Timing of Muscle Activation for a 'Tuned' Muscle-Tendon Elastic Mechanism

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1 PURPOSE

To determine if muscle activation timing can be *'tuned'* to exploit elastic energy storage and return in a compliant muscle-tendon.

2 BACKGROUND

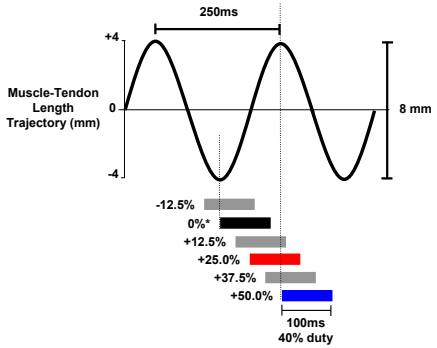
- Recent ultrasound data from human walking (Lichtwark et al., 2007) indicate that the ankle joint muscle-tendon system behaves like a **'catapult'**.
- The ankle **'elastic mechanism'** facilitates high mechanical power outputs with *very little* muscle work.
- Substantial elastic energy storage and return in Achilles' tendon leads to **ankle joint efficiency** during walking that is 3-5 times that of isolated muscle (Sawicki et al., 2008).

--> We hypothesized that there is an 'optimal tuning' of muscle activation onset timing that simultaneously:

1. ***Maximizes*** **muscle-tendon (MT) peak power output.**
2. ***Minimizes*** **muscle (CE) positive work.**

3 *IN VITRO* PROTOCOL

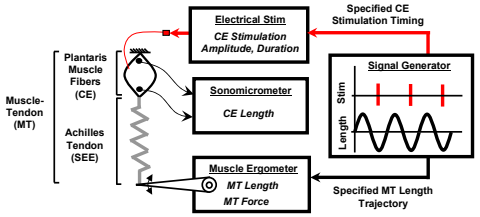
- We tested six adult bullfrog (*Rana catesbeiana*) plantaris-Achilles tendons *in vitro*.



- Muscle-tendon driven sinusoidally with amplitude **± 4 mm** and frequency **4 Hz**.
- Sciatic nerve stimulated supramaximally for 100 ms with onset at: **-12.5%, 0%*, +12.5%, +25%, +37.5% and +50%** of the muscle-tendon length change referenced to initial lengthening (**0%***).
- No stimulation (NS) was control condition.

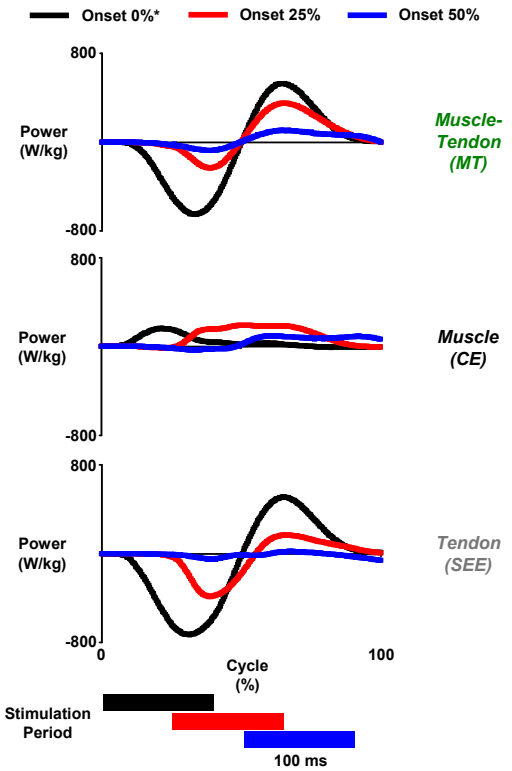
4 EXPERIMENTAL APPARATUS

- An **ergometer** measured muscle-tendon (MT) force and length and drove the prescribed sinusoidal muscle-tendon (MT) length change pattern.
- A **nerve-cuff** stimulated the muscle (CE) with controlled timing set relative to muscle-tendon length (MT) change.

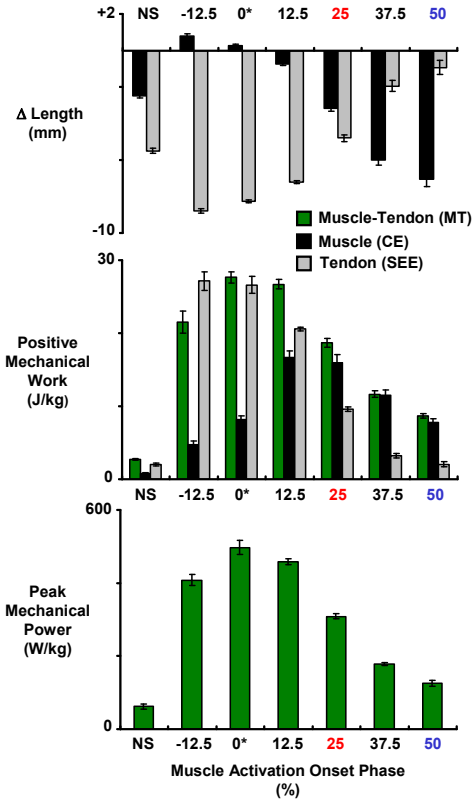


- **Sonomicrometry** crystals measured muscle fiber length changes, effectively **decoupling** muscle-tendon (MT), muscle (CE) and Achilles' tendon (SEE) length changes.

5 MECHANICAL POWER DATA



6 SUMMARY DATA



Muscle (CE) length change is *minimized* for muscle activation onset at 0%* phase (i.e. initial muscle-tendon lengthening).

Muscle (CE) performs *very little* positive mechanical work for muscle activation onset at 0%* phase.

Muscle-tendon (MT) peak positive mechanical power is *maximized* for muscle activation onset at 0%* phase.

7 CONCLUSIONS

1. ***Timing*** **of muscle activation is critical for exploiting the mechanical and energetic benefits of tendon elasticity.**
2. **With 'tuned' timing, high peak muscle-tendon (MT) power is achieved with very little muscle (CE) positive mechanical work.**
3. **In a *'tuned' muscle-tendon* (i.e. 0*% activation phase) the muscle (CE) delivers *only* ~30% of the muscle-tendon (MT) positive work over a cycle.**
4. **Applying these findings could improve the neuromechanical design of artificial muscle-tendon actuators for lower-limb powered prostheses and orthoses.**

8 ACKNOWLEDGMENTS

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