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Original Article

# Differences in Ankle Muscle Activity During Static Balance According to Age and Ankle Proprioception

Seo-hyun Kim[1], PT, BPT, Chung-hwi Yi[2], PT, PhD, Gyu-hyun Han[1], PT, BPT, Su-bin Kim[1], PT, BPT

[1]Department of Physical Therapy, The Graduate School, Yonsei University, [2]Department of Physical Therapy, College of Software and Digital Healthcare Convergence, Yonsei University, Wonju, Korea

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Corresponding Author
Chung-hwi Yi
E-mail: pteagle@yonsei.ac.kr
https://orcid.org/0000-0003-2554-8083

**Key Words**
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**Background:** Older adults use different ankle muscle activation patterns during difficult static balance conditions. It has been suggested that this is related to a decline in proprioception with age, resulting in reduced postural balance. However, the association between proprioception and ankle muscle activity during quiet standing has not been directly assessed.

**Objects:** This study aimed to investigate the effects of age and sensory condition on ankle muscle activity and the association between ankle proprioception and ankle muscle activity.

**Methods:** We recruited 10 young women and 9 older women. Ankle proprioception was evaluated using joint position sense (JPS) and force sense (FS) divided by dorsiflexion and plantarflexion. The electromyographic activity of the tibialis anterior (TA) and gastrocnemius (GCM) muscles was collected during quiet standing.

**Results:** Older women activated GCM muscle more than young during quiet standing and when performing difficult tasks. Older women had more errors in JPS dorsiflexion and FS plantarflexion than did young. The GCM muscle activity is related to JPS dorsiflexion and FS plantarflexion.

**Conclusion:** Lower proprioception of the GCM with age leads to increased muscle activity, resulting in reduced postural balance. There was no difference in TA proprioception or muscle activity among older women with frequent physical activity.

## INTRODUCTION

Postural control is the ability to maintain steady upright standing and is a complex neural process regulated by the visual, vestibular, and proprioceptive systems, all of which are decline with age [1,2]. During quiet standing, the most sensitive information on postural control is provided by proprioceptive inputs, because the proprioceptive threshold for the perception of body sway during quiet standing is lower than that of visual and vestibular systems [2-5]. Many studies have shown that older adults exhibit lower proprioception of the ankle in terms of a larger error of joint position sense (JPS) and force sense (FS), which is associated with reduced postural balance [5-10]. In addition, lower proprioception has been shown to predict falls [11].

A decline in proprioception with age is particularly relevant in reduced balance, as older adults rely more on proprioceptive systems than young adults during postural control [12,13]. Benjuya et al. [13] found that postural balance in older adults was less affected by visual input than in young adults during quiet standing. Wiesmeier et al. [12] found that older adults use proprioceptive inputs more than visual and vestibular inputs during postural control. This difference in the sensory importance of postural balance was accompanied by an age difference in muscle activation patterns, with older adults employing more activation of their lower leg muscles.

When exposed to a difficult balance environment (e.g., change in the support base), older adults are likely to develop compensatory strategies using different muscle activation patterns around the ankle joint to avoid postural instability [14,15]. Laughton et al. [14] found an association between postural balance and plantar flexor muscle activity in older adults who are vulnerable to falls. Benjuya et al. [13] found that older adults demonstrated significantly higher levels of ankle muscle activity with increased postural sway. However, how low proprioception affects ankle muscle activation during postural control remains unclear.

Craig et al. [9] found relationship between proprioception and ankle muscle activity, but they used the muscle co-contraction index calculated using tibialis anterior (TA) and gastrocnemius (GCM) muscle activities. And they did not investigate the difference in FS between young and older adults. Kim et al. [8] found a significant difference in JPS and FS between young and older women with reduced postural balance. However, they did not examine the ankle muscle activity during postural control. The association between proprioception (JPS and FS) and ankle muscle activity has not been directly assessed in previous studies.

The aim of this study was to investigate the influence of age and sensory conditions on ankle muscle activity. We compared the JPS and FS between young and older women and examined the relationship between proprioception and ankle muscle activity. Unlike previous studies, we compared ankle muscle activity during quiet standing and measured ankle proprioception during dorsiflexion and plantarflexion. We hypothesized that there were significant differences in ankle muscle activities according to age and sensory condition and that there was a significant relationship between ankle proprioception and ankle muscle activities.

# MATERIALS AND METHODS

## 1. Participants

Herein, we recruited 10 healthy young women (age: 23.0 ± 2.7 y; height: 161.9 ± 4.1 cm; weight: 59.7 ± 7.4 kg) and 9 healthy older women (age: 61.7 ± 2.6 y; height: 159.0 ± 5.1 cm; weight: 57.0 ± 8.5 kg). An inclusion criterion was that the women engaged in physical activity, outside, more than 3 times per week. Participants were excluded if they had a medical history of any neurological disorders or medication use that could impair postural control. Older women who had fall accidents and had undergone orthopedic surgery of the lower extremities within the last year were excluded. Women who experienced dizziness while standing for a minute were excluded. All participants provided written informed consent to participate in the study, and the experimental procedure was approved by the Institutional Review Board of Yonsei University Mirae Campus (IRB no. 1041849-202204-BM-076-02).

## 2. Procedure

### 1) Joint position sense

The JPS was assessed using a Biodex dynamometer (Biodex System 4 Pro™; Biodex Medical Systems, Inc., Shirley, NY, USA). The participants sat on the chair of the device with a 70° hip flexion and 45° knee flexion. During testing, participants thighs were fixed to the support on a chair using a band [16]. The dynamometer rotation axis was to the device with two strips designed to hold the ankle joint. The ankle joint was initially positioned at 0°, and passively dorsiflexed and plantarflexed by the dynamometer to the target position (10° dorsiflexion and 25° plantarflexion), held for 5 s, and returned to the initial position. Subsequently, the participants were instructed to match the target position using active dorsiflexion and plantarflexion. When the participants felt that they had found the target position, they pressed a stop button and the ankle position angle was recorded. The JPS error was calculated as the difference from the reference angle and was averaged over three trials.

### 2) Force sense

The FS was evaluated using a force reproduction test. The participant sat on a chair as in the JPS test. They could see the force graph generated during isometric contraction on the display. The participant performed isometric contractions for 5 s with a reference force (10 N of dorsiflexion and 25 N of plantarflexion). The participant was asked to perform isometric contractions on the device to maintain the reference force 3 times for 5 s. During testing, participants were blindfolded to exclude any possible visual cues. The FS error value was calculated by averaging the absolute difference between the reference force and the reproduction force for the middle 3 s out of 5 s. The FS error used in the data analysis was averaged over the three trials.

### 3) Muscle activity

The participant stood quietly, barefoot, on the ground with their feet together and arms hanging on the sides of their body. The participants were instructed to stand quietly and avoid voluntary movements during the measurements, each measurement required 60 s. Surface electromyography (EMG; Noraxon TeleMyo DTS; Noraxon Inc., Scottsdale, AZ, USA) was used to record muscle activities from the TA muscle and GCM muscle. Two unipolar surface electrodes were placed in each muscle. The location of the electrodes was recommended by Criswell [17]. Two electrodes, 2 cm apart, were placed lateral to the medial shaft of the tibia for the TA muscle. For the GCM, one electrode was placed on the medial GCM muscle belly and the other was placed on the lateral GCM muscle belly. The EMG signal was normalized to each maximal signal obtained during quiet standing with eyes open (EO) [18].

Each participant was tested under two sensory conditions: EO and eyes closed with the head tilted backward (ECHB). The EO condition involved staring at a stationary sign drawn on a whiteboard on the wall 2 m in front of the participant. The ECHB condition involved staring at a sign mounted on the ceiling approximately 30 cm in front of the participants and then close their eyes. The ECHB condition reduced the influence of visual and vestibular inputs on postural control, allowing the isolation of proprioceptive inputs of postural balance. The participants rested for one minute between each measurement to avoid fatigue.

### 3. Statistical Analysis

A 2 × 2 mixed analysis of variance (ANOVA) was applied to examine the main and interaction effects of age and sensory condition. The dependent variables in this analysis were TA muscle activity and GCM muscle activity. The independent variables were age (young or old) and the sensory condition (EO or ECHB). To determine differences between young and older women, an independent t-test was performed for JPS dorsiflexion, JPS plantarflexion, FS dorsiflexion, and FS plantarflexion. The relationship between proprioception and muscle activity was evaluated using Pearson correlation analysis. Statistical significance was set at $p < 0.05$. All data were analyzed using SPSS statistics version 26 (IBM Co., Armonk, NY, USA).

## RESULTS

### 1. Ankle Muscle Activities

A main effect of age and sensory condition was not observed for TA ($p = 0.143$, $F = 2.357$; $p = 0.125$, $F = 2.600$); however, for GCM, the effect of age and sensory condition was significant ($p = 0.007$, $F = 9.502$; $p = 0.004$, $F = 10.790$). An age × sensory condition interaction was not found for TA ($p = 0.288$, $F = 1.203$), but was found for GCM ($p = 0.005$, $F = 10.441$) (Table 1).

### 2. Age Differences in Ankle Proprioception

Significant differences were observed in JPS dorsiflexion ($p = 0.021$, $t = 2.532$) and FS plantarflexion ($p = 0.010$, $t = 2.910$). These results indicate that older adults produce more errors during JPS dorsiflexion and FS plantarflexion. JPS plantarflexion ($p = 0.123$, $t = 1.623$) and FS dorsiflexion ($p = 0.223$, $t = 1.266$) were not significantly different with respect to age (Table 2).

### 3. Association Between Proprioception and Ankle Muscle Activities

Pearson's correlation demonstrated significant positive associations between JPS dorsiflexion and GCM activity ($r = 0.467$, $p = 0.044$) and between FS plantarflexion and GCM activity ($r = 0.561$, $p = 0.012$) in the EO condition. In the ECHB condition,

**Table 1.** ANOVA analyses by age and sensory condition

| Muscle | Group | | Sensory condition | | Group X Sensory condition | |
|---|---|---|---|---|---|---|
| | F | p-value | F | p-value | F | p-value |
| TA | 2.357 | 0.143 | 2.600 | 0.125 | 1.203 | 0.288 |
| GCM | 9.502 | 0.007* | 10.790 | 0.004* | 10.411 | 0.005* |

TA, tibialis anterior; GCM, gastrocnemius. *p < 0.05.

**Table 2.** Age differences in JPS and FS errors

| Variable | Young | Older | p-value (t) |
|---|---|---|---|
| JPS DF | 1.46 ± 0.65 | 2.93 ± 1.71 | 0.021* (2.532) |
| JPS PF | 2.15 ± 0.68 | 3.11 ± 1.72 | 0.123 (1.623) |
| FS DF | 2.10 ± 1.38 | 2.96 ± 1.59 | 0.223 (1.266) |
| FS PF | 3.43 ± 2.46 | 7.97 ± 4.23 | 0.010* (2.910) |

Values are presented as mean ± standard deviation. JPS, joint position sense; FS, force sense; DF, dorsiflexion; PF, plantarflexion. *p < 0.05.

**Table 3.** Correlation between proprioception and muscle activity

| Variable | JPS DF | JPS PF | FS DF | FS PF |
|---|---|---|---|---|
| EO TA | −0.085 (0.729) | −0.413 (0.078) | −0.222 (0.360) | 0.224 (0.356) |
| EO GCM | 0.467 (0.044*) | −0.110 (0.655) | −0.206 (0.398) | 0.561 (0.012*) |
| ECHB TA | 0.172 (0.481) | −0.227 (0.350) | −0.021 (0.932) | 0.447 (0.055) |
| ECHB GCM | 0.524 (0.021*) | −0.069 (0.780) | −0.135 (0.582) | 0.582 (0.009*) |

Values are presented as r (p-value). JPS, joint position sense; DF, dorsiflexion; PF, plantarflexion; FS, force sense; EO, eye open; TA, tibialis anterior; GCM, gastrocnemius; ECHB, eye closed with the head tilted backward. *p < 0.05.

a positive relationship was revealed between GCM activity and JPS dorsiflexion (r = 0.524, p = 0.021) and between GCM activity and FS plantarflexion (r = 0.582, p = 0.009). Neither sensory condition showed a significant correlation between proprioception and TA activity (p = 0.055–0.932) (Table 3).

## DISCUSSION

The objective of this study was to investigate the effects of age and sensory condition on ankle muscle activity, and the association between ankle proprioception and ankle muscle activities. Our results indicate that the interaction effect of age and sensory condition is due to an increase in the GCM muscle activity. It is associated with low proprioception, particularly in JPS dorsiflexion and FS plantarflexion. However, the association between proprioception and the TA muscle activity remains unclear.

We found that GCM muscle activity was affected by age, sensory condition and age × sensory interaction effect, but TA muscle activity was not affected. In healthy older adults, ankle muscle activities do not significantly differ from those in young adults while quiet standing in a comfortable state [14,15]. However, there is a significant difference when performing difficult balancing activities, such as closing the eyes or narrowing the base of support [13,19]. In our study, participants were instructed to narrow their base of support, and in the ECHB condition, they performed more difficult balancing tasks. Our result is in accordance with previous studies demonstrating that older adults have more GCM activity than young adults during quiet standing with difficult tasks. In addition, the present study confirmed that sensory conditions induced greater GCM muscle activation in older adults. Older adults show increased activation of the GCM muscle by the addition of causes associated with proprioception and aging during postural control in a condition in which proprioception is emphasized.

However, there were no significant main effects or interaction effects on TA activities. In previous studies, there was a noticeable difference in muscle activity between older and young adults TA activities [15,20]; however, our results contradict the literature. During quiet standing, the plantar flexors are continuously activated to maintain a stable balance because the center of mass lies in front of the ankle joint. Dorsiflexors are rarely activated during quiet standing, but people with impaired postural control frequently engage dorsiflexors [18,20]. This suggests that older adults recruited in this study had no difficulty accompanying more TA activation to static balance because they were healthy and performed physical activity for more than 3 times per week.

Previous studies confirmed JPS only with dorsiflexion; however, in this study, we confirmed JPS and FS by performing both dorsiflexion and plantarflexion, and found conflicting results between dorsiflexion and plantarflexion [9,10,21-23]. Significant differences in age were observed in JPS dorsiflexion and FS plantarflexion, but there were no significant differences in age in JPS plantarflexion and FS dorsiflexion. These results suggest that the JPS and FS tests are affected by different factors, depending on the direction.

We found significant association between JPS dorsiflexion and GCM muscle activity in both conditions (EO and ECHB), and between FS plantarflexion and GCM muscle activity in both conditions. This is the first study to confirm the correlation between proprioception and muscle activation after examining proprioception by dividing it into dorsiflexion and plantarflexion. Examining in two directions is a necessary to determine which muscles are affected more by each direction. The JPS test is affected by muscle spindles that are highly sensitive to changes in muscle lengthening, because excessive velocity change or muscle contraction is not required during the JPS test [2,8,24]. It can be assumed that JPS dorsiflexion is affected by lengthening of the plantar flexor muscles. Unlike the JPS test, in which muscle lengthening occurs, there was no change in muscle length in the FS test because isometric contraction was used. Therefore, the FS reflects muscle proprioception by Golgi tendon organs, which are sensitive to muscle contraction [2,8,24]. It can be assumed that the FS plantarflexion is affected by plantar flexor contraction. Considering that proprioception related to the plantar flexor is correlated with GCM muscle activity, it can be noted that the decrease in GCM proprioception in older adults increases GCM muscle activity during quiet standing.

Consequently, according to our results, a decrease in plantar flexor proprioception due to aging causes excessive plantar flexor muscle activity. In the case of healthy older adults who regularly performed physical activity, there was no significant difference in dorsiflexor proprioception according to age, and as a result, there was no significant difference in dorsiflexor muscle activity during quiet standing. Recognition of body movements is delayed by the reduced proprioception of older adults, which is shown in the muscle activation reaction time [25], where older adults show a delay compared to young adults. Delayed perception of body position requires more counter-movements, which increases muscle activity and accompanies increased postural sway. Decreased proprioception in older adults increases postural muscle activity, consequently, reducing postural balance; our results support this idea.

## CONCLUSIONS

The present study demonstrated an association between proprioception and ankle muscle activity in older adults during static balance. Importantly, our results suggest that when proprioception was measured by JPS and FS, the associated muscle was identified by dividing them into dorsiflexion and plantarflexion, which were associated with muscle activity during postural control. However, our results contradicted previous studies that showed that older adults activate the TA muscle more during postural control. This may be because the older adults in this study frequently engaged in physical activity.

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## CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

## AUTHOR CONTRIBUTIONS

Conceptualization: Seo-hyun Kim. Data curation: Seo-hyun Kim, Gyu-hyun Han, Su-bin Kim. Formal analysis: Seo-hyun Kim. Funding acquisition: Chung-hwi Yi. Investigation: Seo-hyun Kim, Gyu-hyun Han, Su-bin Kim. Methodology: Seo-hyun Kim, Gyu-hyun Han, Su-bin Kim. Project administration: Chung-hwi Yi. Resources: Seo-hyun Kim, Gyu-hyun Han, Su-bin Kim. Supervision: Seo-hyun Kim, Chung-hwi Yi. Validation: Seo-hyun Kim, Chung-hwi Yi. Visualization: Seo-hyun Kim, Gyu-hyun Han, Su-bin Kim. Writing - original draft: Seo-hyun Kim. Writing- review & editing: Seo-hyun Kim, Chung-hwi Yi.

## ORCID

Seo-hyun Kim, https://orcid.org/0000-0002-6978-200X
Gyu-hyun Han, https://orcid.org/0000-0002-7738-4271
Su-bin Kim, https://orcid.org/0000-0003-2068-9290

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