsequent steps reveal a temporally-driven hierarchical control response, from immediate mechanical adaptation to longer-term strategic adjustments in muscle function.

Conclusions

Rather than relying on altered activation, the digital flexor muscle's multiarticular arrangement enables rapid energy regulation at the leg-substrate interface. Ongoing analysis aims to link this response cross-scale from muscle-tendon and limb mechanics to whole-body center of mass dynamics.

Acknowledgments

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