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Original Article

Relationships between hamstring morphological characteristics and postural balance in elderly men

Ty B. Palmer, Ahalee C. Farrow, Bailey M. Palmer

Department of Kinesiology and Sport Management, Texas Tech University, Lubbock, TX

Abstract

Objectives: The link between hamstring morphology and postural balance performance in older adults is not well understood. This study aimed to examine the relationships between hamstring morphological characteristics of muscle size (cross-sectional area [CSA]) and quality (echo intensity [EI]) and postural balance with the eyes open and closed in elderly men. **Methods:** Nineteen healthy elderly men (age= 73±4 years) participated in this study. Muscle CSA and EI were determined from ultrasound scans of the hamstrings. Postural balance was assessed with the eyes open and closed using a commercially designed balance testing device, which provides a measurement of static stability based on the sway index. **Results**: The sway index with eyes closed was significantly related to muscle EI (r=0.474; P=0.040) but not CSA (r=0.021; P=0.932). The sway index with eyes open was not related to muscle CSA (r= -0.036; P=0.883) or EI (r= -0.079; P=0.747). **Conclusions:** The significant relationship observed between the sway index with eyes closed and muscle EI suggests that hamstring muscle quality may be a characteristic relevant to postural balance in the absence of visual feedback. These findings may provide important insight regarding the morphological mechanisms involved in maintaining balance and in the development of proper training programs aimed at improving postural stability in older individuals.

Keywords: Cross-Sectional Area, Echo Intensity, Falls Risk, Ultrasound, Visual Feedback

Introduction

In older adults, maintaining a high level of postural balance is essential for the independent and successful performance of activities of daily living[1]. However, numerous studies investigating balance as a function of age have reported substantial decreases in postural balance performances in older populations[1-3]. Decreases in standing balance as indicated by increases in postural sway, have been associated with a higher incidence of falls and fall-related injuries[4,5], which may lead to an elevated risk of future disability and mortality.

The hamstrings and other leg muscles have been identified in the elderly as being important contributors to maintaining standing balance[6]. When standing, older adults activate the hamstrings to stabilize the hip joint (because the hamstrings have been reported to account for a large portion of the hip extension torque produced at 0° of hip flexion[7], these muscles may play an important role in stabilizing the hip joint in the standing position) in an attempt to improve postural balance in the sagittal plane[8,9]. Age-related decreases in hamstring muscle size have been shown to be accompanied by deficits in rapid torque production of the hip extensors[10], and because the ability to produce torque rapidly at the hip is a characteristic relevant to postural sway (individuals with greater postural sway during quiet standing have been shown to exhibit lower hip extension rapid torque production[11]), hamstring morphological characteristics, including measurements of muscle size (i.e. cross-sectional area [CSA]), may influence postural balance in the elderly. Measurements of muscle quality, such as echo intensity (EI), are indicative of a muscle's fat and fibrous tissue content[12] and may also contribute to the age-related deficits in postural balance. For example, the amount of fat and connective tissue within a muscle influences the strength of a muscle's contraction[10] and consequently, a decrease in muscle tissue quality and thus, muscle strength, may in theory, lead to a reduced ability to generate the forces required to successfully regulate postural sway.

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Corresponding author: Ty B. Palmer, PhD, Assistant Professor, Department of Kinesiology and Sport Management, Texas Tech University, Lubbock, TX 79409
E-mail: ty.palmer@ttu.edu

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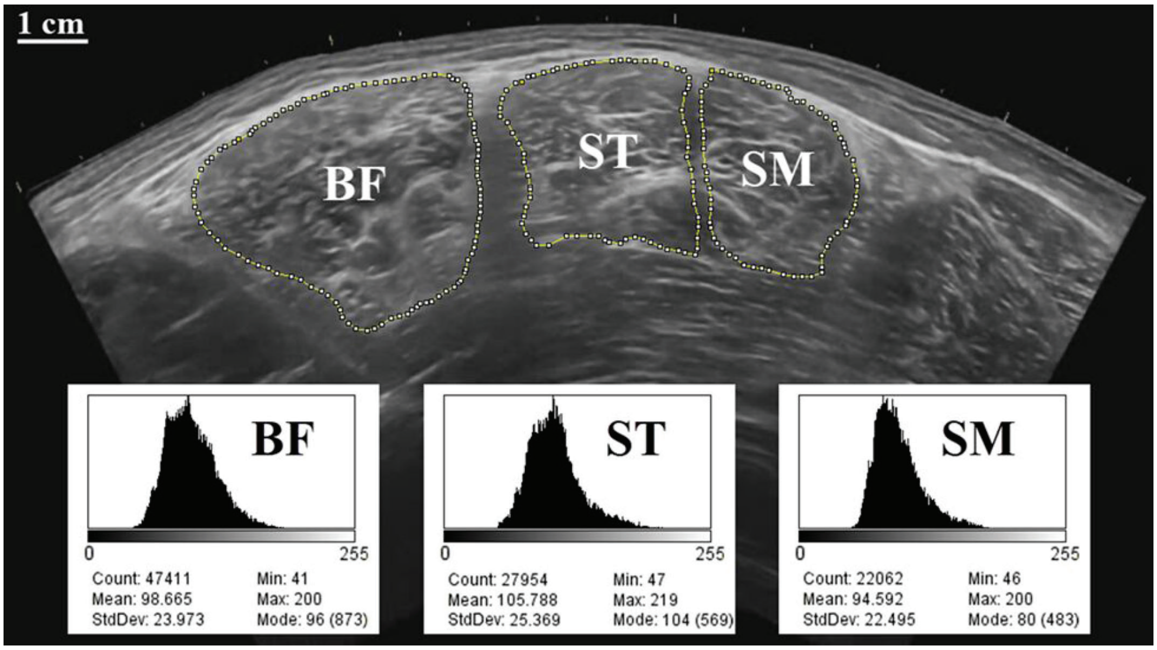

Figure 1. Transverse plane panoramic ultrasound image of the long head of the biceps femoris (BF), semitendinosus (ST), and semimembranosus (SM) muscles. Hamstring muscle cross-sectional area (CSA) and echo intensity (EI) values were determined by taking the sum of the CSAs and the mean of the EIs of the BF, ST, and SM muscles, respectively. Examples of the corresponding gray-scale histogram values from each muscle are provided.

Previous studies have shown significant relationships between hamstring morphological characteristics (i.e. CSA and EI) and functional performance in older adults[10,13]. However, the performance data used in these studies were limited to maximal and rapid strength[10,13] and thus, it remains unclear whether significant relationships exist between hamstring morphology and other functional performance parameters, such as standing postural balance. Moreover, the contribution of the muscles involved in maintaining balance has been reported to change based on the demands of the postural task (i.e., changing the base of support, standing with and without vision)[3,14]. Thus, it may be of great value when examining muscle morphology and balance-based relationships to assess balance in different conditions of varying difficulty, for example, standing with the eyes open and eyes closed. Investigating such relationships may help improve our understanding of the mechanisms that influence balance performance with and without vision as well as guide therapeutic interventions aimed at reducing the risk of falls in older individuals.

According to Laughton et al.[15], older adults exhibit greater hamstring muscle activity than younger adults during quiet standing, which may be due, in part, to the elderly having a more flexed and rigid posture. This flexed posture causes greater forward displacement of the body's center of gravity[15]. By activating the hamstrings, older adults may be attempting to produce hip extension torque to control balance and more specifically, prevent the body's center of gravity from moving further forward[15]. A greater reliance on hip joint action has been reported in the elderly when attempting to regulate postural sway with the eyes closed versus the eyes open[16]. Thus, it is possible that morphological characteristics of the hip joint muscles, including the hamstrings, may play a greater role in producing torque and thereby regulating sway in the absence of visual feedback; however, further research is needed to test this hypothesis. Therefore, the purpose of the present study was to examine the relationships between hamstring muscle CSA and EI and postural balance with the eyes open and closed in elderly men.

Methods

Participants

Nineteen elderly men (mean±SD; age= 73±4 years; height= 174±5 cm; mass= 85±10 kg) volunteered to participate in this study. Each participant completed a self-administered questionnaire prior to testing to assess their health history and volume of physical activity. None of the participants reported any current or ongoing neuromuscular diseases or musculoskeletal injuries specific to the ankle, knee, or hip joints. Of the 19 elderly men, 18 reported engaging in 0.5 – 12 $h \cdot wk^{-1}$ of aerobic exercise and 11 reported 0.5 – 8 $h \cdot wk^{-1}$ of resistance exercise. Given their reported levels of aerobic (4.7±3.5 $h \cdot wk^{-1}$) and resistance (1.6±2.2 $h \cdot wk^{-1}$) exercise behaviors, these individuals might be best categorized as physically active participants[10]. This study was approved by the university's institutional review board for human subject's research, and each participant read and signed an informed consent document.

Procedures

Each participant visited the laboratory on two occasions separated by 2-7 days. During the first visit, panoramic ultrasound imaging assessments of the hamstring muscle group were performed on the right leg, and participants were familiarized with the testing procedures by performing several postural balance assessment trials. During the second visit, participants completed four static balance assessments involving two assessments at each condition (eyes open and eyes closed). Because the effect of leg dominance has not been demonstrated to be important for hamstring muscle CSA[17] nor EI[18], leg dominance was not controlled for, and the right leg only was tested for all ultrasound assessments in this study.

Panoramic ultrasound imaging assessment

Panoramic ultrasound images of the hamstring muscle group (long head of the biceps femoris [BF], semitendinosus [ST], and semimembranosus [SM] muscles) were obtained on the right leg using a portable B-mode ultrasound imaging device (GE Logiq S8, Milwaukee, WI) and linear-array probe (Model ML6-15-D; 4-15 MHz; 50 mm field-of-view) as described previously[10]. Ultrasound settings were optimized for image quality, including gain (50 dB), depth (8 cm), and frequency (12 MHz) and were set prior to testing and held constant across participants. All ultrasound images were scanned with the probe oriented in the transverse plane at 50% of the distance between the greater trochanter and the lateral joint line of the knee. For each participant, two panoramic ultrasound images were taken, and the mean was calculated for each of the dependent variables which included hamstring muscle CSA and EI.

All ultrasound images were analyzed using ImageJ software (version 1.50i; National Institutes of Health, Bethesda, MD) and were scaled from pixels to cm before analysis[19]. Muscle CSA of the BF, ST, and SM were determined using the polygon selection function by selecting a region of interest (ROI) within each muscle that included as much of the muscle as possible without any surrounding bone or fascia (Figure 1)[10]. Muscle quality was determined from the EI values assessed by gray-scale analysis using the standard histogram function of the same pre-selected ROIs that were used to calculate CSA for each muscle (Figure 1)[10]. EI values were corrected for subcutaneous fat thickness[19], which was calculated at the midline of the BF, ST, and SM, using the method described by Young et al.[20]. Hamstring muscle CSA and EI were determined by taking the sum of the CSAs and the mean of the EIs of the BF, ST, and SM muscles, respectively.

Postural balance assessment

Postural balance assessments were performed using a Biodex Balance System SD (Biodex Medical Systems, Inc, Shirley, NY, USA) which provides a measurement of static stability based on the sway index, determined as the postural sway from the center point (of the platform) on which the participant stood[11]. For all testing, participants removed their footwear and stood on the platform of the balance system with feet shoulder width apart and hands positioned on the hips. For each assessment, a custom protocol was used, in which participants were instructed to stand "as still as possible" with their eyes open or closed for 20 s on the platform surface, which was kept locked in a static stability position. Calculation of the sway index involved recording the position of each participant's foot using the coordinates on the platform's grid (participants initially positioned their feet at suggested coordinates based on their height and then small adjustments were made to the heel position and foot angle until the center of pressure as indicated by the cursor was positioned in the middle of the grid on the computer screen[21]) and entering it into the balance system computer, and subsequently deriving the sway index value which was calculated and displayed by the computer at the conclusion of each assessment[11]. The balance system computer calculates the sway index by taking the standard deviation of the stability index[21], which represents body sway in both the anterior-posterior and medial-lateral axes[22]. Two balance assessments were performed with the eyes open and then with the eyes closed[23], and the average sway index of the two assessments for each condition was used for all subsequent analyses. Acceptable reliability for the Biodex Balance System has been demonstrated with an intraclass correlation coefficient of 0.81[21].

Statistical analyses

We inspected data for normality using the Shapiro-Wilk test. Boxplots were used to identify outliers, defined as values that exceeded 1.5 times the interquartile range away from the top or bottom of the box[24]. A paired samples *t*-test was used to compare the sway index between the eyes open and closed conditions. Pearson correlation coefficients (*r*) were calculated to examine the relationships between the sway index with the eyes open and closed and hamstring muscle CSA and EI. Statistical analyses were performed using IBM SPSS Statistics v. 25.0 (SPSS, Inc., Chicago, IL), and an alpha level of $P<0.050$ was used to determine statistical significance.

Results

No outliers were identified, and all data were confirmed as being normally distributed. Table 1 shows the means, SDs, and confidence intervals for hamstring muscle CSA, EI, and the sway index (eyes open and closed). The sway index was significantly higher ($P<0.001$) with the eyes closed than with

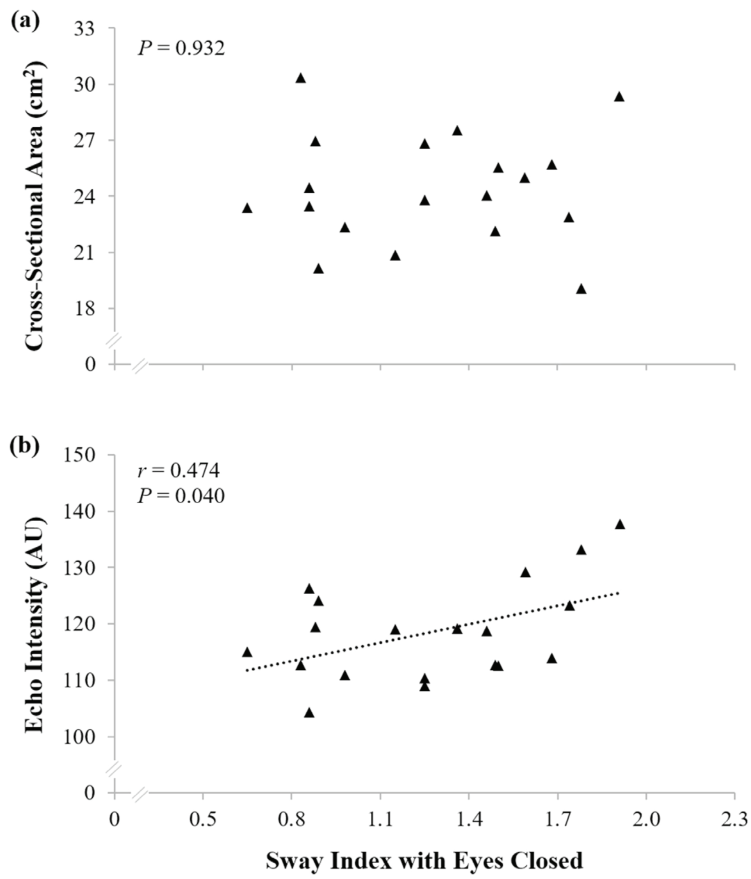

Figure 2. Relationships between the sway index with the eyes closed and hamstring muscle (a) cross-sectional area and (b) echo intensity.

the eyes open. A significant positive relationship was observed between the sway index with the eyes closed and muscle EI (r=0.474; P=0.040) but not CSA (r=0.021; P=0.932) (Figure 2). No significant relationships were observed between the sway index with the eyes open and muscle CSA (r= -0.036; P=0.883) or EI (r= -0.079; P=0.747).

Discussion

Previous studies investigating balance as a function of age have reported reduced postural stability in the elderly[2,3]. Postural balance deficits in elderly adults could be due to a number of different factors including changes in vestibular and visual function, central processing, and neural pathways for motor control[25]. Another possible factor could be age-related changes in muscle quality. In this study, we assessed muscle quality of the hamstrings using EI as an index of the amount of fat and connective tissue within the muscles. Because higher EI values reflect a greater amount of noncontractile tissue (fat and connective tissue) which has been linked to postural instability (i.e. reduced postural stability has been shown in individuals with greater amounts of fat[26]), it is possible that higher EI values which are typically observed with advanced age[10], may be detrimental to standing balance performance in elderly populations. Our findings would support this hypothesis given the significant positive relationship in the elderly men between the sway index with the eyes closed and muscle EI (r=0.474); however, no such relationship was observed between the sway index and muscle CSA (r=0.021) (Figure 2). Since muscle CSA of the hamstrings has been reported to be less affected by age than other variables (i.e. muscle quality)[27], it may not be as important in explaining the variance associated with postural balance or falls risk in older adults. Support for this is based on the findings of Inacio et al.[28] who showed that muscle CSA was less effective than muscle quality of the hamstrings at differentiating between older adults with and without a history of falls. It has been suggested that a high amount of intramuscular fat and connective tissue, because of its adverse effect on muscle quality[12], may cause a decrease in rapid strength[10,29] that could impair one's ability to perform the fast and forceful muscle actions required to successfully regulate postural sway[30,31]. Although further research is still needed to test this hypothesis, the present findings of a significant relationship between the sway index with the eyes closed and muscle EI suggest that hamstring muscle quality

Table 1. Mean, SD, and 95% confidence interval (CI) values for hamstring muscle cross-sectional area, echo intensity, and the sway index with eyes open and closed.

Variable	Mean	SD	95% CI
Cross-Sectional Area (cm^2)	24.41	2.97	22.98-25.84
Echo Intensity (AU)	118.53	8.73	114.32-122.73
Sway Index			
Eyes Open	0.64	0.15	0.56-0.71
Eyes Closed	1.27[a]	0.38	1.09-1.45

[a] *Significantly higher sway index with eyes closed compared to eyes open (P<0.050).*

may be a characteristic relevant to postural balance in the absence of visual feedback.

It is interesting to note that although muscle EI was related to the sway index with the eyes closed, it was not related to the sway index with the eyes open. Previous authors have suggested that during normal quiet standing with eyes open, the amount of postural sway is relatively low and therefore, easily corrected by the smaller muscles at the ankle[3,32]. However, during more challenging postural tasks, the sways become too great for the smaller muscles at the ankle to correct, and as such, larger muscles at the hip, including the hamstrings, must be activated to successfully maintain equilibrium[3]. In this study, the amount of sway as indicated by the sway index was significantly higher with the eyes closed than eyes open (Table 1). Thus, the possibility of greater hamstring involvement to regulate the higher sway produced in the absence of visual feedback may explain why we observed a stronger relationship between hamstring muscle EI and the sway index with the eyes closed.

Although not examined in the present study, we do acknowledge that additional variables and muscles may contribute to the age-related reductions in standing postural balance. Specifically, investigations have suggested that standing balance in older adults may be influenced by changes in muscle composition of the gluteus maximus[28], reciprocal inhibition between the soleus and tibialis anterior[33], and rapid strength of the quadriceps[31] and hip abductors (i.e., tensor fasciae latae, gluteus medius)[30]. Future studies are needed to determine the factors that are most important for explaining the variance associated with postural stability in the elderly.

In summary, our findings revealed that the sway index with the eyes closed was significantly related to hamstring muscle EI, but not CSA in elderly men. These findings suggest that hamstring muscle quality, rather than size, may be a characteristic relevant to postural balance in the absence of visual feedback. Clinicians and practitioners may use these findings as morphological screening tools to help predict balance performances with the eyes closed in older adults. Age-related impairments in these performances may result in difficulties in undertaking activities of daily living that involve challenging situations where vision is either absent or reduced (i.e., getting up at night, walking in a dimly lit area, etc.)[34]. Such impairments may also increase the risk of falling. Consequently, training programs aimed at increasing muscle quality of the hamstrings may be beneficial for improving postural balance as well as reducing the potential risk of falls and fall-related injuries in elderly populations.

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