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Original Article

Age-related Differences in Ankle-joint Proprioception and Postural Balance in Women: Proprioception of Force Versus Position

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Background: During postural control, older adults are more dependent on proprioception than are young adults. Ankle proprioception, which plays an important role in maintaining postural balance, decreases with age. Published studies are insufficient to establish a significant age difference in postural sway resulting from the known age-related decrease in ankle proprioception and do not examine various detailed test conditions.

Objects: The present study aimed to compare ankle proprioception between older and younger groups along dimensions of position vs. force proprioception and dorsiflexion vs. plantarflexion. The present study also aimed to compare postural sway between young and older women during quiet standing under two sensory conditions.

Methods: We recruited seven young women aged 21–24 and seven older women aged 60–63. Ankle proprioception was assessed as the accuracy of the joint position sense (JPS) and the force sense (FS). Postural sway was assessed using center-of-pressure measurements recorded during quiet standing under two sensory positions: eyes open and eyes closed with head tilted back.

Results: Older women had lower JPS in dorsiflexion and lower FS in plantarflexion than did younger women. We found no significant age differences in JPS in plantarflexion or in FS in dorsiflexion. We observed a main effect of group on postural sway in two sway parameters out of three. We observed significant differences in JPS with dorsiflexion, and in FS with plantarflexion.

Conclusion: Proprioception for ankle plantar flexor decreased more significantly with aging than did that for ankle dorsiflexor, accounting for the impaired postural balance observed in older women.

INTRODUCTION

Falls are a serious problem and still the leading cause of accidental injuries in older adults [1,2]. Moreover, fall-related injuries constitute a serious public health problem leading to limited mobility and eventually to severe disability and social burden [2,3]. Falling arises from the deterioration of postural control mechanisms due to aging, which leads to balance impairment [2]. Increased postural sway in older adults has been demonstrated even during quiet standing [4]. A recent study showed that postural control quantified by postural sway parameters can independently predict the risk of falls in older adults [5]. In addition, many studies have reported that in women, falls occur 10%–49% more frequently than in men [6-9].

Postural control is regulated by the visual, vestibular, and proprioceptive systems [10,11]. During static standing, the most sensitive information on body sway is provided by proprioceptive musculoarticular cues from the lower extremities [11-13]. Wiesmeier et al. [14] found that older adults rely on proprioception for postural control more than do younger adults, and ankle proprioception has been shown to be predictive of falls [15]. Chen and Qu [16] found that ankle proprioception significantly affects postural balance in older adults. However, Craig et al. [17] found no significant difference in ankle proprioception between young and older adults. These studies generated contradictory results owing to different methods of measuring ankle proprioception. Therefore, it is necessary to measure and compare ankle proprioception in older and younger adults in greater detail.

Proprioception is an important aspect of effective human interaction with the environment in which they live [18]. Specifically, the ankle joint provides important information for the self-perception of the body's spatial relationships and their changes, contributing to dynamic balance and postural control [19]. A decline in static position sense and an increase in motion detection thresholds at the ankle have been reported in older adults [20,21]. Goble et al. found that older adults made greater errors when trying to reach target angles relatively far from the original ankle position [13]. A study employing a lower-limb matching task suggested that elderly fallers have a lower level of proprioceptive perceptual attunement than do non-fallers, which is potentially an indicator of fall risk [22]. The mechanism of proprioceptive degradation is primarily due to a decline in the sensitivity of peripheral mechanoreceptors in the muscles, skin, and joints [13,17]. A higher incidence of falls has been associated with a decline in functional proprioception in elderly populations [18,23].

Ankle proprioception is most often evaluated by assessing joint position sense (JPS) and force sense (FS) [24,25]. JPS is defined as "the ability to accurately reproduce a given angle" and FS as "the ability to accurately reproduce a given force." FS is a sub modality of proprioception influenced by muscle mechanoreceptors [26,27]. There are several methods of quantifying JPS and FS [26,28]. Angle-reproduction and angle-matching tests of the JPS and force-matching tests of the FS have been used on the ankle [16,17,29]. However, we find little research comparing older women and young women on JPS for dorsiflexion and plantarflexion. Moreover, no study has investigated the differences in FS between younger and older adults.

In the present study, we aimed to compare ankle proprioception (JPS and FS) and postural balance in older and younger women. Unlike previous studies, we measured ankle proprioception during both dorsiflexion and plantarflexion.

MATERIALS AND METHODS

1. Participants

Seven young women and seven older women participated in this study. An inclusion criterion for the older women was engagement in physical activities for more than three hours a week. Participants were excluded if they had a history of any medical condition or medication use that could impair their postural control. The exclusion criteria were fall accidents within the last six months, hip replacement, a history of knee or ankle surgery, and neuromuscular diseases. Participants were also screened for dizziness while standing and questioned about obesity to determine whether this factor necessitated participant exclusion. Written informed consent was obtained from all participants. The study was approved by the ethics committee Institutional Review Board of Yonsei University, Wonju (IRB no. 1041849-202108-BM-120-02). The participant characteristics are summarized in Table 1.

2. Instrumentation

1) Static postural sway test

A force platform (FDM S; zebris Medical GmbH, Isny, Germany) was used to measure postural sway during static standing. Signals were sampled at 100 Hz, and center-of-pressure (CoP) displacements were summarized by the following three measures: AREA (cm^2), the area of the 95%-confidence ellipse around the mean CoP; PATH (mm), the CoP path length; and VEL (mm/s), the mean velocity of CoP displacements. The data were processed and verified using the MR3 ver. 3.16.32 software package (Noraxon Inc., Scottsdale, AZ, USA).

2) Ankle proprioception test

Ankle proprioception was assessed by measuring JPS and FS errors on both sides using a commercial dynamometer (Biodex System 4 Pro™; Biodex Medical Systems, Inc., Shirley, NY, USA). Participants remained seated in a chair with the hip flexed at 70° and the knee flexed at 45°, and the thigh was fixed to the dynamometer chair using a band [30]. The dynamometer rotation axis was aligned with the lateral malleolus and the foot was fixed to the device with strips designed for the ankle joint (Figure 1). The absolute error was calculated as the difference between the reference angle or force and those indicated by the participant.

Table 1. General data of participants

Variable	Young	Older
Age (y)	23.1 ± 1.7	61.3 ± 2.4
Height (cm)	162.7 ± 5.7	158.3 ± 4.6
Weight (kg)	61.3 ± 9.5	57.7 ± 7.4
Body mass index (kg/m^2)	23.2 ± 3.0	23.0 ± 3.3

Values are presented as mean ± standard deviation.

Figure 1. Ankle proprioception test.

3. Protocols

1) Static postural sway test

The participants stood barefoot on the force platform with their feet together and their arms relaxed at their sides. They were instructed to avoid swaying during the measurements, and each measurement required 60 seconds. Each participant was tested under two sensory conditions: eyes open (EO) and eyes closed with the head tilted back (ECHB). Under the EO condition, the participant gazed at a stationary sign printed on a sheet of paper mounted 2 m from the front of the force platform. Under the ECHB condition, the participant gazed at a sign mounted on the ceiling approximately 30 cm in front of the platform and then closed their eyes [19]. The ECHB condition reduced the influence of the visual and vestibular systems on performance, allowing isolation of proprioceptive control of postural balance [31]. A 30-second rest period was used in each condition to avoid fatigue.

2) Joint position sense

To measure the JPS error, the ankle joint was initially positioned at 0°. The joint was then passively dorsiflexed and plantarflexed by the dynamometer to the target position (10° of dorsiflexion and 25° of plantarflexion), held for 5 seconds, and returned to the initial position. Subsequently, the participants were asked to actively dorsiflex and plantarflex their ankle to match the target position. Once the participants felt that they had reached the target, they pressed a stop button, and the ankle position was recorded. The JPS error used for data analysis was averaged over three trials.

3) Force sense

The FS was assessed using a force reproduction test. The participants remained seated in a chair with the same posture as in the JPS test. They could see the force generated during isometric contraction on a display. The participants performed isometric contraction for 5 seconds relative to the reference force (10 N of dorsiflexion and 25 N of plantarflexion). The participants were asked to match the reference force three times by performing isometric contractions on the pedals. During testing, participants were blindfolded to exclude any possible visual cues. The FS error values were calculated as the absolute difference between the reference and the reproduced forces. The FS error used for data analysis was averaged over three trials.

4. Statistical Analysis

To determine differences between age groups, an independent t-test was performed for JPS dorsiflexion, JPS plantarflexion, FS dorsiflexion, and FS plantarflexion. To examine the main and interaction effects of age and sensory condition, a two-way mixed analysis of variance was conducted. The dependent variables in this analysis were AREA, PATH, and VEL. The independent variables were age (young or old) and sensory condition (EO or ECHB). A Bonferroni correction was applied during post-hoc testing. Statistical significance was set at $p < 0.05$. All data were analyzed using SPSS software version 26 (IBM Co., Armonk, NY, USA).

RESULTS

1. Ankle Proprioception

We found significant intergroup differences in JPS in dorsiflexion ($t = 2.624$, $p = 0.022$) and FS in plantarflexion ($t = 2.433$, $p = 0.032$), indicating that older adults produced more errors during JPS dorsiflexion and FS plantarflexion (Figure 1). JPS plantarflexion ($t = 1.114$, $p = 0.287$) and FS dorsiflexion ($t = 0.915$, $p = 0.378$) were not significantly different between groups (Figure 2).

2. Postural Sway

The complete postural sway data are presented in Table 2. The two-way mixed ANOVA found significance for a main effect of group on PATH ($F = 9.265$, $p = 0.010$) and VEL ($F = 7.834$, $p = 0.016$), and for a main effect of sensory condition on AREA

(F = 17.054, p = 0.001), PATH (F = 123.232, p < 0.001), and VEL (F = 118.471, p < 0.001). Significance was not found for a main effect of group on AREA (F = 0.415, p = 0.531) or for group × sensory-condition interaction effects on AREA (F = 0.197, p = 0.665), PATH (F = 2.365, p = 0.150), or VEL (F = 3.471, p = 0.087) (Table 3).

DISCUSSION

The purpose of this study was to compare proprioception between older women and young women using tests for both JPS and FS, both in dorsiflexion and plantarflexion, and to confirm the existence of a significant age difference in postural sway.

In the JPS, we found a significant age difference for dorsiflexion, but not for plantarflexion. Most studies supporting a lower JPS in the elderly have examined only dorsiflexion or used comparisons that did not distinguish between dorsiflexion and plantarflexion [16,17,23,32-34]. Confining our attention to the studies examining JPS in dorsiflexion, the results of this study were opposite to those of Craig et al. [17], in which angle matching was tested but not angle production. The angle-matching test can eliminate the potential confounding factor of memory loss in older women but can be limited in that it relies heavily on the use of both lower extremities and thus on inter-hemispheric communication in the brain, and poor performance may therefore not reflect a decrease in proprioception due to aging [13].

In examining dorsiflexion and plantarflexion, the JPS test accesses the proprioception of plantar flexor and dorsiflexor muscles, respectively. When conducting a JPS test without excessive velocity change or muscle contraction, muscle proprioception is influenced by muscle spindles, which are highly sensitive to changes in muscle length [35]. Therefore, it can be assumed that JPS dorsiflexion is sensitive to stretching of the plantar flexor muscles and JPS plantarflexion is sensitive to stretching of the dorsiflexor muscles. The significant difference in JPS dorsiflexion that we observed can therefore be interpreted as a difference in proprioception of the plantar flexor.

We found no significant age difference in FS for dorsiflexion but a significant difference for plantarflexion. Unlike the JPS test, in which muscle lengthening occurs with either dorsiflexion or plantarflexion, there is no change in muscle length

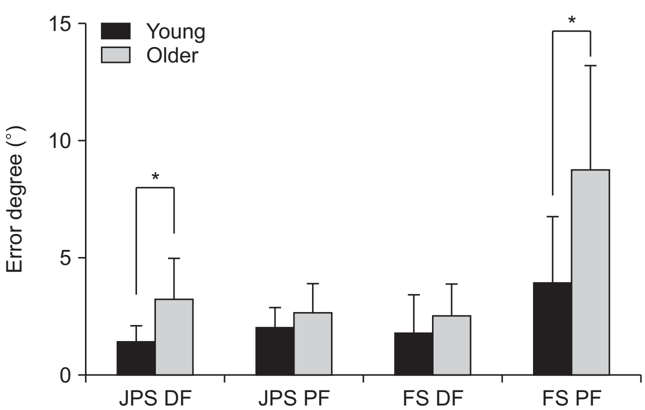

Figure 2. Results of independent t-test in JPS and FS. JPS, joint position sense; FS, force sense; DF, dorsiflexion; PF, plantarflexion. *p < 0.05.

Table 2. Postural sway data of all participants

Variable	Young		Older	
	EO	ECHB	EO	ECHB
AREA[a]	527.14 ± 256.60	877.14 ± 458.31	584.57 ± 228.53	956.00 ± 366.56
PATH[b]	625.29 ± 182.89	1055.71 ± 223.80	798.86 ± 133.38	1367.71 ± 126.90
VEL[c]	11.00 ± 3.00	17.71 ± 3.55	13.29 ± 2.29	22.57 ± 2.30

Values are presented as mean ± standard deviation. EO, eyes open; ECHB, eyes closed with head tilted back. [a]The mean sway area of the 95% confidence ellipse (cm^2). [b]The center of pressure path length (mm). [c]The mean velocity of the center of pressure displacements (mm/s).

Table 3. ANOVA analyses by group and sensory conditions

Variable	Group		Sensory condition		Group × Sensory condition	
	F	p-value	F	p-value	F	p-value
AREA[a]	0.415	0.531	17.054	0.001***	0.197	0.665
PATH[b]	9.265	0.010*	123.232	< 0.001***	2.365	0.150
VEL[c]	7.834	0.016*	118.471	< 0.001***	3.471	0.087

[a]The mean sway area of the 95% confidence ellipse (cm^2). [b]The center of pressure path length (mm). [c]The mean velocity of the center of pressure displacements (mm/s). *p < 0.05, ***p < 0.001.

in the FS test because it uses isometric contraction. Thus, the FS reflects muscle proprioception by the Golgi tendon organs, which are sensitive to muscle force [35,36]. The Golgi tendon organ is in an ideal position to encode changes in force developed by contracting muscle fibers and contributes to the sense of force [35]. The significant age difference that we observed in the FS for plantarflexion can thus be interpreted as resulting directly from differences in proprioception of the plantar flexors.

During quiet standing, the plantar flexor is continuously activated to prevent the body from toppling forward because the center of mass always lies in front of the ankle joint [19,36]. The plantar flexor is thus a major muscle in postural balance, and a decrease in its proprioception makes it difficult for the person to perceive the movement of their body, which increases postural sway due to delayed postural control. Our observations agree with a study that found that the JPS error in dorsiflexion is correlated to postural sway, but the JPS error in plantarflexion is not [34].

Regarding postural sway, our results showed that the PATH and VEL measures in older women were significantly greater than in young women. In the AREA measure, we found no significant main effect of group. This agrees with a previous study that examined which parameters reflect the difference between older and young adults and found that AREA did less [37]. Our null result for AREA can be attributed to the fact that this study included only those older women who engaged in physical activity for more than three hours a week [38].

We found no significant interaction effects between group and sensory condition. The ECHB position minimizes the influence of the vestibular system by tilting the neck back and minimizes the influence of the visual system by closing the eyes; thus, the influence of proprioception can be isolated for testing [31]. Older women tend to rely more on proprioception during postural control than do young women; thus, ECHB is a more advantageous position for older women, which resulted in no significant interaction effect [14].

Our finding that the older women had greater error in JPS dorsiflexion and in FS plantarflexion than did the young women is very important and means that the JPS in dorsiflexion is related to the FS in plantarflexion. Kim et al. [29] reported no significant correlation between JPS and FS, but they examined the relationship between JPS and FS for dorsiflexion, and between JPS and FS for plantarflexion. There is limited evidence of an association between the JPS and FS. Additional studies are needed to examine the association between JPS dorsiflexion and FS plantarflexion, and between JPS plantarflexion and FS dorsiflexion, and to confirm how the differences between JPS and FS manifest in ankle muscle activity.

Our study has several limitations. First, ankle-joint proprioception was only examined in the sagittal plane. Whether ankle proprioception in different anatomical planes yields different results is currently unknown. Second, because a small number of women participated in this study, it is difficult to interpret the results of this study as evidence for a difference between the elderly and the young.

CONCLUSIONS

In summary, the findings of this study suggest that the JPS and FS are indicators of proprioception and that the two indicators can be explained by proprioception of the same muscle when tested in opposite directions. Decreased ankle plantar flexor proprioception can result in impaired postural control in older women. In addition, it was confirmed that the age-related reduction in ankle plantar flexor proprioception was more significant than that in ankle dorsiflexor proprioception and led to impaired postural balance in older women. This may be due to the use of the ankle plantar flexor as a major muscle of postural control during quiet standing.

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CONFLICTS OF INTEREST

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

AUTHOR CONTRIBUTIONS

Conceptualization: SK. Data curation: SK, JL. Formal analysis: SK. Funding acquisition: CY. Investigation: SK, JL. Methodology: SK, CY, JL. Project administration: CY, OL. Resources: SK, OL. Supervision: SK, CY, OL. Validation: CY, SK. Visualization: SK, JL. Writing - original draft: SK. Writing- review & editing: SK, OL.

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