2006

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Recommended Citation

Masterson, M. M., Morgan, A. L., Multer, C. E., & Cipriani, D. J. (2006). The Role of Lower Leg Muscle Activity in Blood Pressure Maintenance of Older Adults. *Clinical Kinesiology, 60*(2), 8-17.

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Comments
This article was originally published in *Clinical Kinesiology*, volume 60, issue 2, in 2006.

The Role of Lower Leg Muscle Activity in Blood Pressure Maintenance of Older Adults

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ABSTRACT

Purpose. Age-associated muscle weakness, postural instability, and orthostatic hypotension have been identified as contributing factors to falls, but the relationships among them are not clear. Therefore, the purpose of this study, a two-way factorial design, was to investigate the differences in lower extremity (LE) muscle activity, blood pressure (BP), and heart rate (HR) between young and older individuals in an upright position. *Methods.* Ten young males (20-24 yrs.) and 10 older males (65-82 yrs.) stood for 15 minutes while BP, HR, and LE electromyography (EMG) were recorded at one minute intervals. A two-way ANOVA was used for data analysis, p=.05. *Results.* Mean arterial pressure of both groups significantly increased from supine values within one minute of standing (young = 86.5±1.68 to 96.9±3.16 mmHg, old = 100.3±4.42 to 114.0±5.40 mmHg). BP variables remained elevated during the 15 minutes of standing despite a significantly attenuated HR response in the older group (young = 85±4.51 bpm, old = 73±3.98 bpm). Standing EMG activity of the older group was significantly greater than the young group. *Conclusion.* This study suggests that increased LE muscle activity may play a role in the ability of older individuals to maintain BP in the standing position.

Key Words: aging, electromyography, orthostatic hypotension, blood pressure regulation

INTRODUCTION

Age-associated changes in skeletal muscle, including declines in muscle mass, strength, and function, have been identified as contributors to balance deficits and falls in the older population (5, 6). It is also possible that these age-associated skeletal muscle changes diminish the effectiveness of the skeletal muscle pump mechanism of older individuals when in the upright position, allowing for greater displacement of central venous volume to the lower extremities (LE). Thus, in addition to balance deficits, age-associated changes in skeletal muscle may be a contributing factor to falls in the older population by adversely affecting BP maintenance in the upright position.

Normally, LE skeletal muscle tone/tension and activity, components of the skeletal muscle pump mechanism, act to help maintain BP in the upright position by minimizing displacement of central blood volume to the LE and by assisting with venous return to the heart. Even during quiet standing without voluntary muscle contraction, the intramuscular pressures due to rhythmic changes in LE muscle activity act to maintain balance during weight bearing and reduce the quantity of blood that is redistributed due to gravity (1). For example, LE intramuscular pressure (which reflects muscle tone) in individuals with a history of fainting was 6-9 mmHg as compared to 15-24 mmHg in non-fainters (1). Further, rhythmic muscle activity and muscle tone are reduced when the LE are not weight bearing allowing for greater displacement of central venous volume. This totally passive position can prove deadly, and was the basis for the ancient practice of crucifixion (21).

A less extreme example of the influence of skeletal muscle tension and activity on BP was demonstrated by Smith et al (17) who used a lower body negative pressure (LBNP) protocol to simulate the effects of gravity on the cardiovascular system in the upright position. Electromyography (EMG) was used to monitor the activity of the LE musculature during three 20-minute trials of LBNP, one trial with the LE in a relaxed state and the other two trials with LE isometric contractions equivalent to 5% and 10% of a maximal voluntary contraction. Blood pressure was significantly decreased during the trial when the LE muscles were in a relaxed state as compared to the trials of isometric muscle contraction in which BP was slightly elevated throughout the duration of the trial.

Sampson et al (16) compared blood pressure responses to the upright position (on a tilt table) of subjects with recent spinal cord injury (SCI) resulting in flaccid paralysis of the lower extremities to those with long-standing SCI in which spasticity (increased muscle tone) had developed in the lower extremities. Mean systolic blood pressure was significantly lower for a given degree of vertical tilt in subjects with recent SCI. There was also a significant decrease in the overall degree of tilt that those with a recent SCI could tolerate. Electrical stimulation was then applied to the flaccid lower extremity muscles of subjects with recent SCI while vertically tilted and mean systolic blood pressure was significantly greater as compared to blood pressure values without stimulation. Subjects were also able to tolerate a greater degree of vertical tilt.

The results of these previous studies support the notion that lower extremity muscle tone/tension and activity, whether due to active contraction, external electrical stimulation, or spasticity, is an important factor in minimizing the displacement of central blood volume to the lower extremities in order to adequately maintain BP in the upright position. However, the influence of age-associated changes in skeletal muscle on BP regulation has not been established. Skeletal muscle mass has been shown to decline with age because of a decrease in the number of muscle fibers and motor units, as well as an increase in the denervation of Type II muscle fibers, both of which contribute to an overall reduction in muscle activity and maximum voluntary contraction strength (5, 6). It has been suggested that the reduction in lower extremity muscle mass and muscle activity associated with aging may decrease the effectiveness of the skeletal muscle pump mechanism to limit central blood volume displacement to the LE in the upright position resulting in decreases in BP (8, 12, 20).

Although there were no previous studies found that measured and compared changes in LE volume to BP in young and older subjects after moving from the supine to standing position, Gabbett et al (7) examined the relationship between LE EMG activity and BP in young and older men. No significant differences in EMG activity between or within groups were found, suggesting that the skeletal muscle pump did not significantly contribute to BP regulation in either group. However, a head-up-tilt (HUT) protocol on a tilt table was used in which subjects were secured to the table with straps. Thus, subjects were not required to maintain standing balance, which may have contributed to the lack of significant changes in EMG activity for both groups.

It is possible that in an unsupported standing position, which requires greater muscle activity for balance, the influence of age-associated changes in skeletal muscle on BP maintenance would be more apparent. Therefore, the purpose of this study was to investigate the influence of age-associated changes in lower extremity skeletal muscle activity on LE volume and BP regulation of young and older males while maintaining an unsupported standing position. It was hypothesized that:

1. LE muscle activity (as measured by EMG) would be less in older subjects than young subjects during standing
2. LE volumetric changes would be greater in older subjects than young subjects after standing for 15 minutes, possibly due to less LE muscle activity
3. BP would be less in older subjects than young subjects during standing, possibly due to less LE muscle activity and greater volumetric changes.

METHODS

Subjects. Twenty male subjects volunteered for this research study. Subjects were divided into two groups; ten young subjects aged 20-30 years (22 ± 0.46) and ten older subjects aged 65-85 years (72 ± 1.63). Only male subjects were asked to volunteer to eliminate the confounding variable of menstrual cycle, which influences total blood volume and blood pressure in younger females. To control for fitness level, a physical activity survey adapted from Dipietro et al (4) was used to rank the subjects' vigorous and leisure activity level. Only subjects whose total score was considered to be inactive or leisurely active were included. Exclusion criteria were a history of cardiovascular, pulmonary, muscular, or peripheral vascular disease that required medications such as diuretic or hypertensive medications and any neurological or musculoskeletal disorders that prevented them from being able to stand unsupported for 15 minutes.

Procedures. The research protocol was approved by the Institutional Review Boards of the Medical University of Ohio and the University of Toledo and written informed consent was obtained from each subject. Subjects were instructed to refrain from consuming food or drink after midnight and to refrain from drinking alcohol for 24 hours prior to testing to control for hydration status. Subjects' height and weight were measured, and they were required to drink 5 ml of water per kg of body weight before testing so that they were similarly hydrated (14).

Prior to testing, subjects practiced a volumetric measurement used to determine the volume of the lower leg prior to and after the unsupported standing protocol. To control for reliability and testing error, a standardized test protocol previously described by Stern (18) was used, and the same researcher administered the test. Pre-test measurements required subjects to immediately sit up at the edge of a mat table from the supine position. Subjects then slowly lowered their dominant foot and leg into a leg volumeter until the foot was in full contact with the bottom and the water level was at the tibial tubercle. They were instructed to hold their leg as still as possible until the overflow of water was complete (less than 30 seconds). Subjects were observed to ensure proper technique and were given verbal feedback as needed. Post-test measurements were performed in the same manner, but required subjects to move from the standing to sitting position by pivoting onto the edge of the mat table, which was positioned directly next to them. The sitting test position was used for both pre and post test measurements to ensure standardization of the test procedure and for safety reasons. Only the subjects' position prior to testing (supine and standing) was different.

After practicing the volumetric measurement, subjects rested supine and an automated monitor was used to measure blood pressure (BP) and heart rate (HR) every three minutes (Propaq 104® automated non-invasive BP and HR monitor, Protocol Systems, Inc., Beaverton, OR, calibrated by the institution's Biomedical Services Department) until three consecutive systolic blood pressure (SBP) measurements were within 3 mmHg. This ensured that total blood volume was evenly distributed and the effects of gravity were minimized. The subject then sat upright and the volumetric measurement of the dominant foot and lower leg was obtained as previously described.

The extrinsic foot and ankle muscles that are primarily responsible for ankle balance strategies used during quiet standing and that assist with the skeletal muscle pump mechanism were selected for EMG testing. However, because of the inaccessibility of the soleus muscle to surface EMG electrodes, the gastrocnemius muscle, also a plantarflexor, was used for this study. Thus, the skin surfaces overlying the muscle bellies of the lateral gastrocnemius and anterior tibialis muscles of the dominant leg were shaved and cleansed with alcohol. Surface EMG electrodes were affixed in parallel fashion to the skin overlying the mid-portion of each of the muscle bellies and connected to an eight-channel telemetry system (Noraxon Inc., Scottsdale, AZ). The subject was placed in a semi-reclined position on a Cybex bench (Lumex, Inc., Ronkonkoma, NY) with the lower extremity in an extended position with the knee slightly bent, the foot supported on a rigid foot plate, and the ankle in a neutral position. Raw EMG data were collected during three five-second maximal isometric contractions with a one-minute rest period between each trial. The EMG data were amplified with a gain of 500 and processed with a band pass filter at 10-500 Hz. The signal was converted with an A/D board at a sampling rate of 1500 samples per second.

After maximal EMG data collection, the subject rested in the supine position again and BP measurements and heart rate (HR) measurements were taken every three minutes until three consecutive SBP measurements were within 3 mmHg. Heart rate was recorded in supine and during the standing protocol to monitor other cardiovascular responses in the upright position, specifically the baroreflex, which also influences BP regulation. After resting supine, he subject was instructed to quickly assume the standing position with feet shoulder width apart and arms hanging at the sides, and to stand quietly with minimal movement of any part of the body. Immediately upon standing, the subject's BP and HR were measured and EMG data were collected for 20 seconds. BP and HR were measured and EMG data were collected every one minute thereafter, for 15 minutes. For safety purposes, the subjects' tolerance to prolonged standing was monitored each minute by asking them to rate any symptoms of lightheadedness, dizziness, or nausea using the Perceived Pre-Syncope (PPS) scale (a scale of 0-3 with 0 = "no symptoms" and 3 = "severe symptoms") described by Sampson et al (16). All of the subjects were able to complete the 15 minutes of standing without any incidences of lightheadedness, dizziness, or nausea. The standing test session was terminated after 15 minutes and the volumetric measurement was repeated.

Data Analysis. The difference between pre- and post-test volumetric measurements was calculated and normalized as a percent of total blood volume (BV) using a nomogram for BV relative to age and body mass (9). The EMG data were smoothed using root-mean-square with a window of 50 ms (Myoresearch®, Noraxon Inc., Scottsdale, AZ). Average EMG activity was determined for each of the three 1-RM trials and for the 20 seconds of EMG activity of each muscle for each standing time interval. The 1-RM trial with the greatest EMG activity for each muscle was used to normalize the EMG activity of the respective muscle during each of the standing time intervals. Thus, standing EMG data were recorded as a percent of the maximal EMG activity.

The last recorded BP and HR measurements taken during the subjects' resting period were used as the "supine" data points. Resting and standing mean arterial pressures (MAP) were calculated according to the formula: MAP = 1/3(SBP-DBP)+DBP.

Statistical Analysis. Because the EMG data did not meet the assumptions of normality (i.e., the data were skewed) all EMG data were transformed using the base 10 log transformation. Log transformation is recommended to minimize the issue of unequal variance and skewness, prior to performing inferential statistical procedures, particularly with EMG data (15). In order to test for an interaction between age group and time on each of the dependent variables (i.e., to test whether changes over time were dependent on age group – to test if the rate of change in the dependent variables was influenced by age group), this study used a factorial analysis of variance statistical procedure. A two-factor ANOVA was used to test for interactions on each of the dependent variables. The between factor was group (i.e. young group vs. older group) and the within group factor was time (i.e., each of the time points of data collection). The within factor (time) was the repeated measures factor of this two-factor ANOVA. The dependent variables included the following: MAP, SBP, DBP, HR, and EMG. In addition, a two-factor ANOVA was used to test for an interaction between age group and time (i.e., pre-test and post-test) on lower leg volume. In the event of any significant interactions, simple main effects were tested with the appropriate t-tests (i.e., paired and independent) in order to determine where in the variance differences exist. A p-value of ≤ .05 was used for significance. All data are reported as mean ± SEM.

RESULTS

There were no significant differences in weight or body mass index (BMI) between the two groups. However, the young subjects were significantly taller than the older subjects ($p \le .05$) (Table 1).

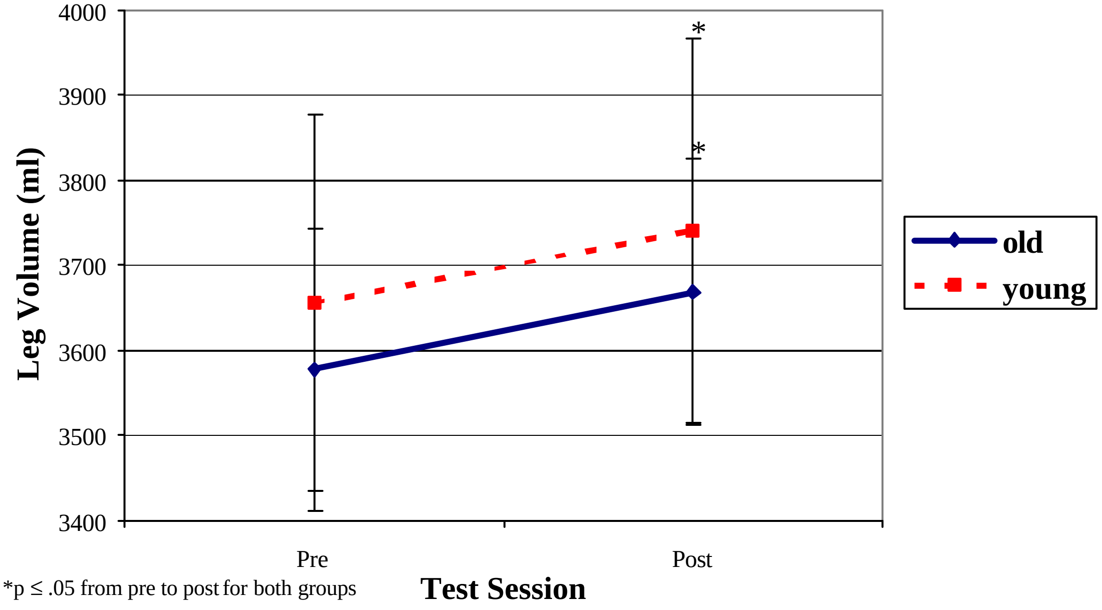
Lower Leg Volume. The volume of the dominant leg and foot significantly increased for both groups (within group comparison) from baseline after standing for 15 minutes ($p \le .05$) (Figure 1). Between group comparisons were made with the normalized volume data. The increase in lower leg blood volume was 1.75% of total blood volume for the older group and was 1.36% for the young group, which was not significantly different between groups.

TABLE 1. Subject characteristics (mean ± SEM).

VARIABLE	YOUNG (n = 10)	OLD (n = 10)
Age (years)	22 ± .46	72 ± 1.63
Age Range (years)	20-24	65-82
Height (cm)	182 ± 1.00	174 ± 2.05*
Weight (kg)	85 ± 3.95	87 ± 4.10
Body Mass Index (BMI)	26 ± 1.43	29 ± 1.30

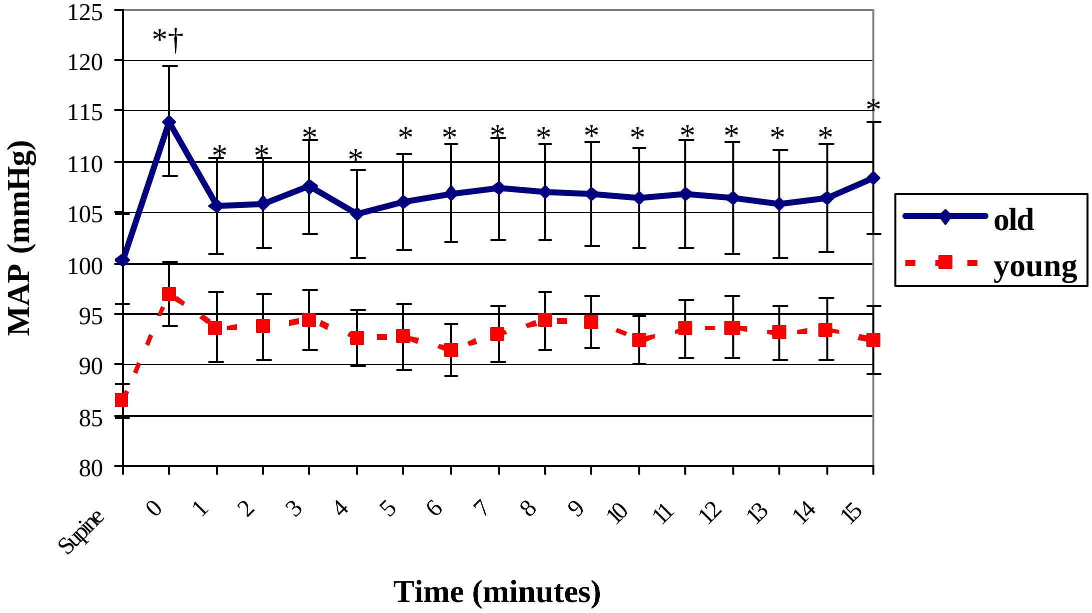
*p ≤ .05 between groups

Figure 1. Pre and post-standing volumetric measurements.



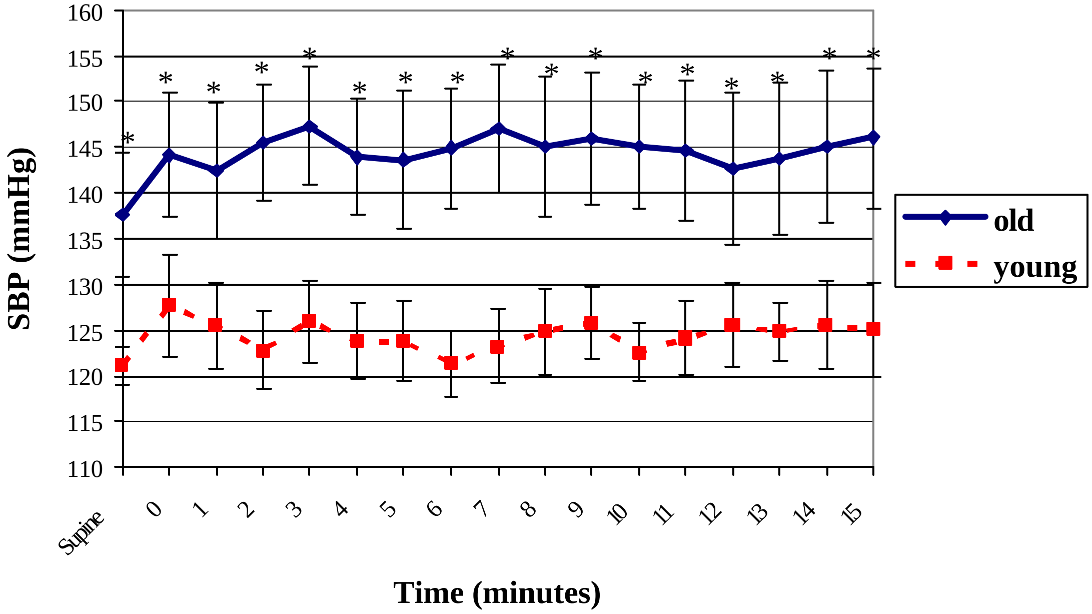
*p ≤ .05 from pre to post for both groups

FIGURE 2. Average mean arterial pressure (MAP) during testing.



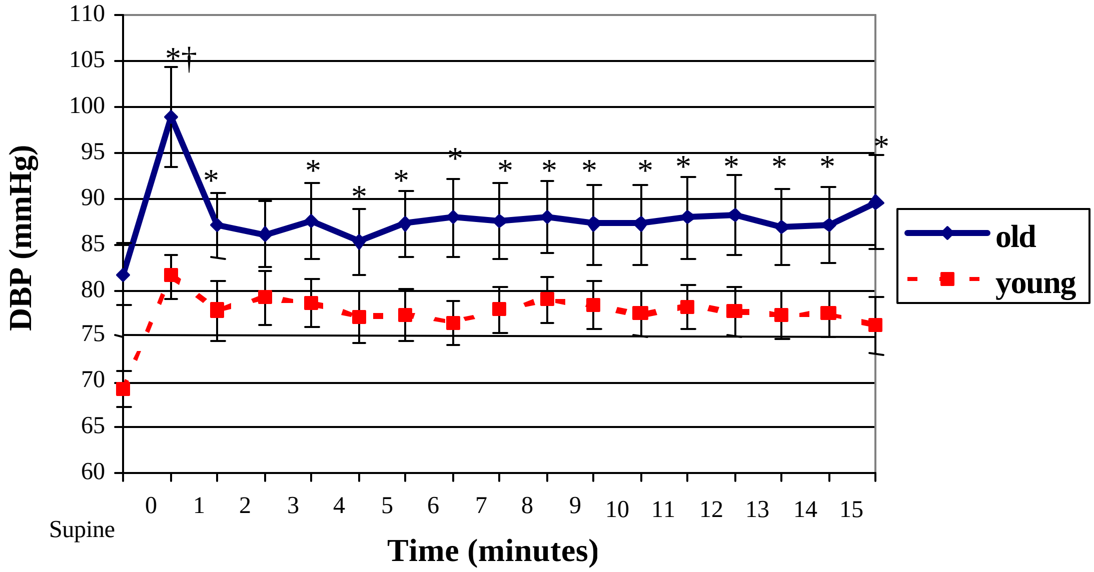
*p = .05 between groups
†p = .05 from supine to minute 0 for both groups

FIGURE 3. Average systolic blood pressure (SBP) during testing.



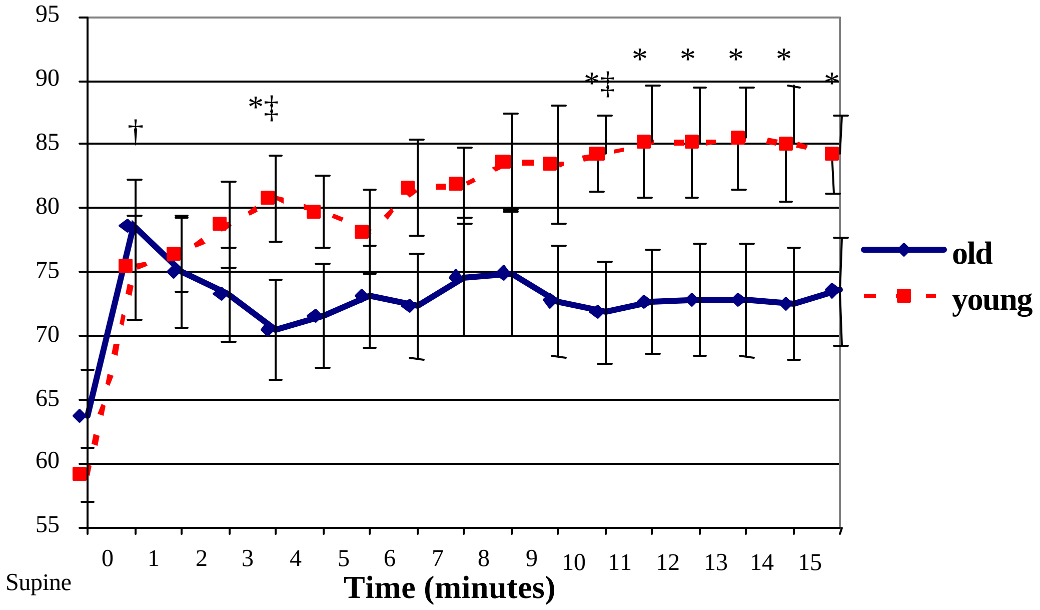
*p = .05 between groups

FIGURE 4. Average diastolic blood pressure (DBP) during testing.



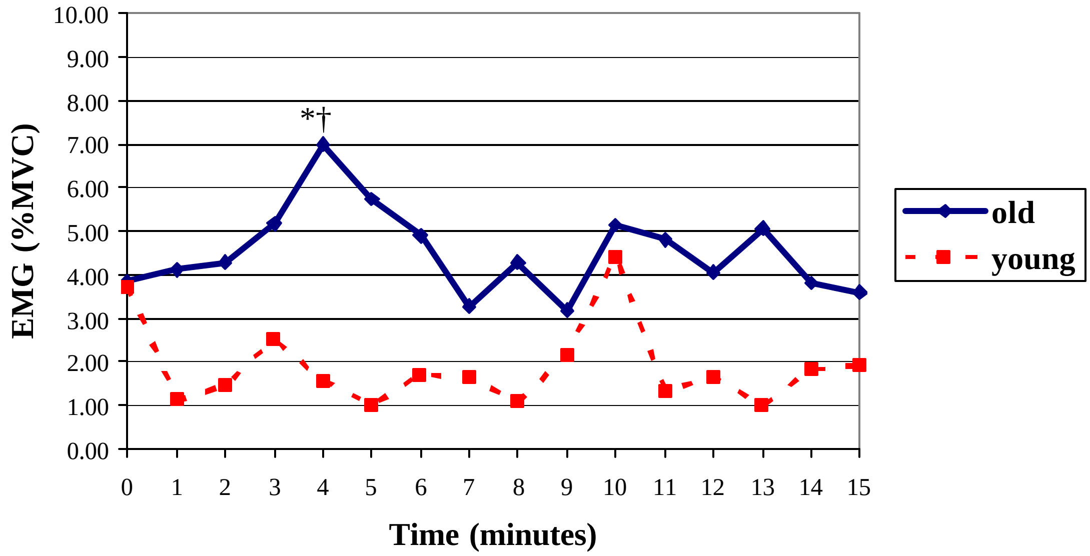
*p = .05 between groups
†p = .05 from supine to minute 0 for both groups

FIGURE 5. Average heart rate (HR) during testing.



*p = .05 between groups
†p = .05 from supine to minute 0 for both groups
‡p = .05 group x time for minutes 0-3 and minutes 5-10

FIGURE 6. Average gastrocnemius EMG during testing.



*p = .05 between groups

†p = .05 group x time for minutes 0-4

Mean Arterial Pressure (MAP). MAP was significantly greater in the older group during each time point ($p \leq .05$) (Figure 2). In addition, the MAP of both groups significantly increased ($p \leq .05$) from the supine position to minute 0 (data recorded within 30 seconds of standing up from the supine position), but did not significantly change within groups thereafter.

Systolic Blood Pressure (SBP). SBP of the older group was significantly greater than the young group during each time point ($p \leq .05$) (Figure 3). However, there were no within group differences throughout the entire testing protocol.

Diastolic Blood Pressure (DBP). DBP of the older group was significantly greater than the young group during each time point except for minute 2 ($p \leq .05$) (Figure 4). In addition, DBP increased significantly from supine to minute 0 for both groups ($p \leq .05$), but did not significantly change within groups thereafter.

Heart Rate (HR). HR of the older group was significantly lower than the young group at minute 3 and again near the end of the test protocol during minutes 10-15 ($p \leq .05$) (Figure 5). In addition, HR significantly increased from supine to minute 0 for both groups ($p \leq .05$). Further, there was a significant interaction ($p \leq .05$) during the first 3 minutes of the standing protocol such that the older group's HR began to decrease after minute 0 while the HR of the young group continued to increase. A significant interaction was also found during minutes 5-10 at which time the HR of the older group remained steady at approximately 73 bpm while the HR of the young group continued to increase.

Electromyography (EMG). The older group's gastrocnemius EMG activity was significantly greater than the young group during minutes 1-2, 4-6, 8, 11, and 13 ($p \leq .05$) (Figure 6). In addition, there was a significant interaction ($p \leq .05$) during minutes 0-4 such that the gastrocnemius EMG activity of the older group increased, whereas the EMG activity of the young group generally decreased during the initial 5 minutes of standing.

The older group's anterior tibialis EMG activity was significantly greater ($p \leq .05$) than the young group during minutes 0-5 of standing (Figure 7). In addition, anterior tibialis EMG activity significantly decreased ($p \leq .05$) over time within each group during minutes 0-4. There were no other significant differences in anterior tibialis EMG activity for the remainder of the standing test session.

DISCUSSION

It was hypothesized that age-associated changes in skeletal muscle would result in decreased LE EMG activity of older subjects during quiet standing resulting in greater displacement of central blood volume to the LE and decreased ability to maintain BP. However, older subjects demonstrated greater LE EMG activity during the standing test session, demonstrated similar changes in LE volumes as young subjects, and were able to adequately maintain BP during 15 minutes of quiet standing. Thus, the hypotheses of this study were not supported. In contrast, the results of this study suggest that any age-associated changes in skeletal muscle tone and activity were not of sufficient magnitude to adversely affect the ability of the LE musculature to limit central venous volume displacement during quiet standing. Furthermore, the greater LE EMG activity exhibited by the older subjects may have helped to compensate for an attenuated HR response found in the older subjects during the 15 minute standing test session.

The HR response of the older group in this study is consistent with other studies that have demonstrated similar BP responses between young and older groups during an orthostatic stress, despite a blunted HR response in the older subjects. Specifically, older subjects demonstrated a pronounced flattening of the HR response relative to young subjects during unsupported standing (3), during a lower body negative pressure (LBNP) protocol (19), and during a head-up tilt (HUT) protocol (7). However, BP was comparable in both groups during standing, LBNP, and HUT. Thus, regardless of the type of orthostatic stress, older individuals were consistently able to maintain BP despite an attenuated HR response, suggesting that other mechanisms are involved in BP regulation in older individuals.

One such mechanism might be an augmented vasomotor response (vasoconstriction) via increased sympathetic efferent activity to increase total peripheral resistance, which would result in increased DBP. Although sympathetic activity was not directly measured in this study, DBP of both groups increased similarly, indicating that the older group did not have an augmented vasomotor response. These results are consistent with findings in which plasma norepinephrine (NE) levels, an indicator of sympathetic efferent activity, were not different between young and older subjects during quiet standing or LBNP (19), or during a head-up tilt protocol (7). As a result, there were similar increases in DBP during all three orthostatic protocols. Thus, mechanisms other than sympathetic control must be involved in BP maintenance of the older group to compensate for the blunted HR response, specifically factors that limit or minimize the displacement of central venous volume to the lower extremities, such as the greater LE muscle activity found in this current study.

Although muscle mass, muscle innervation, muscle activity, and muscle strength have all been shown to decline with age, the greater LE EMG activity found in this study is consistent with studies regarding balance and LE EMG activity. For example, older subjects demonstrated greater EMG activity relative to young subjects during various standing conditions (2). Specifically, tibialis anterior EMG activity was greater for older subjects when standing with both a narrow and wide base of support and during eyes open and eyes closed conditions. The soleus/anterior tibialis EMG ratio, which represents the level of co-contraction of the muscles around the ankle was also greater for the older group for all standing conditions. The authors suggest that older individuals rely more on muscle co-contraction than on sensory input to maintain balance in standing. Thus, increased LE muscle activity may not only help older subjects maintain balance, but, as demonstrated in this study, may also assist with BP regulation in the standing position.

In two related studies, it was found that over 50% of relatively healthy individuals aged 62 years and older, living independently, had a fear of falling (13). Older subjects with a reported fear of falling tended to stiffen their musculature in an upright position as evidenced by increased co-contraction of antagonist muscles in the lower extremity (11). Although subjective reports of fear of falling were not obtained for this study, anecdotal comments made by the older subjects regarding the effort required to stand still for so long may infer that they used greater LE muscle activity for co-contraction to "stand still and quietly with minimal movement" as instructed.

In addition to greater muscle tone and activity, displacement of central venous volume to the LE may have also been limited in the older group by changes in the collagen content of the LE skeletal musculature and/or in venous compliance. The collagen concentration in skeletal muscle has been shown to increase with age, which would result in stiffer, less compliant muscle tissue thereby reducing the amount of blood volume displaced to the LE in standing (10). Venous compliance has been shown to decrease with age, which could reduce the ability of the veins to distend with increasing amounts of displaced blood volume during standing (7). Although these two factors were not measured in this study, one would expect less displacement if LE veins and muscle tissue were less compliant. In contrast, LE volumes of both groups increased comparably after 15 minutes of standing.

CLINICAL IMPLICATIONS

Both young and older subjects demonstrated similar increases in BP during standing, and vasomotor regulatory mechanisms adequately contributed to BP regulation for both groups as evidenced by similar increases in DBP. However, older subjects exhibited a blunted HR response relative to young subjects, suggesting that mechanisms other than vasomotor regulation were involved in BP maintenance of the older group. The increased LE EMG activity of the older group found in this study may have been a compensatory mechanism by which they were able to maintain BP despite an attenuated HR response. Previous studies support the role of increased LE muscle activity via co-contraction to assist in maintaining balance as individuals age. The results of this study suggest that increased LE muscle activity is also important for maintaining BP as one ages. Thus, clinicians should specifically focus on LE muscle function and strength in the examination and evaluation of older clients. The role of the LE musculature in balance, falls, and BP maintenance of older clients must also be considered and addressed in the plan of care and specific interventions used in the clinical setting. Further research is needed to identify and clarify the precise role that LE muscle function has in the complex mechanisms of both balance and BP regulation associated with aging.

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