The contribution of residual force enhancement to the stretch-shortening cycle effect

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Summary

During locomotion, muscle-tendon units (MTUs) often actively stretch before they shorten. This length-change pattern is referred to as a stretch-shortening cycle (SSC). During SSCs, a MTU's force capacity is increased during shortening, which is known as the SSC effect. We investigated the contribution of residual force enhancement (rFE) to the SSC effect. For our experimental conditions, the mechanisms underpinning rFE made up more than 50% of the SSC effect.

Introduction

The SSC is a basic MTU pattern during locomotion. During SSCs, force, work and power outputs during the shortening phase are enhanced compared with a shortening contraction without preceding muscle stretch, and the relative enhancement is referred to as the SSC effect. The SSC effect is based on various mechanisms, including those underpinning rFE [1]. A recent study [2] further showed that the transient and long-lasting force enhancement effects triggered by active muscle stretch (i.e. eccentric contraction) contribute approximately one third to the SSC effect. Therefore, we aimed to gain further insight into the contribution of long-lasting rFE to the SSC effect.

Methods

Twenty-one participants (9 women, 12 men; age: 24±2 yrs., height: 177±12 cm, mass 72±14 kg) were tested on one day. For testing, participants laid prone on the bench of a dynamometer (IsoMed2000, Ferstl GmbH, GER) with their right foot tightly strapped onto a footplate attachment to avoid heel lift during contractions. The rotation axis of the dynamometer was aligned with the ankle's axis of rotation (approximated by the lateral malleolus) via a laser pointer and the thighs and pelvis were fixed to the dynamometer bench with straps to minimize accessory movements. During testing, participants performed seven contraction conditions, including two fixed-end reference (REF) conditions at 15° dorsiflexion (DF) and 10° plantar flexion (PF; 0° defined as the shank perpendicular to the foot sole), and dynamic conditions including one stretch condition, two SSC conditions, and two shortening (SHO) conditions. To better investigate the rFE contribution to the SSC effect, one SSC condition was delayed such that shortening occurred 3 s after stretch and one SHO condition was time matched to this condition. All dynamic contractions were performed over a 25° range of motion between 15° DF and 10° PF, with MTU stretch and shortening angular velocities of 40°/s and 120°/s, respectively. Submaximal tetanic contractions at 30% of maximum voluntary torque at the final ankle angle of each contraction condition were elicited by electrical stimulations (1-ms square-wave pulses). Electrical stimulations were delivered for 12-s at 50 Hz over the triceps surae muscle bellies using a constant-current stimulator (Digitimer DS7AH, UK) controlled by Spike2 software (v8.02, CED, Cambridge, UK). Resultant ankle joint torque and crank arm angle were sampled at 2000 Hz using a 16-bit A/D card within a Power 1401 data acquisition interface in combination with Spike2 software (CED). rFE was calculated as the percent difference between the mean torque 2.5-3 s following the end of stretch and the time-matched mean torque of the REF at 15° DF. The SSC effect for immediate and delayed shortening was determined as the percent difference in mean torque during the shortening of the SSC conditions compared with the mean torque during the respective SHO conditions. To verify whether rFE, SSC effects, and mean torques during shortening were significant, we performed paired t-tests and a two-way repeated-measures ANOVA with Sidak-Holm post-hoc tests, respectively.

Results and Discussion

We found significant rFE of 8.9±13.0% ($p=0.006$) following stretch contractions. We also found a significant condition (SSC vs. SHO) × time (immediate vs. delayed shortening) interaction ($p<0.020$) for mean torques during shortening. Although mean torques during SHO conditions were similar (difference=0.3 Nm; $p=0.713$), we found significantly different SSC effects ($p=0.008$) for immediate and delayed shortening of 23±15% and 13±16% ($p<0.001$ and $p=0.002$), respectively.

Conclusions

By assuming that no stretch-induced transient forces contribute to the SSC effect during delayed SSC shortening, we conclude that under our experimental conditions, the mechanisms underpinning rFE contribute more than 50% to the overall SSC effect. As rFE was recently directly linked to elevated titin-based forces [3], this viscoelastic element presumably has a strong contribution to the SSC effect.

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References

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