# HOW THE RECTUS FEMORIS MECHANICALLY "WORKS" DURING PERTURBED WALKING

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## Introduction

Major challenges to studying multi-scale (*i.e.*, COM, joint, muscle, etc.) contributions to stability are that 1) the explicit demand of a destabilizing perturbation is difficult to quantify and 2) there are few measures that can be directly compared across different scales. To address these challenges, we proposed an approach based in mechanical energetics that quantified the demand of a transient unilateral treadmill belt acceleration using mechanical work and related those changes between the whole leg and joint levels. [1] This framework leverages the fact that, on average, COM work over a level ground, steady state stride must be zero, so changes in work from steady state caused by a perturbation represent a destabilizing energetic demand. Using this approach, we previously found changes in contralateral knee work were most strongly related to contralateral leg work during the perturbed stride, suggesting proximal joints and muscles play a large role in compensating for transient energetic demands.

In this work we extended our paradigm to the muscle level by relating changes in rectus femoris (RF) muscle-tendon unit (MTU) and fascicle work with work at the joint and COM levels. The RF was a muscle of interest since it provides both hip flexion and knee extension to combat the hip extension and knee flexion induced by the treadmill belt acceleration. Based on our previous findings, we hypothesized that both RF MTU and fascicle work would be strongly related to changes in knee and COM work on the contralateral side during the perturbed stride.

## Methods

7 subjects (5M/2F, avg 25 y/o, 72.7 kg, 178.5 cm tall) walked on a split-belt treadmill and each experienced 40 transient unilateral belt accelerations. [1] Unilateral COM power was calculated as the dot product of ground reaction force and COM velocity. [2] Joint powers were calculated using OpenSim 4.0 inverse dynamics. RF fascicle force was estimated by combining EMG and B-mode ultrasound (Fig 1A). [3] RF MTU and fascicle power were calculated using OpenSim MTU and ultrasound-based fascicle velocities, respectively. Timeseries data (Fig 1 B,C) were averaged over trials and sides to merge EMG and fascicle lengths, resulting in 14 total data points (7 subjects x 2 onset timings). Linear regressions were calculated from mechanical work differences relative to the pre-perturbation stride.

## Results and Discussion

Of all contralateral lower limb joints, we found knee and hip work were the most highly correlated with COM work on the perturbed stride ($R^2$=0.72, ankle = 0.48, hip = 0.62), although unexpectedly hip work was negatively correlated with COM work. This trend drove the relationship between the RF MTU/ fascicle work and COM work – RF MTU and to a lesser extent fascicle work were positively correlated with hip work (Fig 1 D,G), but negatively correlated with knee work (Fig 1 E,H). Overall, RF MTU and fascicle work were negatively correlated with COM work (Fig 1 F,I).

These findings highlight that 1) the RF distributes the COM-level energetic demand of a perturbation between joints and 2) the RF MTU and fascicles are sources of dissipation during locomotion. [4]

## Significance

This work serves as the first estimate of muscle mechanical energetics based on in-vivo ultrasound and EMG during unstable walking. Further, it demonstrates the utility of our paradigm for investigating multi-scale responses to transient perturbations. Future work will investigate how exoskeletal assistance alters the role of proximal musculature in responding to perturbations.

## Acknowledgments

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## References

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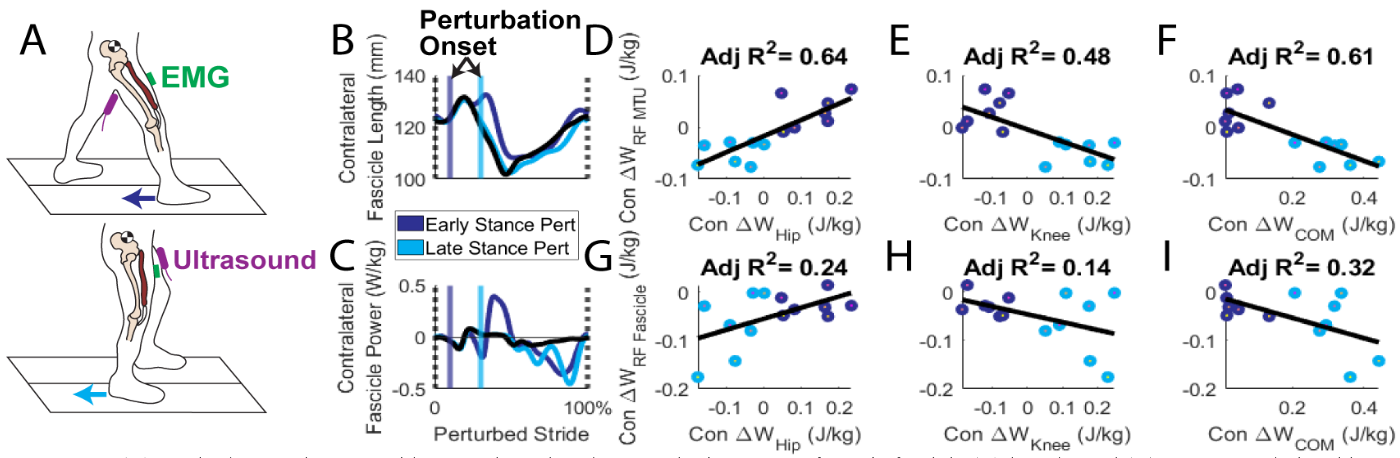


**Figure 1:** (**A**) Methods overview. For side contralateral to the perturbation, rectus femoris fascicle (**B**) lengths and (**C**) powers. Relationships between RF MTU and (**D**) hip, (**E**) knee, and (**F**) COM work. Relationships between RF fascicle and (**G**) hip, (**H**) knee, and (**I**) COM work.