Examining Changes to Proprioceptive Signals with Increased Muscle-Tendon Compliance In Situ

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Summary
A major challenge in neuromechanics, particularly relevant to human health, is linking muscle-tendon (MT) morphology to proprioception. In anesthetized rats, we recorded intra-axonal sensory signals from active MT contractions. To modify the functional morphology, we physically added in-series springs. We demonstrated that as compliance increases, the gain of a muscle spindle declines. Therefore, conditions that alter MT compliance, like exercise, pregnancy, disease or aging, may modulate movements informed by sensory feedback.

Introduction
Muscle-tendon (MT) compliance can be altered by pregnancy, exercise, aging or disease, but, we know little about how series compliance affects sensory signals. This is because the field of sensory physiology has focused on conditions where MT length and fascicle length are coupled (passive stretches) and has often ignored the influence of elastic tissues (tendons, aponeuroses) on muscle dynamics. During a contraction, the presence of series elastic elements allows active muscle fascicles to shorten against net MT length that is isometric or stretched [1].

Generally, we characterize sensory sensitivity as a function of firing rate (FR) plotted against muscle length where the slope is called gain (AFR/ΔLMT). With added compliance, we expect that the gain of length-related sensors (classically muscle spindles) will decrease and the threshold (LMT*) will increase in response to active MT stretching. Here, we only examine the gain component of sensitivity.

Methods
To create a mechanistic understanding of how MT morphology affects the sensory system, we combined in situ MT preparations with simultaneous intra-axonal recordings (Wistar rats, IACUC #: A18042).

We changed fixed end compliance (FEC, muscle fascicle strain in response to isometric MT contraction) by suturing surgical tubing to the MT.

Results and Discussion
In this repeated measures study, we found that acute changes in MT compliance decrease the muscle spindle gain. These data suggest changes in morphology can affect sensory feedback.

Conclusions
Despite the importance of musculoskeletal morphology, we know little about how it relates to sensory physiology. We demonstrated that as MT compliance increases, the sensitivity of this muscle spindle feedback declines. This indicates that, without compensatory changes in motor coordination, conditions where MT compliance tends to increase (ex. aging, pregnancy), attenuated spindle feedback may impair response to locomotor perturbations. We expect to apply this paradigm to directly compare young and old MTs and gather insight into how assistive technologies could modify morphology to mitigate sensory deficits due to increased compliance [3].

References

Figure 1: Medial gastrocnemius (MG) activated by stimulation of ventral root and instrumented with sonomicrometry crystals to measure muscle fascicle length. Firing rate of proprioceptors measured with intra-axonal microelectrode in the dorsal root and physiologically characterized as a muscle spindle or golgi tendon organ [2].

Figure 2A: We added compliance to change functional morphology of the MT. From top panel to bottom: MT Force (N), MT Length (mm), Muscle Fascicle Length (mm), Muscle Spindle Action Potential (V), Instantaneous Firing Rate (Hz). 2B: During active stretch, muscle spindle gain decreased with added compliance.