The Influence of Age on the Viscoelastic Stretch Response

Eric J. Sobolewski,[1] Eric D. Ryan,[1] Brennan J. Thompson,[2] Malachy P. McHugh,[3] and Eric C. Conchola[4]

[1]Neuromuscular Research Laboratory, Department of Exercise and Sport Science, University of North Carolina, Chapel Hill, North Carolina; [2]Human Performance Laboratory, Department of Health, Exercise, and Sport Sciences, Texas Tech University, Lubbock, Texas; [3]Nicholas Institute of Sports Medicine and Athletic Trauma, Lenox Hill Hospital, New York, New York; and [4]Applied Musculoskeletal and Human Physiology Laboratory, Department of Health and Human Performance, Oklahoma State University, Stillwater, Oklahoma

Abstract

Sobolewski, EJ, Ryan, ED, Thompson, BJ, McHugh, MP, and Conchola, EC. The influence of age on the viscoelastic stretch response. *J Strength Cond Res* 28(4): 1106–1112, 2014—Passive stretching is commonly recommended to help reduce passive stiffness in older adults, yet their acute viscoelastic stretch responses are still unclear. The purpose of this study was to determine the influence of age on the acute viscoelastic responses to a practical stretching intervention. Twenty-two younger (24 ± 3 years) and 14 older (67 ± 3 years) males performed four 30-second passive stretches of the plantar flexors at a predetermined torque threshold. The absolute and relative change in stress relaxation (decline in torque during each 30-second stretch) and creep (increase in ankle joint angle across the 4 stretches) were recorded. Passive stiffness was calculated as the slope of the angle-torque curve at 10° angle of dorsiflexion. There were no differences for the absolute stress relaxation responses ($p \geq 0.118$); however, the relative change in stress relaxation was greater ($p = 0.010$) for the younger vs. older men at stretch 1 (13.0 vs. 8.6%) and decreased across stretches for the younger men (stretch 1 > 3 and 4; $p \leq 0.018$), whereas the older men demonstrated a similar relative change across all 4 stretches ($p = 0.917$). No age related differences were found for either the absolute or relative creep responses ($p \geq 0.072$). Passive stiffness was also greater in the older men ($p = 0.044$). These results suggest that the younger men displayed a greater initial relative stress relaxation response that diminished across the repeated stretches, whereas the older men experienced a smaller relative response that remained constant across the four 30-second stretches. However, the increase in range of motion for a given stretch torque (creep) across all 4 stretches was similar between groups despite differences in passive stiffness.

Key Words plantar flexors, stretching, creep, stiffness, stress relaxation, range of motion

Introduction

Skeletal muscle is considered to be both elastic and viscous in nature, and when passively stretched, it exhibits time-dependent viscoelastic properties. For example, there is a decline in the resistance or force (stress relaxation) when skeletal muscle is stretched to a constant length or an increase in the length (creep) when stretched at a constant force. These properties have been examined previously in both animal (35) and human (21,30) models. Stress relaxation is more commonly examined in the literature as many previous authors have evaluated these responses during a single stretch (7,18,21) and across repeated stretches (17,19,39) in both the hamstrings and plantar flexor muscles. An in vivo examination of creep has also recently been observed in the plantar flexors during a single stretch (30), across multiple stretches (29), and indirectly measured through changes in range of motion from stretch to stretch (33).

Stretching is a common intervention used to improve maximum range of motion and decrease passive stiffness in older populations. Previous studies have demonstrated improvements in mobility tasks such as the timed up-and-go test and 10-m walk times (10) after chronic stretching routines. Although there are many studies and/or recommendations (3,38) for older adults to participate in stretching interventions, the acute viscoelastic responses of commonly used stretching routines in older populations are still unclear.

Previous studies have indicated that aging is associated with an increase in passive stiffness (4,8,9) which has been attributed to an increase in collagen content (1), glycolytic (12) and collagen (11) cross-linking, and a greater proportion of stiffer slow-twitch muscle fibers (2,16). It is possible that the mechanisms that contribute to the age-related increases

Address correspondence to Eric D. Ryan, edryan@email.unc.edu.

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in passive stiffness may also influence viscoelastic creep and stress relaxation. We are aware of only 1 study by Gajdosik et al. (6) who examined the stress relaxation response in older women, but did not compare these responses with younger healthy men and women. A recent study by Sobloewski et al. (33) found that when younger healthy men were ranked by passive stiffness and dichotomized into high and low groups, the group with the greatest passive stiffness values exhibited a smaller creep response over 4 consecutive 30-second stretches when compared with the less stiff group. Thus, based on these findings, it is possible that older adults may also have an altered stress relaxation and/or creep response when compared with younger adults because of their greater passive stiffness. Therefore, the purpose of this study was to determine the influence of age on the acute viscoelastic responses to a practical stretching intervention.

Methods

Experimental Approach to the Problem

This study was designed to evaluate the differences in viscoelastic stretch responses between younger and older men. All participants visited the laboratory on 2 occasions (familiarization and experimental trial) separated by 2–7 days. During the familiarization trial, each participant practiced the 30-second stretches and determined their maximal tolerable passive torque threshold or the passive torque they will maintain the stretch at (i.e., stretch intensity). The maximum tolerable torque threshold was determined during a series of passive stretches with the dynamometer programmed in passive mode similar to the procedures used by Ryan et al. (30). The torque threshold was progressively increased to the point of discomfort, but not pain, as verbally acknowledged by the participant. This predetermined torque threshold was used during each experimental trial. During the experimental trial, each participant performed a passive stiffness assessment and a maximal voluntary contraction (MVC) before four 30-second constant-angle stretches of the plantar flexors with a 30-second rest period between stretches and a 5-minute rest between assessments.

Subjects

Twenty-two younger (mean ± *SD*: age, 24 ± 3 years; stature: 177 ± 4 cm; mass: 87 ± 12 kg) and 14 older males (age, 67 ± 3 years; stature: 175 ± 6 cm; mass: 84 ± 7 kg) volunteered for this investigation. None of the participants reported any current or ongoing neuromuscular diseases or musculoskeletal injuries specific to the ankle joint. This study was approved by the University Institutional Review Board, and all participants completed a written informed consent form and a pre-exercise testing health history questionnaire.

Procedures

Each participant was seated with restraining straps over the pelvis, trunk, and thigh on a calibrated Biodex System 4 isokinetic dynamometer (Biodex Medical Systems Inc., Shirley NY, USA). Each participants' leg was at full extension (leg flexion angle of 0°), and the lateral malleolus was aligned with the input axis of the dynamometer. The foot was secured to a foot plate through a thick rubber heel cup and straps over the toes and metatarsals (distal to the malleoli so that they did not impede any passive foot movement). The foot started at 20° of plantar flexion (0° = neutral or 90° between the foot and leg) and was then passively dorsiflexed at a constant velocity of $5° \cdot s^{-1}$ until the predetermined threshold was met. When the torque threshold was reached, the dynamometer was immediately stopped to ensure the ankle remained at this angle of dorsiflexion (constant position) for the entire 30-second stretch (Figure 1).

After the 30-second stretch, the foot was released back to 20° of plantar flexion for a 30-second rest period and repeated for the remaining stretches. All participants were

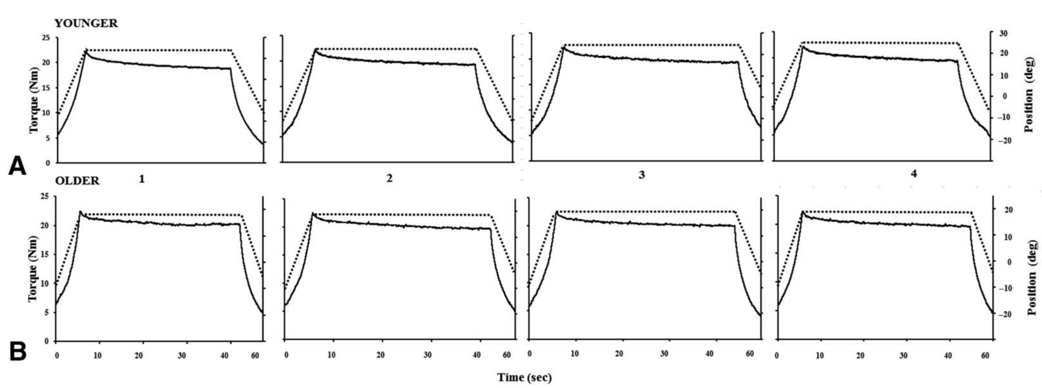

Figure 1. An example of the raw position and torque responses for a younger (A) and older (B) participant during the four 30-second constant angle stretches. The position (secondary *y*-axis) is represented as a dotted line and remains constant over the 30-second stretch, whereas torque (primary *y*-axis) is represented by the solid line that diminishes over the same period.

instructed to remain as quiet and relaxed as possible during all 4 stretches. During each 30-second stretch, torque (Nm) values were examined at the beginning and end of the stretch with a 500-ms epoch using a custom-written software (LabVIEW version 8.5, National Instruments, Austin, TX, USA). To ensure all stretches were passive, preamplified active surface electrodes (EL254S, Biopac Systems, Santa Barbara, CA, USA; gain = 350) were placed over the medial gastrocnemius (MG) and soleus (SOL) muscles (13). Electromyographic (EMG) amplitude values were calculated with a root mean squared function at 0, 15, and 30 seconds with the same 500-ms epoch, and then normalized to maximum voluntary contraction (MVC) EMG amplitude values similar to those reported by Gajdosik et al. (6).

Stress Relaxation

The torque responses during the 30-second stretch were used to examine stress relaxation. The absolute change in torque was determined from the difference between the initial and final torque values (39). The relative change in torque was also examined using the following formula described by McHugh et al. (21)

$$\text{Relative change in torque} = \left(\left(\text{torque at 30s} - \text{torque at 0 s}\right) / \left(\text{torque at 0 s}\right)\right) \times 100$$

Creep

Creep was indirectly measured from the position changes seen during the subsequent stretches similar to the procedures used by Sobolewski et al. (33) and Taylor et al. (35). Given the torque threshold did not change between stretches, any increase in the ankle dorsiflexion would demonstrate properties of creep. The absolute change was the change in position from the first stretch to the last stretch. Relative change was examined similar to stress relaxation with the difference in position between the first and last stretch.

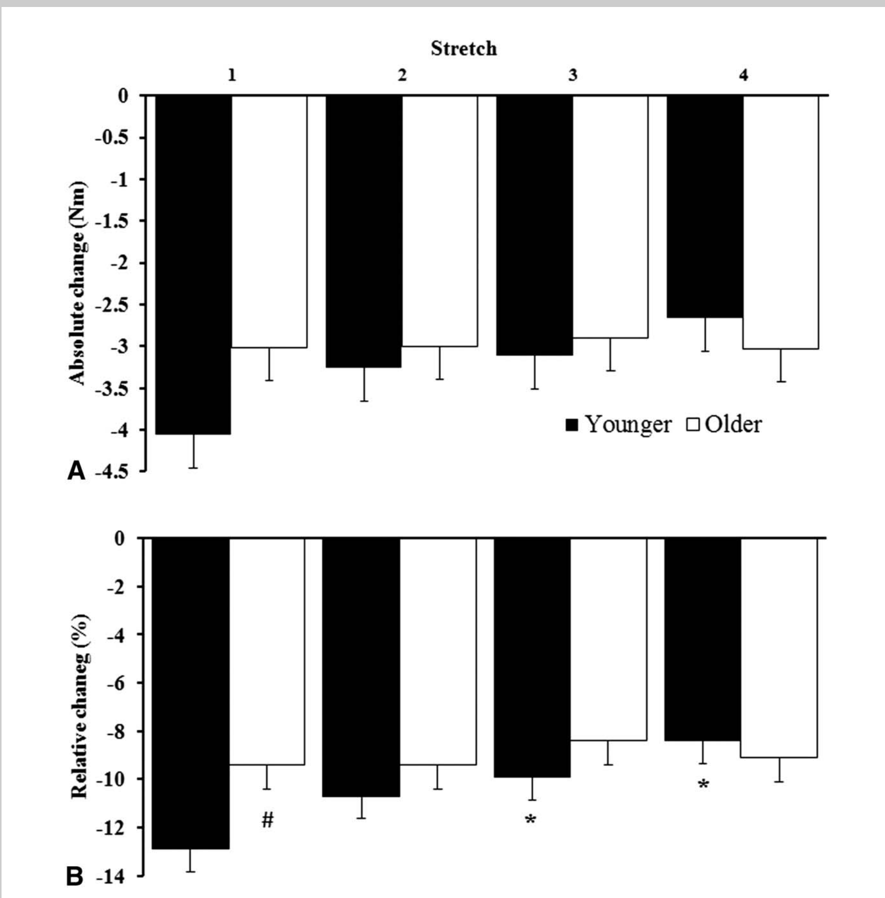

Figure 2. The absolute decrease in torque (A) and the relative decrease in torque (B) values for the younger and older groups across all four stretches. * indicates that stretch 1 had a greater relative change in torque than stretches 3 and 4 ($p \leq 0.05$) for the younger group only. # indicates that the younger group had a greater relative decrease for stretch 1 than the older group. Values are mean ± *SE*.

Passive Stiffness

To determine passive stiffness, the dynamometer lever arm passively dorsiflexed the ankle at 5° angle·s^{-1} starting at 20° angle of plantar flexion to the participants' maximally tolerated range of motion (20) where the dynamometer was manually stopped by the investigator and immediately returned to the starting position. The angle-torque curve was gravity-corrected for the weight of the foot plate and fit with a fourth-order polynomial function (25,28). Passive stiffness values were calculated as the slope of the angle-torque curve at 10° angle of dorsiflexion using a 200 ms epoch. All passive stiffness values were normalized to corrected calf-girth measurements per the recommendation of Ryan et al. (31).

Corrected Calf Girth

During the familiarization trial, each participant's calf girth was measured using a standard Gulick anthropometric tape measure (AliMed, Dedham, MA, USA) and a Lange skinfold caliper (Santa Cruz, CA, USA). With the subject seated, calf

Table 1. Mean (*SD*) for absolute and relative stress relaxation.*

	Absolute (Nm)			Relative (%)		
	Younger	Older	ES	Younger	Older	ES
Stretch 1	−4.1 (2.2)	−3.0 (2.1)	0.46	−12.9 (4.9)	−9.4 (4.8)†	0.67
95% CI	−4.9 to −3.3	−4.1 to −1.9		−14.9 to −10.9	−11.9 to −6.9	
Stretch 2	−3.3 (2.3)	−3.0 (2.3)	0.13	−10.7 (5.5)	−9.4 (5.5)	0.24
95% CI	−4.2 to −2.4	−4.2 to −1.8		−13.0 to −8.4	−12.3 to −6.5	
Stretch 3	−3.1 (1.9)	−2.9 (1.9)	0.11	−9.9 (4.0)‡	−8.4 (4.0)	0.38
95 % CI	−3.9 to −2.3	−3.9 to −1.9		−11.6 to −8.2	−10.5 to −6.3	
Stretch 4	−2.6 (1.7)	−3.0 (1.6)	0.17	−8.4 (3.5)‡	−9.1 (3.5)	0.21
95% CI	−3.4 to −1.8	−3.9 to −2.1		−9.9 to −6.9	−11.0 to −7.2	

*ES = effect size; CI = confidence interval.
†Significant difference between younger and older men.
‡Significant difference from stretch 1.

circumference was recorded at the maximum girth of the calf muscle (34). A vertical skinfold on the medial aspect of the gastrocnemius was measured at the same location and corrected calf girth was calculated from the formula described by Stewart et al. (34).

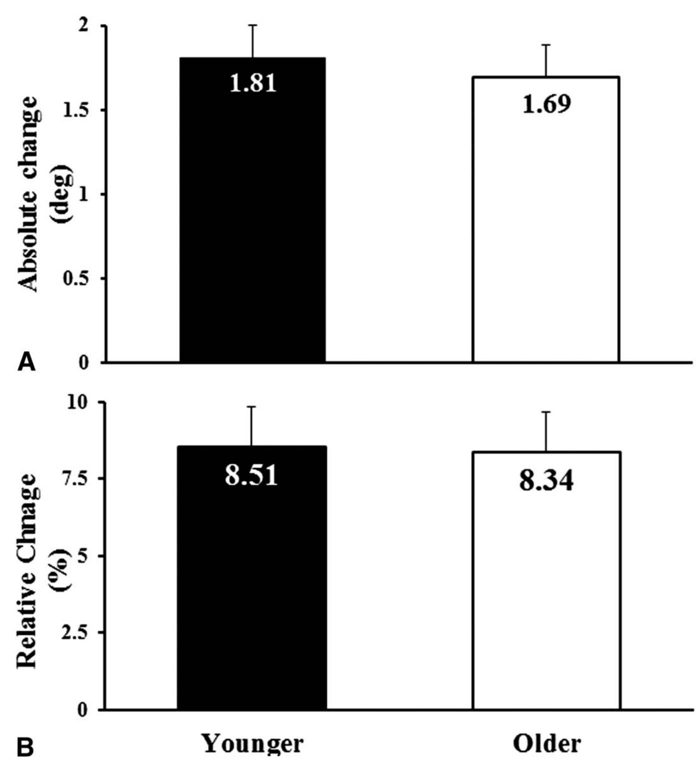

Figure 3. The absolute increase in position (A) and the relative increase in position (B) for the younger and older groups from a neutral joint angle (0° = 90° between the foot and leg). Values are mean ± *SE*.

Signal Processing

The torque (Nm), position (°), and EMG (μV) signals were sampled simultaneously at 2 kHz with a Biopac data acquisitions system (MP150WSW, Biopac Systems, Camino Goleta, CA, USA) during each of the 30-second constant-angle stretches and the passive stiffness assessment. All signals were stored on a personal computer (Dell OptiPlex, GX270, Dell Inc., Round Rock, TX, USA) and processed offline using a custom-written software (LabVIEW version 8.5). Torque and position were smoothed using a zero-phase 100-point moving average, and all EMG signals were filtered with a band-pass zero-phase fourth-order Butterworth filter (10–500 Hz). All subsequent analyses were performed on the filtered signals.

Statistical Analyses

The absolute and relative changes in torque were analyzed using 2 separate 4 × 2 (stretch × age)-mixed factorial analysis of variance (ANOVAs). For viscoelastic creep, the absolute and relative change in position was analyzed using 2 separate independent samples *t*-tests. Electromyographic responses for the MG and SOL were analyzed using 2 separate 4 × 3 × 2 (stretch × time ×

age)-mixed factorial ANOVAs. In addition, all demographic data (body mass, stature, stretch torque threshold, stretch angle, and passive stiffness values) were examined using independent sample *t*-tests.

Statistical analyses were performed using SPSS version 19.0 (IBM SPSS Data Collection, Chicago, IL, USA). When a significant interaction was found, follow-up analyses included lower-order ANOVAs with Bonferroni corrected comparisons and independent *t*-tests. An alpha level of $p \leq 0.05$ was used to determine statistical significance.

Results

For the absolute change in stress relaxation values (Figure 2), there was no interaction ($p = 0.068$), no main effect for age ($p = 0.774$), and no main effect for stretch ($p = 0.078$). There was, however, a significant interaction ($p = 0.038$) for the relative change values. For the older men, the relative change in stress relaxation was not different between the 4 stretches ($p = 0.917$); whereas for the younger men, the relative change in stress relaxation decreased across stretches (1 > 3 and 4; $p = 0.018$ and 0.002, respectively). In addition, the relative change in stress relaxation was greater for the younger than the older men for stretch 1 ($p = 0.010$); however, there were no statistically significant differences between all other stretches ($p = 0.090$–0.932). Means, confidence intervals, and effects sizes are displayed in Table 1.

For viscoelastic creep (Figure 3), there was no difference in the absolute ($p = 0.720$) and relative ($p = 0.917$) increase in position between the younger and older men. In addition, there were no 3-way interactions ($p = 0.105$–0.788), no 2-way interactions ($p = 0.105$–0.788), and no main effects ($p = 0.105$–0.830) for EMG amplitude values for both the MG and SOL muscles. Overall, EMG amplitude values were minimal (3.7% of MVC), which has been considered passive (10,14,33).

The older men (0.155 ± 0.068 $Nm \cdot deg^{-1} \cdot cm^{-1}$) exhibited greater passive stiffness values at a common joint angle ($p = 0.044$) when compared with the younger men (0.114 ± 0.048 $Nm \cdot deg^{-1} \cdot cm^{-1}$). The younger ($22.73 \pm 8.71°$ angle) and older men ($21.09 \pm 7.26°$ angle) stretched at a similar joint angle ($p = 0.560$) and the passive torque threshold ($p = 0.168$; younger = 30.8 ± 9.8 Nm; older = 37.1 ± 16.8 Nm). In addition, the younger and older men had a similar body mass ($p = 0.267$) and stature ($p = 0.464$).

Discussion

The primary findings of this study indicated that age influences the relative but not the absolute stress relaxation responses during repetitive constant-angle stretching. The absolute changes in torque across stretches were similar between age groups. However, the relative change in torque was greater for the younger vs. the older men at stretch 1 (13.0 vs. 8.6%) and decreased across stretches for the younger men (stretch 1 > 3 and 4), whereas the older men demonstrated a similar relative change in torque across all 4 stretches (Figure 2). In contrast and contrary to our hypothesis, the younger and older groups experienced similar absolute and relative increases in position across the 4 stretches, indicating that creep was unaffected by age.

These findings are in agreement with other previous studies that have evaluated the stress relaxation response in vivo using similar plantar flexor stretching protocols in younger healthy adults. For example, Sobolewski et al. (33) observed a similar reduction in the relative change in torque after a single 30-second stretch (~12%), whereas studies examining slightly longer stretch durations 45-s (22) to 1 minute (7,36) have reported a 15–17% reduction in torque. In addition, the decrease in the relative change in stress relaxation across all 4 stretches (Figure 2B) is similar to previous studies examining stress relaxation in vivo (17,19,33,39). For example, Magnusson et al. (17,19) reported that the greatest relative change in stress relaxation occurred in the first stretch then diminished in subsequent stretches of the hamstrings. Furthermore, Weir et al. (39) reported a reduction in stress relaxation from the first to second stretch, and Sobolewski et al. (33) reported a decrease in the relative change in stress relaxation between the first and the fourth stretch in the plantar flexor muscles.

The discrepancies between the absolute and relative stress relaxation responses (Table 1) may be due to the fact that the stretching torque thresholds (the torque value at the onset of each stretch) were nonsignificantly ($p = 0.168$) greater for older men (37.1 ± 16.8 Nm) when compared with the younger men (30.8 ± 9.8 Nm). We are aware of only 1 study (6) that has evaluated the stress relaxation response during a single constant-angle stretch in older participants. Gajdosik et al. (6) observed an ~17% reduction in torque for older women during a 60-s stretch. It is possible that the differences between our findings and those reported by Gajdosik et al. (6) could be attributed to stretch duration (30-seconds vs. 60 seconds), stretch intensity (point of discomfort vs. maximally tolerated dorsiflexion), and/or sex (males vs. females). Additionally, in contrast to the younger men, the older men experienced a similar relative change in stress relaxation across all 4 stretches, whereas the younger men demonstrated a diminishing response. With this being the only study to date addressing the stress relaxation responses in older men across multiple stretches, it is difficult to compare our results with previous studies. However, it is possible that these differences may be a result of the same mechanisms responsible for the age-related increase in passive stiffness reported in this study and other previous animal (15) and human studies (4,8,9).

It has been suggested that the stress relaxation response during a constant angle stretch is primarily a viscous response (33). The term viscoelasticity refers to a combination of viscous and elastic responses (21). Elastic resistance to elongation is instantaneous and proportional to the elongation. Viscous resistance is time dependent and relative to the rate of elongation (35). Thus, in a stress relaxation trial, the elastic resistance is constant (elongation held fixed) and the viscous resistance declines in a time dependent manner from an initial value that will be somewhat dependent on the rate of stretch used to achieve that initial value (5). The structures and mechanisms responsible for the viscous response have been attributed to slipping and/or rearrangement of collagen fibers (24,26), relaxation of collagen fibers (27), and/or the unfolding of titin (37). It is possible that these mechanisms may be affected by age because animal and human models have demonstrated an increase in collagen cross-linking (11) and concentration (1), glycation-related cross-linking (12), and a reduction in the extracellular water in older populations (32). Although the precise mechanism responsible for the stress relaxation response cannot be determined from this study, we have demonstrated that the stress relaxation responses during multiple repeated stretches are altered in older men.

Previous studies have examined viscoelastic creep in both human (29,30,33) and animal models (27,35); however, to the best of our knowledge, this is the first study to examine the influence of age on the in vivo viscoelastic creep responses during passive stretching. Our results demonstrated that both younger and older men experienced similar absolute ($p = 0.720$) and relative ($p = 0.901$) increases in range of motion across all 4 stretches. A previous study by Sobolewski et al. (33) showed that when using a similar stretching protocol, participants with the highest passive stiffness values exhibited the smallest increases in range of motion (creep) over all 4 stretches. Based on these findings (33), we speculated that the age-related increase in passive stiffness would also result in smaller increases in range of motion across the 4 stretches; however, our findings did not support this hypothesis. Dierick et al. (4) observed an increase in elastic stiffness and a decrease in viscous stiffness with age in the plantar flexors; thus, it is possible that an increase in passive stiffness (as reported in this study) and a corresponding decrease in viscous stiffness would result in a negligible change in creep between age groups. Yet, like stress relaxation, the underlying mechanisms that are affected by age are still unclear. Future studies should examine the influence of age on changes in muscle and tendon length during both constant-angle and constant-torque stretching (23).

In conclusion, these findings demonstrated that the viscoelastic stress relaxation responses during 4 consecutive 30-second stretches are influenced by age. Younger men display a greater initial relative stress relaxation response that diminished across repeated stretches; whereas the older men experienced a smaller relative response that remained constant across repeated stretches. Furthermore, older adults exhibited an increase in passive stiffness, but this did not influence viscoelastic creep.

Practical Applications

The results from this study have notable practical implications for the strength and conditioning professional and clinician. Despite increases in stiffness among the older men, they experienced the same increase in range of motion as their younger counterparts from stretch to stretch when held at the same torque. However, the older men experienced a smaller change in relaxation than the younger men for the first stretch. Furthermore, for the older men the stress relaxation response was similar for all stretches; whereas for the younger men, the stress relaxation response declined with repeated stretches. For clinicians and coaches of older adults, these findings may suggest that practical stretching protocols (four 30-second stretches) are equally effective in increasing passive ROM in both younger and older men, despite differences in the relaxation responses across stretches.

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