Ankle Proprioception Associated Gait Patterns in Older Adults: Results from the BLSA

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Abstract

INTRODUCTION—Ankle proprioception training has been found to improve balance-related gait disorders; yet, the relationship between ankle proprioception and specific gait patterns in older adults with and without impaired balance has not been systematically examined.

METHODS—This study characterizes gait patterns of 230 older adults aged 60 – 95 evaluated in the Baltimore Longitudinal Study of Aging (BLSA) gait laboratory with (n=82) and without impaired balance (inability to successfully complete a narrow walk) and examines ankle proprioception performance.

RESULTS—Participants with impaired balance had a higher angle threshold for perceiving ankle movement than those without impaired balance even after controlling for the substantial age difference between groups ($p = 0.017$). Gait speed, stride length, hip and ankle range of motion and mechanical work expenditure from the knee and ankle were associated with ankle proprioception performance ($p < 0.050$ for all) in the full sample, but in stratified analysis these associations were evident only in participants with impaired balance.

CONCLUSION—Ankle proprioception in older persons with balance impairment may play a role in balance related gait disorders and should be targeted for intervention.

Keywords

ankle proprioception; mechanical work expenditure; BLSA gait lab; impaired balance in gait

Introduction

Evaluating gait performance is an important component of monitoring the health of older adults. Analysis of gait performance not only provides insight into health status in older

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individuals, but also helps detect physiologically abnormal patterns which may lead to unstable locomotion and falls (6, 17). Impaired balance and instability during walking commonly occur in older adults (7, 12) and may directly contribute to falls as well as activity restriction and mobility limitation (8, 19, 22). Overall, age-related gait patterns of older adults are often less efficient for forward locomotion as reflected in constrained kinematic performance including slower speed, shorter stride length, and smaller range of motion of lower extremity joints.

Balance problems are likely to be associated with defects in gait performance that often emerge with aging (9). Balance problems that occur during walking can be easily and quickly assessed using a tandem walk over a defined distance on which poorer performance (low speed and inability to maintain the tandem) has been associated with falling (4, 5). Evaluating the association between performance on this relatively simple balance test and gait parameters assessed in a gait laboratory may help improve understanding of mechanisms that support stability during walking and also identify targets for interventions aimed at improving mobility in older adults. Ankle proprioception, the perception of position and motion of the ankle joint during movement, is essential for precise locomotor control (2, 14). Considering the primary role of ankle proprioception in both sensing and controlling movement of the feet and ankles, ankle proprioception can be crucial for balance and gait (20, 21). Ankle proprioception training has been found to improve balance-related gait disorders (20); yet, the relationship between ankle proprioception and specific gait patterns in older adults with and without impaired balance has not been examined systematically.

The present study examines the relationship between ankle proprioception performance and impaired balance in older adults and explores the hypothesis that poor ankle proprioception is associated with impaired balance during walking. We also examined whether ankle proprioception is associated with gait characteristics indicative of impaired balance.

Methods

Participants

Data were collected on 230 men (53%) and women aged 60 to 92 years evaluated in the Baltimore Longitudinal Study of Aging (BLSA) gait laboratory who had a clinic visit between January 2008 and April 2013. Participants were classified as having impaired balance (N=82) who could not attempt or failed narrow walking (unable to stay within the marked path on any trial) or not (N=148) based on the ability to successfully complete a narrow walk, described below. The BLSA is a continuous enrollment cohort study initiated in 1958 to study normative aging and is currently supported by the Intramural Research Program of the National Institute on Aging, National Institutes of Health. Participants with no hip or knee joint replacements, no report of severe knee osteoarthritis or history of stroke or Parkinson's disease, able to follow instructions and safely walk without using aids were eligible for gait laboratory testing and included in the study. The BLSA protocol was approved by the Institutional Review Board of record at the time of data collection (MedStar Health Research Institute, Baltimore, MD or National Institute of Environmental Health

Sciences, NC). Participants were given a detailed description of the study and consented to participate.

Gait laboratory measurements

The procedure for the gait analysis performed in the BLSA gait laboratory has been described previously (11). Briefly, participants were instrumented with 20 reflective markers placed at anatomical landmarks: anterior and posterior superior iliac spines, medial and lateral knees, medial and lateral ankles, toe (second metatarsal head), heel, and lateral wands over the mid-femur and mid-tibia. To avoid errors in hip joint calculation due to excessive adipose tissue of over-weight and obese participants, a tie band was used in the pelvic area, and the distance between left and right anterior superior iliac spines (ASIS) was measured manually. A Vicon 3D motion capture system with 10 digital cameras (Vicon 612 system, Oxford Metrics Ltd., Oxford, U.K.) measured the 3D locations of all markers on the landmarks of lower extremity segments (60 Hz sampling frequency). After all markers were positioned on the skin and non-reflective, form-fitting spandex pants, participants were asked to walk across a 10m long gait laboratory walkway at their self-selected usual speed ("like walking in the street"). Trials were performed until at least 3 complete gait cycles starting from both the left and right sides, with the entire foot landing on the force platform, were obtained (11). Gait parameters were averaged over the successful trials. For the narrow base walk test, participants were asked to walk within a narrow path outlined by tape on the walking surface. The width of narrow path was standardized to 50% of the distance between the subject's ASIS (Anterior Superior Iliac Spines) (18). The raw coordinate data of marker positions were digitally filtered with fourth-order zero-lag Butterworth filter with a cutoff at 6 Hz. For the present study, fundamental gait parameters included gait speed, stride length, step width, and lower extremity joint (hip, knee, and ankle) kinematics (range of motion; ROM) and kinetics (weight normalized mechanical work expenditure for one gait cycle; MWE) in the sagittal plane. MWEs were calculated by numerical integration of joint power for the duration of one gait cycle (11)

Ankle proprioception test

The procedure for the ankle proprioception test in the BLSA has been described previously (10). This test was developed to assess proprioception in the ankle joint by measuring ability to sense movement and control static and dynamic position. Participants included in ankle proprioception test did not report severe pain in their lower limbs during ankle rotations of plantarflexion and dorsiflexion. The current study focuses on the two most reliable performance components of the ankle proprioception test (1, 10). The threshold test assesses the minimal angular displacement (degrees) required for perception of passive movement in the proper direction (plantar flexion or dorsiflexion). The tracking test evaluates the ability to track continuous passive ankle angular rotations in plantar flexion and dorsiflexion produced by the machine on the right ankle by rotating the free pedal of the left ankle. Tracking performance is measured by calculating the normalized cross-correlation at zero lag of the ankle rotation curves of left and right sides, thus higher scores indicate better performance. Averages of two repeated tests were used for both measurement of threshold and tracking.

Statistical analysis

Characteristics of the study population and ankle proprioception scores were compared using general linear regression analysis and were reported as mean values and standard errors separately for persons with and without balance impairment (Table 1). Next, the associations between ankle proprioception and balance impairment were examined before and after covariate adjustment. Lastly, the relationship between ankle proprioception performance and kinematic and kinetic gait parameters were examined in adjusted models with consideration of balance impairment and the interaction of balance impairment (Table 2). All models were adjusted for age, sex, weight and height. Statistical significance was defined using a p value less than 0.05. Statistical analyses were performed with SAS 9.2 Statistical Package (SAS Institute, Inc., Cary, North Carolina, USA).

Results

Participants with impaired balance were older ($p < 0.001$) and had poorer ankle proprioception performance in threshold and tracking (for both; $p < 0.001$) than those without impaired balance (Table 1). After adjusting for age, ankle proprioception, assessed as movement threshold was still higher in those with impaired balance compared to those without impaired balance ($p = 0.017$). Participants with impaired balance had slower gait speed ($p < 0.001$), shorter stride length ($p < 0.001$), smaller hip and knee ROM ($p = 0.029$, and $p < 0.001$, respectively), and lower MWEs in hip ($p = 0.046$), knee ($p < 0.001$), and ankle ($p = 0.009$), compared to the participants without impaired balance (Table 2). In the whole sample, poor ankle proprioception was associated with slower gait speed ($\beta = -0.043$; $p = 0.012$), shorter stride length ($\beta = -0.046$; $p < 0.001$), and smaller ROM from the hip and ankle joints ($\beta = -1.193$; $p = 0.004$, and $\beta = -0.745$; $p = 0.032$, respectively). Poor ankle proprioception was also associated with lower knee eccentric MWE ($\beta = -0.014$; $p = 0.037$) and lower ankle concentric MWE ($\beta = -0.016$; $p = 0.007$). No significant associations between gait parameters and ankle proprioception performance were found in participants without impaired balance. Ankle proprioception indicated by tracking test showed significant association only with stride length ($\beta = 0.557$, $p = 0.009$; for the participants with impaired balance; Table 3).

Discussion

Independent of age, ankle proprioception threshold was higher in older adults with impaired balance compared to those without impaired balance as indicated by the inability to maintain a narrow walking path without stepping out. Poorer ankle proprioception performance (higher threshold to discern movement) was also associated with less favorable gait characteristics – specifically slower gait speed, shorter stride length, smaller hip and ankle ROM, higher knee energy absorption and lower ankle energy generation – all of which were also associated with impaired balance. It is important to note, however, that associations of between ankle proprioception with gait characteristics detected in the whole population were driven by the participants with impaired balance. These associations were not evident in participants with intact balance; that is, those who successfully performed the narrow walking test.

Slower gait speed, shorter stride length, and smaller hip ROM in participants with impaired balance, all of which can either reflect deficits in stability or compensatory strategies to reduce forward momentum during locomotion, were associated with poorer ankle proprioception. This finding suggests that poor or diminished awareness of foot rotation in older adults may impact specific gait characteristics associated with balance problems. These results confirm previous studies on the importance of ankle proprioception for precision in motor control (2, 14) and support the relationship between ankle proprioception and balance problems (15).

Smaller knee ROM and lower hip concentric MWE were observed in participants with balance impairment, but these measurements of knee kinematics and hip kinetics, were not associated with ankle proprioception. It is interesting to note that these measures of knee kinematics and hip kinetics are controlled by the knee flexors and hip extensors, respectively, and these two gait parameters are commonly governed by the hamstrings. Thus, instead of direct affect from ankle proprioception, these balance related gait pattern differences may be due mainly to weakness in the leg muscles of the thigh. In contrast, poorer ankle proprioception performance was associated with lower knee eccentric and ankle concentric MWE both of which are mainly generated during late stance for knee flexion and ankle plantar flexion, respectively as a function of calf muscle (gastrocnemius) contraction (3) (Figure 1). The observed relationship between ankle proprioception and ankle MWE supports previous observations of the contribution of ankle plantar flexion power to gait characteristics (13, 16). Lower mechanical energy (or work) generation during late stance from ankle and knee joints may explain lower propulsion generation, which limits forward momentum through the swing phase resulting in slower gait speed, shorter stride and smaller ROM, which may result in impaired balance during walking.

This study has some limitations. Other factors or impairments such as fear of falling, past fall experience, muscle weakness or plantar cutaneous sensation, which can be related to balance problems in narrow walking were not evaluated in this study. Thus, some portions of associations between ankle proprioception and gait parameters with different narrow walk performance may be partially explained by factors not included in this study. Future studies should consider these and other factors associated with balance problems.

Results suggest that assessing ankle proprioception performance in older adults, especially those with impaired balance may provide important insights for better targeting interventions to improve balance related gait disorders. Deteriorated gait stability in older adults can be better understood by evaluating whether it stems from muscle weakness or is due to a combination of diminished distal awareness of movement and related muscle activations. If the results of present study can be confirmed through longitudinal study, then the use of a simple balance test combined with ankle proprioception evaluation may prove to be a robust pair of assessments for detecting subtle, but important gait deterioration in older adults and may facilitate early intervention for optimal gait performance.

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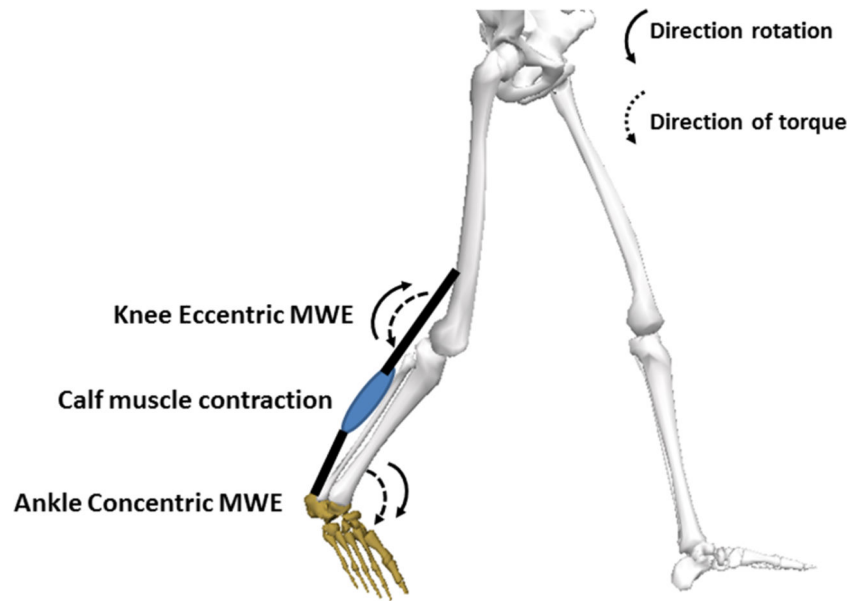
Figure 1.
Knee eccentric MWE and ankle concentric MWE during late stance for knee flexion and ankle plantar flexion, respectively.

Table 1

Characteristics and ankle proprioception performance of participants by balance impairment group

	With Impaired balance (N=82)	Without impaired balance (N=148)	p-value
	mean (SE)	mean (SE)	
Characteristics			
Age, yr	80 (0.731)	70 (0.545)	**< 0.001**
Sex, female (%)	43 (NA)	50 (NA)	0.289
Height, cm	167.1 (1.0)	168.5 (0.8)	0.266
Mass, kg	76.1 (1.7)	78.3 (1.3)	0.316
Ankle proprioception (Without age-adjustment)			
threshold, degree	1.427 (0.075)	0.926 (0.056)	**< 0.001**
Tracking, score	0.878 (0.006)	0.905 (0.004)	**< 0.001**
Ankle proprioception (With age-adjustment)			
threshold, degree	1.286 (0.087)	1.005 (0.060)	**0.017**
Tracking, score	0.885 (0.007)	0.901 (0.005)	0.100

Table 2

Gait and ankle proprioception (threshold) associations for the participants with impaired and without impaired balance

Gait parameters	Associations with ankle proprioception (Threshold)[a]					Group Comparisons	
	whole sample		stratified analysis			Between with impaired and without impaired balance	
	Slope β	*p*-value	Balance impairment	Slope β	*p*-value	Mean (SE)	*p*-value
Spatiotemporal gait parameters							
Gait speed, meter/sec.	−0.043	**0.012**	yes	−0.045	**0.041**	1.020 (0.023)	**< 0.001**
			no	−0.016	0.530	1.150 (0.016)	
Stride length, meter	−0.046	**< 0.001**	yes	−0.064	**< 0.001**	1.119 (0.016)	**< 0.001**
			no	−0.003	0.843	1.221 (0.011)	
Step width, meter	0.004	0.090	yes	0.005	0.153	0.108 (0.003)	0.066
			no	0.002	0.579	0.100 (0.002)	
Range of motion, degree							
Hip	−1.193	**0.004**	yes	−1.453	**0.007**	36.531 (0.558)	**0.029**
			no	−0.573	0.355	38.182 (0.387)	
Knee	−0.292	0.516	yes	−0.441	0.446	51.424 (0.589)	**< 0.001**
			no	0.512	0.441	54.393 (0.409)	
Ankle	−0.745	**0.032**	yes	−1.058	**0.021**	24.000 (0.472)	0.164
			no	−0.188	0.721	24.884 (0.328)	
Mechanical work expenditure, J/kg							
Hip Concentric	−0.008	0.150	yes	−0.007	0.290	0.173 (0.007)	**0.046**
			no	−0.004	0.587	0.192 (0.005)	
Hip Eccentric	−0.005	0.705	yes	−0.011	0.501	0.427 (0.016)	0.266
			no	−0.002	0.925	0.402 (0.011)	
Knee Concentric	−0.004	0.289	yes	−0.001	0.855	0.082 (0.005)	0.395
			no	−0.007	0.217	0.088 (0.004)	
Knee Eccentric	−0.014	**0.037**	yes	−0.011	0.197	0.237 (0.009)	**< 0.001**
			no	−0.009	0.385	0.284 (0.006)	
Ankle Concentric	−0.016	**0.007**	yes	−0.020	**0.011**	0.271 (0.008)	**0.009**
			no	−0.006	0.504	0.298 (0.005)	
Ankle Eccentric	0.004	0.231	yes	0.001	0.943	0.127 (0.005)	0.478
			no	0.004	0.429	0.122 (0.003)	

All models are controlled for age, height, weight, and sex

[a] in threshold, - sign mean positive association with gait parameters because lower threshold score means higher performance

Table 3

Gait and ankle proprioception (tracking) associations for the participants with impaired and without impaired balance

| Gait parameters | Associations with ankle proprioception (Tracking)[a] | | | | | Group Comparisons | |
| | whole sample | | stratified analysis | | | Between with impaired and without impaired balance | |
	Slope β	p-value	Balance impairment	Slope β	p-value	Mean (SE)	p-value
Spatiotemporal gait parameters							
Gait speed, meter/sec.	0.144	0.499	yes	0.053	0.862	1.020 (0.023)	**< 0.001**
			no	0.015	0.958	1.150 (0.016)	
Stride length, meter	0.302	**0.045**	yes	0.557	**0.009**	1.119 (0.016)	**< 0.001**
			no	−0.060	0.755	1.221 (0.011)	
Step width, meter	0.002	0.952	yes	0.043	0.351	0.108 (0.003)	0.066
			no	−0.018	0.663	0.100 (0.002)	
Range of motion, degree							
Hip	6.213	0.224	yes	8.164	0.281	36.531 (0.558)	**0.029**
			no	2.181	0.750	38.182 (0.387)	
Knee	1.559	0.778	yes	10.218	0.198	51.424 (0.589)	**< 0.001**
			no	−10.163	0.157	54.393 (0.409)	
Ankle	3.208	0.456	yes	11.223	0.078	24.000 (0.472)	0.164
			no	−4.624	0.422	24.884 (0.328)	
Mechanical work expenditure, J/kg							
Hip Concentric	−0.025	0.699	yes	−0.138	0.153	0.173 (0.007)	**0.046**
			no	0.035	0.687	0.192 (0.005)	
Hip Eccentric	−0.153	0.299	yes	−0.230	0.294	0.427 (0.016)	0.266
			no	−0.133	0.501	0.402 (0.011)	
Knee Concentric	0.033	0.493	yes	0.025	0.725	0.082 (0.005)	0.395
			no	0.031	0.638	0.088 (0.004)	
Knee Eccentric	−0.009	0.912	yes	0.145	0.222	0.237 (0.009)	**< 0.001**
			no	−0.061	0.570	0.284 (0.006)	
Ankle Concentric	0.089	0.218	yes	0.057	0.595	0.271 (0.008)	**0.009**
			no	0.074	0.443	0.298 (0.005)	
Ankle Eccentric	0.011	0.812	yes	−0.007	0.908	0.127 (0.005)	0.478
			no	0.014	0.802	0.122 (0.003)	

All models are controlled for age, height, weight, and sex

[a] in thracking, - higher tracking score means highs performance