Acute effects of static stretching on the shear elastic moduli of the medial and lateral gastrocnemius muscles in young and elderly women

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Abstract

Purpose: Generally, static stretching (SS) is the recommended intervention for a decline in the range of motion among elderly adults. However, no study has investigated the acute effects of SS on the shear elastic modulus in elderly people. The aims of the present study were to investigate the acute effects of SS on the shear elastic moduli of the medial and lateral gastrocnemius muscles and to examine the differences in these acute effects between young and elderly women.

Methods: This study included 15 healthy young women (age: 23.1 ± 3.4 years) and 15 healthy elderly women (age: 75.9 ± 2.8 years) with no history of neuromuscular disease or musculoskeletal injury involving the lower limbs. The shear elastic moduli of the medial and lateral gastrocnemius muscles (MG and LG, respectively) were measured using ultrasound shear wave elastography at 30° plantar flexion, 0°, and 20° dorsiflexion before and immediately after 5 min of SS with the knee extended.

Results: The shear elastic moduli of the MG and LG in all ankle position decreased after SS in both the young and elderly women, and there were no significant differences in the percent changes in the shear elastic moduli of the MG and LG at all ankle positions between the young and elderly women.

Conclusions: These results suggested that 5 min of SS might be effective for decreasing shear elastic modulus in both young and elderly women and that the effects on shear elastic modulus are similar between young and elderly women.

Keywords: static stretching, elderly, gastrocnemius, ultrasound, shear wave elastography

Introduction

Range of motion (ROM) is well-known to decrease with aging (Gajdosik et al. , 2005a, Gajdosik et al. , 1996), and a decrease in ROM is known to cause declines in ambulation and balance (Holland et al. , 2002, Nonaka et al. , 2002). Generally, static stretching (SS) is the recommended intervention to prevent a decline in ROM among elderly adults. In fact, previous studies have reported an increase in ROM after stretching interventions among elderly adults (Gajdosik et al. , 2005b, Johnson et al. , 2007), and some studies have reported that stretching interventions were effective for improving mobility tasks, such as the timed up-and-go test and 10-m walk speed test (Gajdosik, 2005b, Stathokostas et al. , 2012, Watt et al. , 2011, Zotz et al. , 2014). In addition, the aim of stretching interventions is to not only increase ROM but also to change the passive properties of muscle, such as passive muscle tendon unit stiffness and muscle stiffness. A previous study demonstrated that the decline in ankle dorsiflexion ROM was associated with the risk of falls in the elderly (Gehlsen and Whaley, 1990); thus, it is expected that decrease in muscle stiffness of the gastrocnemius muscle can result in prevention of falls in the elderly. In addition, stretching is expected to improve ability to perform activities of daily living, which leads to improvement in the quality of life (American College of Sports Medicine 2000, Alter 2004). Thus, stretching is a recommended intervention, especially in elderly adults.

In vivo, many previous studies (McHugh et al. , 1998, Mizuno et al. , 2013, Toft et al. , 1989) recommended passive torque measurement and estimation of the passive stiffness during passive stretching using a dynamometer. However, these measurements are influenced by several factors, such as synergistic muscles, aponeuroses, tendons, joint capsules, and ligaments. Therefore, another previous study pointed out that these measurements do not reflect the passive property of individual muscles accurately (Maisetti et al. , 2012). Muscle stiffness can be estimated with the shear elastic modulus measured using a shear wave elastographic imaging technique. This technique enables assessment of the passive property of individual muscles quickly and easily. The reliability and validity of measurement of shear elastic modulus were confirmed in previous studies (Eby et al. , 2013, Miyamoto et al. , 2015, Nakamura et al. , 2016, Yoshitake et al. , 2014). Previous studies indicated that shear elastic modulus measurement could provide an accurate estimation of individual muscle tension during both muscle contraction and stretching (Ates et al. , 2015, Koo et al. , 2013, Koo and Hug, 2015, Yoshitake, 2014). In addition, some previous studies have investigated the effects of SS on the shear elastic modulus (Akagi and Takahashi, 2013a, Nakamura et al. , 2014, Taniguchi et al. , 2015, Umegaki et al. , 2015). These studies reported that the shear elastic moduli of the gastrocnemius muscles (consisting of the medial and lateral gastrocnemius muscles [MG and LG, respectively]) and the hamstrings (consisting of the semitendinosus, semimembranosus, and biceps femoris muscles) decreased after 2–6 min of SS in healthy young male individuals. However, because no study has investigated the acute effects of SS on the shear elastic modulus in elderly people, it is unclear whether the acute effects of SS on the shear elastic modulus are similar between young and elderly people. As described above, since the decline in ROM and flexibility leads to an increase in fall risk and decrease in the quality of life of the elderly (Gehlsen and Whaley, 1990), it is important to verify whether there are any differences in the effect of SS on shear elastic modulus between young and elderly people.

The aims of the present study were to investigate the acute effects of SS on the shear elastic moduli of the MG and LG and to compare the acute effects of SS between young and elderly women. A previous study which investigated the difference in viscoelastic stretch responses between young and elderly people found that changes in viscoelastic properties were similar between young and elderly people (Sobolewski et al. , 2014). Therefore, we hypothesized that the effect of SS on shear elastic modulus was also similar between young and elderly people.

Methods

Subjects

This study included 15 healthy young women and 15 healthy elderly women, who volunteered to participate. Elderly subjects were community-dwelling and lived independently in Kyoto, Japan. The inclusion criteria were as follows: ability to walk and climb stairs without assisting devices and non-athletes. In addition, subjects with a history of dementia, trauma, surgery, neuromuscular disorders, metabolic disorders, or acute and chronic diseases that impair muscle quantity, quality and strength, or physical function were excluded. In addition, subjects with a history of neuromuscular disease or lower extremity musculoskeletal injury were excluded. Written informed consent was obtained from all subjects, and this study was approved by the ethics committee.

A priori ample size calculation

We calculated the sample size needed for the paired t test (alpha error = 0.05, effect size = 0.80 [large], power = 0.80), and the requisite number of participants for this study was 15 in each group. We chose a large effect size on the basis of previous studies of investigating the acute effect of SS on shear elastic modulus (Akagi and Takahashi, 2013a).

Experimental procedure

The experimental design of this study was an observational study. Before (PRE) and immediately after (POST) 5 min of SS for the gastrocnemius in the dominant leg, the final angle and shear elastic moduli of the MG and LG were measured. The dominant leg was determined by asking the participants which leg they would prefer to kick a ball. The details of each measurement are described below.

Assessment of the final angle

The subjects were seated with adjustable lap belts over the pelvis, trunk, and thigh on the Biodex System 4.0 (Biodex Medical Systems Inc., USA) at 70° of hip flexion. In addition, the dominant knee was maintained in full extension, and the ipsilateral foot was securely attached to the dynamometer footplate with adjustable lap belts to prevent the heel from moving away from the footplate (Fig 1). The footplate of the dynamometer was moved manually by an examiner, starting from an ankle angle at 30° plantarflexion to the dorsiflexion angle at which subjects started to feel discomfort or pain. The subjects were instructed to inform the examiner verbally when they started to feel discomfort or pain, and the angle just before this point was defined as the final angle (Akagi and Takahashi, 2013a, 2014).

Assessment of the shear elastic modulus

The shear elastic moduli of the MG and LG were measured using ultrasound shear wave elastography (Aixplorer; SuperSonic Imagine, Axi-en-Provence, France) with a linear array probe (50-mm long SL-15-4 liner ultrasound transducer) using a musculoskeletal

(MSK) mode. Based on the method used in previous studies (Akagi et al. , 2012, Chino et al. , 2012), the shear elastic moduli of the MG and LG were measured at the proximal 30% of the lower leg length (from the popliteal crease to the lateral malleolus). An ultrasound transducer was positioned on the measurement points parallel to the direction of the muscle fibers, which were confirmed by tracing several fascicles without interruption across the B-mode image (Umegaki, 2015).

The region of interest (ROI) was set near the central part of the muscle belly at the point of maximum thickness, and measurement was taken confirming that the color distribution was stable for at least 3 s. For quantitative assessment, a 5-mm-diameter circle was drawn around the center of the ROI. The shear elastic modulus (kPa) was calculated from the shear wave speed that was automatically determined within the circle (Akagi and Takahashi, 2013a, 2014, Nakamura, 2014).

In accordance with previous studies (Akagi, 2012, Chino, 2012), the shear elastic moduli were measured in the following three ankle joint positions: 30° plantar flexion (PF 30°), 0° dorsiflexion (Neutral), and 20° dorsiflexion (DF 20°). The shear elastic moduli were measured in each muscle for <10 s to avoid stretching effects. The shear elastic moduli of the MG and LG were measured twice each, and the mean values were used for further analysis.

Static stretching

The SS intervention was performed using a dynamometer in the sitting position with the knee extended, similar to conditions during the final angle and shear elastic moduli measurements. The footplate of the dynamometer was manually moved by an examiner, starting from 30° plantar flexion to the final angle, and the ankle joint was held at the final angle for 5 min (constant-angle stretching) based on previous studies (Morse et al. , 2008, Nakamura et al. , 2011).

Statistical analysis

Descriptive data are presented as mean ± standard deviation. Differences between the young and elderly women for all variables at PRE were assessed using the unpaired *t*-test. Differences between PRE and POST for all variables were assessed using the paired *t*-test in both the young and elderly women. Furthermore, the percentage changes in values between PRE and POST were calculated to compare the effects of SS between the young and elderly women as follows: percentage change = (PRE value − POST value) / (PRE value) × 100. Because the Shapiro–Wilk tests showed that the percentage changes were not normally distributed, differences in the percent changes between the young and elderly women were determined using the Mann–Whitney *U* test. All statistical analyses were performed using SPSS (version 21.0, IBM Corp., Armonk, NY). A P-value <0.05 was considered to indicate statistical significance.

Results

Characteristics of the participants

This study included 15 healthy young women (mean ± SD: age, 23.1 ± 3.4 years; height, 159.4 ± 5.2 cm; body mass, 49.3 ± 7.9 kg) and 15 healthy elderly women (age, 75.9 ± 2.8 years; height, 150.3 ± 5.1 cm; body mass, 49.9 ± 6.4 kg.

Comparison between the young and elderly women at PRE

All variables at PRE in the young and elderly women are presented in Table 1. The unpaired *t*-test revealed that the final angle in elderly women was significantly lower than that in young women (31.3 ± 8.7° vs. 24.7 ± 2.7°, $P < 0.01$). However, there were no significant differences in the shear elastic moduli of the LG and MG at the three ankle joint positions between the young women and elderly women.

Changes in the final angle and shear elastic moduli between PRE and POST

In both the young women and elderly women, POST values of the final angle were significantly higher than the PRE values (young women: PRE, 31.3 ± 8.7°; POST, 38.7 ± 7.2°, $P < 0.01$; elderly women: PRE, 24.7 ± 2.7°; POST, 31.6 ± 4.0°, $P < 0.01$). The changes in the shear elastic moduli of the MG and LG between PRE and POST in the young women and elderly women are presented in Table 2. In both the young women and elderly women, the POST values of the shear elastic moduli of the MG and LG at the three ankle positions were significantly lower than the PRE values.

Comparison of the percent changes between young and elderly women

Comparison of the percent changes between the young women and elderly women is presented in Figure 2. There was no significant difference in the percent change in final angle between the young and elderly women. In addition, there were no significant differences in the percent changes in the shear elastic moduli of the MG and LG at the three ankle positions.

Discussion

The present study showed that there was no significant difference in shear elastic moduli of the LG and MG between the young women and elderly women at PRE, whereas the final angle in elderly women was significantly lower than that in young women. Our results suggested that there was no difference in individual muscle stiffness between young and elderly women, although decline in ankle dorsiflexion ROM was observed in elderly women. Furthermore, the present study showed that the shear elastic moduli of the MG and LG decreased after 5 min of SS in both young and elderly women and that there were no differences in the effects of SS on the shear elastic modulus between young and elderly women. Our results suggested that there was no difference in the acute effect of SS on individual muscle stiffness of the gastrocnemius muscle between young and elderly women. To the best of our knowledge, this is the first report on the investigation of the effects of SS on the shear elastic modulus among elderly people.

In this study, the final angle at PRE was higher in young women than in elderly women, which is consistent with the findings of previous studies that reported a decrease in ROM with age (Gajdosik, 1996, Gajdosik et al. , 1999, Vandervoort et al. , 1992). Previous studies (Maisetti, 2012, Weppler and Magnusson, 2010) pointed out that ROM measurements were influenced by several factors, such as synergistic muscles, aponeuroses, tendons, joint capsules, ligaments, and stretch tolerance. Therefore, muscle stiffness, reflected by the shear elastic modulus, is recommended as an index for passive property of the muscle. In this study, there were no significant differences in the shear elastic moduli of the LG and MG at all ankle joint positions between young and elderly women. Considering the age-related changes in passive properties, a decrease in ROM might be influenced by changes in ligament, joint capsule, and tendon flexibilities with age or a change in stretch tolerance. Therefore, a future study is needed to investigate the factors influencing ROM reduction with age, including ligament, joint capsule, and tendon flexibilities and stretch tolerance, as well as muscle stiffness.

In this study, there were no significant differences in the shear elastic moduli of the LG and MG at all ankle joint positions between young women and elderly women. There were some studies investigating the changes in the shear elastic modulus with age. The previous study reported that there was no significant correlation between age and the shear elastic modulus of the tibialis anterior muscle among middle-aged and elderly people (Domire et al. , 2009). In addition, there were no significant differences in the shear elastic modulus of the vastus medialis at rest between young adults and middle-aged adults (Debernard et al. , 2011), or that of the vastus intermedius between elderly and young subjects (Wang et al. , 2014), which are consistent with the results of the present study. However, Eby et al. (2015) reported that the shear elastic modulus of the biceps brachii increased with advancing age. In addition, Akagi et al (2015) reported that the shear elastic moduli of the rectus femoris and LG were significantly higher in young individuals than in elderly individuals, but there was no age-related difference with regard to the soleus. Therefore, there is no consensus regarding the age-related changes in the shear elastic modulus, which suggests that the age-related changes in the shear elastic modulus might vary according to the muscle. In addition, it is possible that the motor function and physical activity of the subject may affect the shear elastic modulus. However, the reason for the absence of changes in the elastic moduli of the MG and LG with age in this study is unclear. Therefore, a further study is needed to clarify the reason for the variation of age-related changes in the shear elastic modulus according to the muscle and motor function, physical activity.

In the present study, we found that the POST values of the shear elastic moduli of the MG and LG at all ankle positions were significantly lower than the PRE values in both young women and elderly women, which suggested that muscle stiffness of the MG and LG decreased after 5 min of SS in both young women and elderly women. This finding is consistent with the findings of previous studies that investigated the effects of SS on the stiffness of the gastrocnemius muscle and hamstrings in young men (Akagi and Takahashi, 2013a, Nakamura, 2014, Taniguchi, 2015, Umegaki, 2015). In addition, our results showed that there were no significant differences in the percent changes in the shear elastic moduli between young women and elderly women, which suggested that there were no differences in the acute effects of SS on muscle stiffness between young and elderly women, which is consistent with our hypothesis. Since we did not measure muscle activity and muscle force, there is a possibility that changes in muscular conditions after stretching could have affected the changes in shear elastic moduli of MG and LG. However, a previous study has reported that there was no change in muscle activity before and after SS (Hirata et al., 2017). Therefore, it is assumed that there was little possibility that changes in muscle activity affected the results of this study.

Previous studies have reported that passive stiffness, which is an index of muscle properties on the longitudinal axis, increased with age (Dierick et al. , 2011, Gajdosik et al. , 2004). On the other hand, Sobloewski et al. (2014) investigated the difference in viscoelastic responses between young and elderly men, and found that changes in viscoelastic properties were similar between young men and elderly men. Sobloewski et al. (2014) measured passive stiffness, which represents muscle properties on the longitudinal axis, according to passive resistance during passive stretching, whereas we measured muscle stiffness according to the shear elastic moduli, which represents muscle properties on the transverse axis, and this is distinct from passive stiffness (Akagi and Takahashi, 2013b, Chino, 2012, Gennisson et al. , 2005, Murayama et al. , 2000). The absence of significant differences in the percent changes of the shear elastic moduli between young and elderly women noted in this study is consistent with the finding of a previous study (Sobolewski et al. 2014) that investigated passive stiffness. Therefore, in addition to treatment to improve flexibility (ROM) in not only young people but also elderly people SS may be effective in decreasing muscle stiffness. With regard to the SS duration that is effective for increasing ROM, previous studies indicated that 30 s of SS was effective in young people (Bandy and Irion, 1994), whereas 60 s of SS was effective in elderly people (Feland et al. , 2001), suggesting that a longer SS duration may be needed in elderly people than in young people. In this study, 5 min of SS was adopted as the SS duration, which is longer than that in previous studies (Bandy and Irion, 1994, Feland, 2001). Therefore, it is possible that similar effects of SS were obtained between elderly and young people in our study. Future studies are needed to investigate the effects of various SS durations on muscle stiffness.

This study has several limitation. First, the investigator was not blinded to the subject’s group. Second, only women were recruited in this study as a previous report showed gender differences in shear elastic modulus (Akagi et al. , 2015). Therefore, future studies should clarify the effect of SS on shear elastic modulus in young and elderly male subjects.

Conclusion

Our results showed that 5 min of SS might be effective for decreasing the muscle stiffness of the MG and LG in both young women and elderly women and that these effects on muscle stiffness are similar between young women and elderly women.

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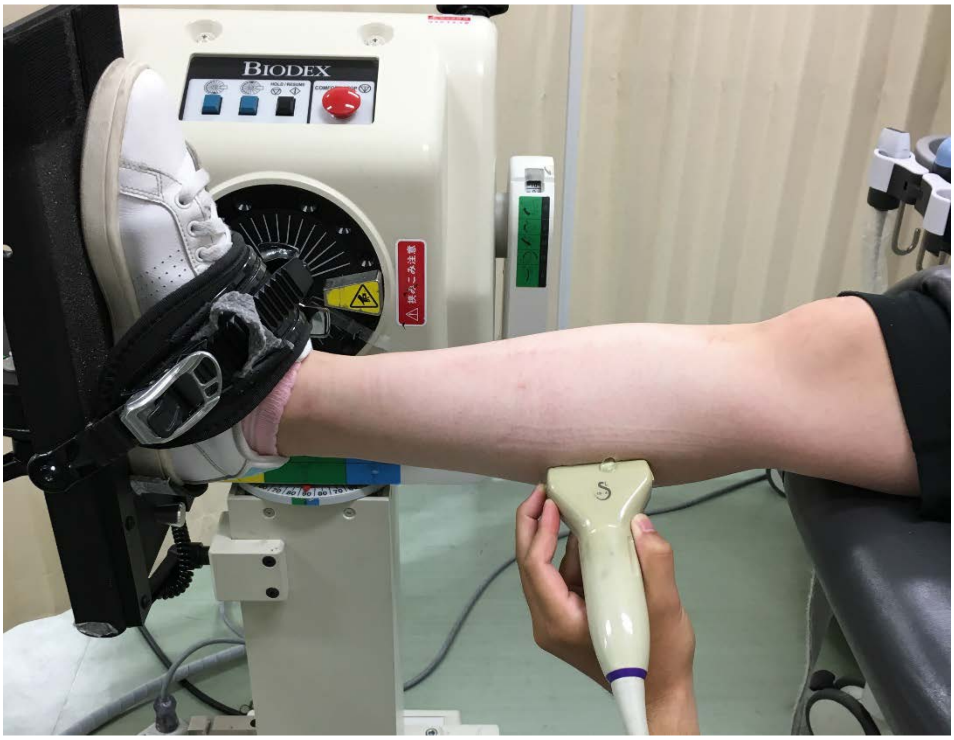
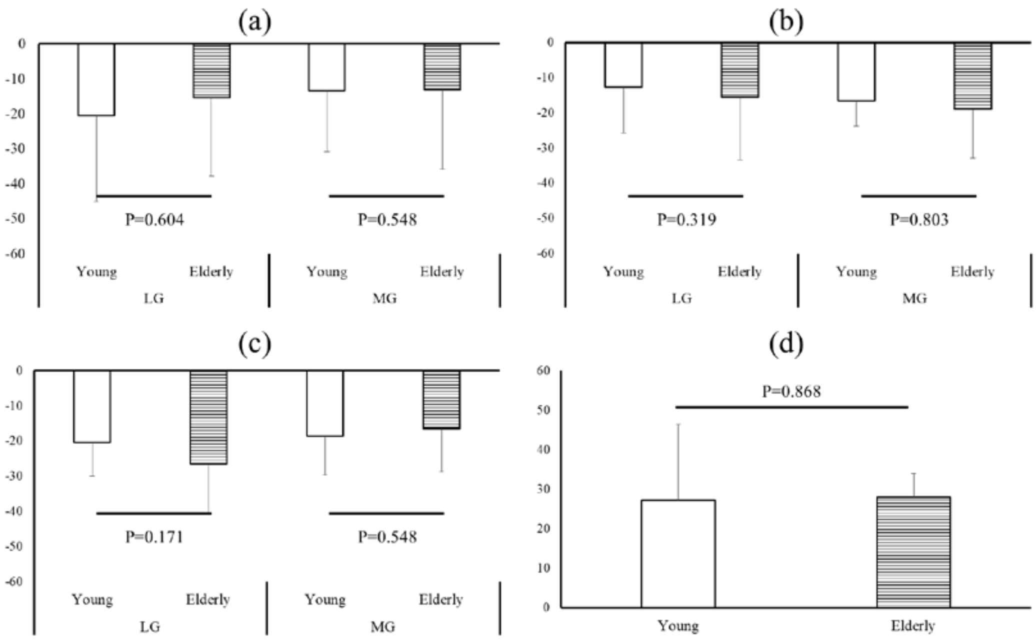
Figure 1 Experimental set-up of shear elastic modulus measurement



The ankle of the dominant leg was attached securely to the dynamometer footplate by adjustable lap belts to prevent the heel that moving away from the footplate. Shear elastic moduli of MG and LG in three ankle joint positions (30° plantar flexion, 0° dorsiflexion, and 20° dorsiflexion) were measured.

Figure 2. Comparison of the percent changes between young and elderly women



(a): PF at 30°; (b): 0°; (c) DF at 20°; (d): Final Angle

PF, plantarflexion; DF, dorsiflexion; LG, lateral gastrocnemius; MG, medial gastrocnemius

Table 1. Comparison between the young and elderly women at PRE

		Young	Elderly	P-value	95%CI
Final angle (°)		31.3 ± 8.7	24.7 ± 2.7	P < 0.01	1.83, 11.46
Shear elastic modulus	LG	8.3 ± 3.7	8.5 ± 2.1	P = 0.92	-2.35, 2.13
at PF 30° (kPa)	MG	6.3 ± 3.4	7.8 ± 3.4	P = 0.14	-3.50, 0.54
Shear elastic modulus	LG	13.2 ± 5.1	14.0 ± 2.9	P = 0.62	-3.85, 2.34
at 0° (kPa)	MG	18.3 ± 6.0	15.2 ± 3.7	P = 0.24	-0.589, 6.91
Shear elastic modulus	LG	34.2 ± 11.3	41.5 ± 20.4	P = 0.21	-19.6, 5.05
at DF 20° (kPa)	MG	65.9 ± 12.6	68.3 ± 21.7	P = 0.72	-15.6, 10.9

PRE, before 5 min of static stretching; DF, dorsiflexion; PF, plantarflexion; CI, confidence interval

Table 2. Changes in the shear elastic moduli of the MG and LG between PRE and POST

Shear elastic modulus (kPa)		Young PRE	Young POST	Young 95%CI	Elderly PRE	Elderly POST	Elderly 95%CI
PF at 30°	LG	8.3 ± 3.7	6.1 ± 2.1**	0.74, 3.79	8.5 ± 2.1	7.0 ± 1.9**	0.50, 0.46
	MG	6.3 ± 3.4	5.3 ± 1.5*	0.17, 1.78	7.8 ± 3.4	6.2 ± 1.7*	0.27, 2.75
0°	LG	13.2 ± 5.1	11.1 ± 3.2**	0.64, 3.47	14.0 ± 2.9	11.5 ± 2.1**	0.88, 4.04
	MG	18.3 ± 6.0	15.2 ± 4.5*	1.95, 4.25	15.2 ± 3.7	12.1 ± 2.8**	1.71, 4.44
DF at 20°	LG	34.2 ± 11.3	27.6 ± 11.0**	4.95, 8.30	41.5 ± 20.4	30.5 ± 17.0**	6.86, 15.1
	MG	65.9 ± 12.6	53.9 ± 13.0**	8.48, 15.5	68.3 ± 21,7	56.8 ± 21.1**	6.57, 16.4

*P < 0.05, **P < 0.01; significantly different from PRE

PRE, before 5 min of static stretching; POST, immediately after 5 min of static stretching; PF, plantarflexion; DF, dorsiflexion; LG, lateral gastrocnemius; MG, medial gastrocnemius; CI, confidence interval

Highlight

- The effect of static stretching on shear elastic modulus was examined
- The differences in acute effects between young and elderly women was examined
- The shear elastic modulus decreased in both the young and elderly women.
- There were no significant differences of effect between the young and elderly women.