Effects of Stretch velocity and Preactivation on Muscle Performance during stretch-shortening cycle –A Simulation Study

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SUMMARY
The purpose of the study was to use a Hill-type muscle-tendon complex model (MTC) to examine the effects of stretch velocity and preactivation on muscle performance during stretch-shortening cycle (SSC). Active state in each condition was stabilized at a certain preactivation level before release: 0, 10, 20, 30, 40, 50 and 60% of the maximum possible activation level. MTC was released and a mass with a downward velocity from 0 to 1.5 m/s landed on the supporting object. At the same time, the stimulation linearly raised at 220% /s until 90% of the maximum possible stimulation level. Results showed that both preactivation and stretch velocity can affect MTC mechanical output. Increasing preactivation level from 0 to 10% or 20% with stretching velocity at 0.5 m/s, the simulated jump height increased 53% and 64%, respectively. Increasing stretch velocity could not increase jump height until preactivation level is greater than 30%. We conclude that increasing preactivation could increase muscle performance regardless stretch velocity, however high stretch velocity must be accompanied with high preactivation in order to maximize muscle performance.

INTRODUCTION
During stretch-shortening cycle, greater stretch velocity may increase the amount of the storage of elastic energy (Cavagna et al., 1968). However, an in vivo study (Fukashiro et al., 2006) using ultrasonography suggested that performance enhancement results from the minimized lengthening in muscle fascicles which facilitate storage and recoil of elastic energy in the series elastic element (SEE). Preactivation of the muscles were observed in the study, and the authors argued that this preactivation made it possible to maintain the length of contractile element (CE) during countermovement. However, it remains a question how the different stretch velocities and preactivation levels affect the length change in muscle fascicles and then regulate contribution of elastic energy during SSC since unsynergetic activation could decrease the mechanical output of the muscle tendon complex (Arakawa et al., 2010). The purpose of this study was to investigate the effects of stretch velocity and preactivation on muscle mechanical output during drop jump using computer simulation.

METHODS
A Hill-type three component muscle-tendon complex model (MTC) with a fixed proximal end of CE (Nagano et al., 2004) (Fig. 1) was used for this study. A weightless supporting object, kept at the same position until the release time, was affixed to the distal end of SEE. A 70 kg weight with a downward velocity landed on the supporting object at the release time. The downward motion and lifting of this mass through the SSC of the MTC corresponds to jump.

The magnitude of CE force produced depends on stimulation-activation (SA), force-activation (FA), force-velocity (FV), and force-length (FL) relations. SEE behavior was characterized by an undamped and non-linear force-extension relationship. CE was activated at one certain level before release. Through this process, CE would be shortened and SEE would be stretched. When CE length was below optimal length, parallel elastic element (PEE) did not produce any force. CE and SEE forces were equal. After the system reached its equilibrium, t = release, the supporting object was released and the stimulation linearly rose at 220%/s (Bobbert and Casius, 2005) until reaching the certain level 0 (no preactivation occurs), 10, 20, 30, 40, 50 and 60%. Before release, active state in each condition was stabilized at the certain preactivation level. When t = release, the MTC was released and the mass with a downward velocity landed on the supporting object. At the same time, stimulation rose again at 220%/s until 90% maximum possible stimulation level. Some low preactivation levels may not reach 90% since stimulation only lasts 0.8s.

During sprinting, the maximum muscle stretch velocity can reach close to 1.5 m/s (Komi, 2000). Therefore, we set the downward velocity of the mass from 0 to 1.5 m/s with 0.1 m/s increment. These velocities represent the initial MTC stretch velocities.

Figure 1. Three components Hill-type muscle tendon complex: contractile (CE) series elastic (SEE) and parallel elastic elements (PEE). (Adapted from Nagano et al., 2004.)
RESULTS AND DISCUSSION
As shown in Figure 2, increasing preactivation level, especially for lower levels (0-20%), dramatically enhanced muscle performance, as evaluated by jump height, for all tested stretch velocities. For example, the jump height increased 53 and 64% respectively when the preactivation level increased from 0 to 10 and 20% with stretching velocity at 0.5 m/s. Based on our previous observation, we chose realistic preactivation levels starting from 0 with an increments of 10% up to 60% since the preactivation of 0% is realistic even in jumping-like movements (Ruan and Li, 2010). Stretch velocity enhanced muscle performance only with moderate to high preactivation levels. With 0 or 10% preactivation level, increasing stretch velocity reduced muscle performance, which is in agreement with our previous study (Ruan and Li, 2008).

“On” and “off” control (100 and 0%) stimulation has been used to represent stimulation dynamics (Nagano et al., 2004), but it is not suitable for studying preactivation. Normalized surface EMG has also been used to represent stimulation dynamics, where EMG has been argued as an output signal of the muscle rather than the stimulation input. A constant rate of 220%/s was used in a countermovement jump study (Bobbert and Casius, 2005). We chose the constant rate of stimulation development as a suitable model to investigate the effect of preactivation and stretch velocity since it does not favor any experiment condition, although it may be different from the actual stimulation dynamics.

![Figure 2: Jump by the mass dring simulation, with 0 – 60% of pre-activation levels.](image)

Preactivation is important for fast movements like sprinting and jumping, with total contact time about 90-100 ms (Komi, 2000) and less than 50ms braking phase. Fast movements are generally coupled with a very high stretch velocity. An in vivo study showed that the maximum stretch velocity of Achilles tendon-triceps surae complex at a high running speed (9.02 m/s) could reach 1.3 m/s (Komi, 2000). Because of time constraint, stimulation development during ground contact is very limited and the active state level will be exclusively dependent on the preactivation level. A study on human experiments (Kakihana and Suzuki, 2001) has reported that muscles were highly preactivated before landing during sprinting and long jump. Combining these findings and our results (Figure 2, failure observed at 0 and 10% pre-activation with high stretch velocities), it is concluded that preactivation of moderate to high level is a prerequisite for those SSCs with high stretch velocities and time constraint. In other words, for explosive movements like sprinting, long jump, high jump and triple jump, low preactivation can lead to movement failure.

CONCLUSIONS
Both preactivation and stretch velocity can affect MTC mechanical output. For 0 to 20% preactivation levels, increasing preactivation level alone can significantly increase the jump height for all stretch velocities we tested, but increasing stretch velocity may decrease the jump height. For preactivation levels greater than 30%, mechanical output may not increase significantly with increased preactivation level alone. On the contrary, increasing stretch velocity from 0 to 1.5 m/s, jump height increased 11.7, 15.4, 11.9 and 8.5%, with 30, 40, 50 and 60% preactivation, respectively. Therefore, to maximize muscle performance, fast stretch velocity must be accompanied by high level of preactivation.

REFERENCES