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RESIDUAL FORCE ENHANCEMENT OF THE KNEE EXTENSORS IN OLDER ADULTS IS NOT RELATED TO ALTERATIONS IN MUSCLE ARCHITECTURE

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SUMMARY

Young and old adults experienced a similar level of residual force enhancement (RFE) following a conditioning stretch of the knee extensors. There was greater RFE, and greater passive force enhancement (PFE) at long vs. short muscle lengths in both groups. Fascicle length and pennation angle changes of the vastus lateralis following stretch did not contribute to RFE in either group. The stretch amplitude may not have been large enough to engage sufficient passive force transmitting elements which has been shown previously to contribute to greater RFE in older adults.

INTRODUCTION

Isometric torque is greater following a conditioning stretch than an isometric contraction without a prior stretch at the same length. This feature is termed residual force enhancement (RFE) and is suggested to be due to a combination of active and passive components of the musculotendinous unit. Also, RFE is more pronounced when stretch is applied at long versus short muscle lengths (i.e., descending limb of the force-length (F-L) relationship) due to a greater contribution of passive force enhancement (PFE) [1].

In young adults, stretch induced changes in fascicle length and pennation angle of the knee extensors and ankle dorsiflexors does not contribute to RFE [2,3]. Recently, older adults were shown to have greater RFE of the ankle dorsiflexors than young [4], although the mechanisms are unknown. With adult aging, muscle fascicles become shorter and less pennated and these architectural changes have been shown to contribute up to 40% of age-related force loss [5]. Thus, if older adults perform an active stretch prior to an isometric contraction this may temporally ameliorate some of the ‘negative’ age-related changes in muscle architecture, thus improving force production in the older adult. Furthermore, muscles of older adults with shorter fascicles may fall further along the descending limb of the F-L relationship than young. Therefore, older adults could potentially benefit from greater stretch amplitude effectively increasing RFE on the descending limb (long muscle length) of the F-L relationship, owing mainly to a greater contribution of passive components.

Accordingly, the purpose of this study was to investigate RFE and changes in muscle architecture of the knee extensors in young and old men at short and long muscle lengths which presumably fall on the ascending (short muscle length) and descending limbs (long muscle length) of the F-L relationship [6,7]. It was hypothesized that due to the age-related increase in RFE [4], older adults will exhibit greater RFE compared with young particularly at long muscle lengths owing to a greater contribution of PFE. Finally, due to age-related changes in muscle architecture which contribute to force loss, when tested during the steady state phase following the conditioning stretch, older adults may benefit from a more optimal fascicle length and pennation angle reorganization, which could contribute to enhanced force production compared to the reference isometric condition.

METHODS

Isometric neuromuscular properties (voluntary & electrically evoked) were assessed at 100^o of knee extension (180^o straight leg) on a CYBEX dynamometer. Brief (10s) maximal voluntary isometric contractions (MVC) in 11 young (25.7±2.6y) and 11 old (76.8±5.7y) men were performed as reference, and then again following an active stretch (eccentric loading) of 30^o/s over a 60^o joint excursion either from 180-120^o; ascending, or from 140-80^o; descending limb. Torque recordings of the pre- and post stretch MVCs were compared.

Electromyography (EMG) was collected using self-adhering Ag-AgCl surface electrodes (1.5 X 1cm; Kendall, Mansfield, MA). Prior to electrode placement, the skin was cleaned aggressively with pre-soaked alcohol swabs. A bipolar electrode configuration was used with the active and reference electrodes positioned 1cm apart over the muscle belly of the vastus lateralis (VL) and a ground electrode was placed over the patella. The EMG for the VL muscle was recorded during the reference MVC and was expressed as a root mean square (RMS) value over each 1s epoch. Following stretch, EMG was analyzed over each of the 6 1s epochs. All subsequent RMS values of EMG of voluntary contractions were normalized to the EMG RMS values for MVCs obtained during baseline.

Ultrasound images were collected in a sub-set of 5 young (26y) and 5 old (77y) via a linear array probe (GE model M12L, 4.9 mm, 5-13 MHz), using a Vivid 7 system (GE Healthcare, Mississauga, Ontario, Canada). Images were collected at rest, during the reference MVC, and during the isometric steady-state following stretch at both short and long muscle length conditions. The probe was placed over the VL at approximately 50% of the length of the femur between the lateral epicondyle and the greater trochanter. Once a suitable placement was determined, the location was marked on the subject's skin using indelible ink. The probe was held firmly in place by one operator for all tests.

Residual force enhancement was calculated by determining the mean torque value over 1s epochs during the reference MVC, divided into the mean torque value for 1s during the steady state of the MVC following the end of stretch corresponding to the same time point and muscle length as the reference MVC (Figure 1.) Force enhancement was analyzed for 6 1s time epochs following stretch and during the reference MVC. Residual force enhancement was defined as the percent increase in isometric torque following stretch, relative to the reference MVC.

A 2 way analysis of variance (Age x Muscle length) was performed to assess neuromuscular function of the young and old adults. The level of significance was set at $P<0.05$. A linear regression analysis (R^2) was performed to evaluate the relationship and shared variance between muscle architecture and RFE.

RESULTS AND DISCUSSION

At rest the old had ~18% shorter and ~22% less pennated fascicles than young. The old were ~37% weaker for MVC despite similarly high (>95%) voluntary activation (Table 1), ~27% weaker for eccentric strength (ECC), resulting in ECC:MVC ratios being ~17% greater in old. Percent RFE for young (Y) and old (O) at short and long muscle lengths was **Y**:5-13%; **O**:4-10% and, **Y**:9-20%; **O**:7-18%, respectively (Figure 1A,B). Passive force enhancement was greater at long (1.1-1.4N·m) vs. short (0-0.3N·m) muscle lengths, with a trend for greater PFE in old at long lengths. The RMS EMG level was similar in both young and old during the steady-state MVC compared to reference MVC at both short and long muscle lengths (Figure 1C,D).

Fascicle length and pennation angle were not different between the reference and isometric steady state following stretch for either group. There was little to no relationship or shared variance between the relative change in fascicle length or pennation angle and RFE (R^2=0.07-0.49, P>0.05; Figure 1E).

In a system with compromised isometric force production but well-maintained force during stretch (i.e., age-related maintenance of eccentric strength) force enhancement in old was comparable to a 'normal' functioning system of a young adult at short and long muscle lengths. In this particular model, PFE was similar in young and old at long muscle lengths, while PFE was lower in old than young at short muscle lengths. Perhaps the stretch amplitude was not as great in this paradigm as other models such as the ankle dorsiflexors, in which old experienced greater RFE and PFE compared to young. Thus, the greater RFE previously observed in older adults [4] may be more related to passive force transmitting elements rather than the maintenance of eccentric strength.

Impaired isometric force production in the older adult has been attributed to a reduction in the number of viable cross-bridges and average force produced per motor [8]; if this is true, the weakened system would benefit greatly during stretch via increased cross-bridge attachment and average force per cross-bridge. These findings are in line with the cross-bridge action theory [1] of residual force enhancement. Another possibility is that older adults with shorter fascicles [5] could have fallen on a different portion of the length-tension curve than young. In the present study, older adults did not benefit from greater stretch amplitude or alterations in muscle architecture. The aged musculotendinous system may require greater stretch amplitude to engage passive force transmitting elements for elevated RFE.

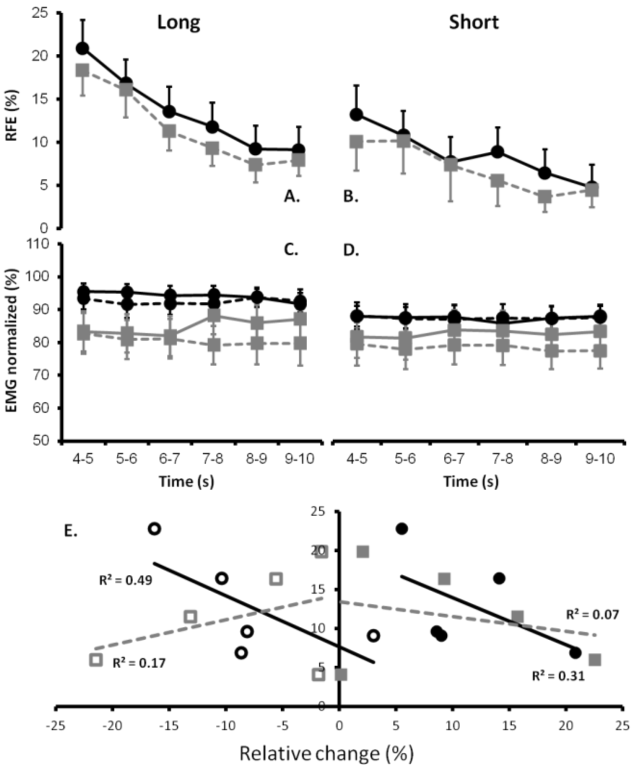

Figure1. RFE at long muscle lengths (A). RFE at short muscle lengths (B). EMG at long muscle lengths (C). EMG at short muscle lengths (D). Relationship between muscle architecture and RFE (E). **Young**; solid black line and circles, **Old**; dashed grey line and squares. **PA** is open symbol, **FL** is closed symbol.

CONCLUSIONS

Passive force enhancement contributed 13% and 4% to RFE at long muscle lengths in old and young, and 2% and 0.5% to RFE at short muscle lengths in old and young. Although both groups experience similar relative RFE the contribution of PFE was greater in older adults. Thus, while the exact mechanisms are not known, stretch appeared to attenuate the detrimental effects of aging on subsequent force production which was unrelated to changes in muscle architecture.

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Table 1. Neuromuscular Properties

	Voluntary Contractile Properties							
Group (n=11)	Isometric Strength (N·m)	Eccentric Strength (N·m)	Ecc:Iso (%)	Opt. Ecc (deg)	PFE Short (N·m)	PFE Long (N·m)	RFE Long (N·m)	RFE Short (N·m)
Young	276.1±61.5*	323.2±79.6*	1.11±0.16*	93.9±3.2*	0.33±0.38*	1.05±0.60	~18-41*	~10-24
Old	174.8±34.1	234.9±42.4	1.30±0.13	97.3±4.5	0.04±0.12	1.38±0.56	~10-20	~8-14