Series elastic compliance protects actuators during high-powered deceleration

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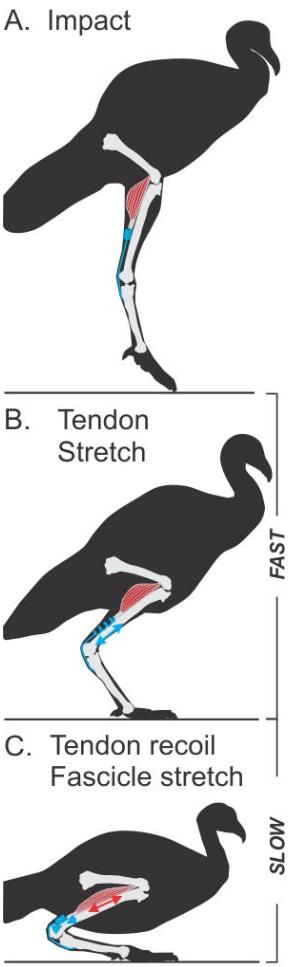
Muscles are the motors powering movement, but also the brakes that decelerate activities like downhill running and jump or drop landings. When operating as brakes, muscles lengthen actively to dissipate movement energy, leaving them susceptible to stretch injury. The elasticity of tendons that connect muscles with bones plays critical roles when muscles produce energy, but the mechanical interplay between muscle contraction and series elastic compliance during energy dissipation is poorly understood.

We tested the idea that tendon elasticity serves as a mechanical buffer, preventing high and potentially damaging negative velocities and powers during active muscle lengthening. We used wild turkey lateral gastrocnemius as it permits direct measurements of single muscle force and strain in rapid and high-powered energy dissipation during controlled landings. Strain of the muscle tendon unit was measured using video kinematics to isolate tendon strain from muscle strain measured using sonomicrometry.

Immediately following impact, tendon stored the energy of impact by stretching like a spring. Therefore, the rapid lengthening of the muscle-tendon unit involved little or no lengthening of the muscle. Later in the contact period, after most of the joint flexion, the muscle lengthened slowly against tendon recoil to dissipate the impact energy. Temporary storage of energy in tendon stretch meant a significant reduction in muscle fascicle lengthening velocity and rate of energy absorption.

Our results show that the spring-like action of tendon functions as a power attenuator. Power attenuation likely protects muscle against damage from rapid and forceful lengthening during energy dissipation. Moreover, the delayed and slowed transfer of energy from tendons to muscles likely limits the peak forces generated, protecting not only the muscle fascicles, but also surrounding connective tissues and bones from damage.

The use of series elastic compliance to protect actuator hardware may benefit several lines of bio-inspired design, including aiding robots in decelerating and stopping, and making prosthetics and orthoses tolerant of high-powered impact impulses.



During deceleration, the compliance of series elastic tendon protects the muscle actuator against damage. Energy is rapidly absorbed by spring-like stretch of the tendon. Muscle is pre-activated to stiffen in preparation for impact, and then lengthens to dissipate impact energy as it is released via elastic recoil of tendon.