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Association between ankle muscle strength and limit of stability in older adults

SIR—Loss of balance and falls in the elderly constitute a major problem associated with human suffering as well as high costs for society [1]. Falls might occur during various daily activities, such as tripping or tangling the feet, reaching movements or bending [2]. Many of these activities are constrained by limits of stability (LOS). LOS can be described as the maximum distance a person can intentionally displace his/her centre of gravity, and lean his/her body in a given direction without losing balance, stepping or grasping. Accordingly, one's LOS capacity is likely to be an important prerequisite for the successful planning and execution of movements such as using a step stool to reach into a high cabinet as well as bending over from standing position to pick up an object from the floor.

Ageing is associated with decreased LOS [3–5], muscle strength [6] and foot sensation [7]. Investigators have reported significant correlations between postural stability, quadriceps, ankle dorsiflexion and hand-grip strength [8–11], tibialis anterior latency [8] and functional clinical balance testing [12] among older adults. However, the relationships between lower-limb muscle strength and falls are unclear. Several studies show minimal or no differences in strength between fallers and non-fallers [13, 14] while others show no strength–falls relationships [15].

Cutaneous mechanoreceptors at the soles of the feet contribute to postural stability when standing [16]. Those with reduced feet sensation have a higher risk of falling [17] and greater instability [18]. Reduced foot sensation may contribute to reduced LOS, since older adults might not

Table 1. Characteristics and outcomes of subjects

	All subjects, $n = 43$	Male, $n = 16$	Female, $n = 27$	P value
Mean age (years)	78.1 ± 6.2	78.4 ± 5.9	77.9 ± 5.5	0.27
Height (cm)	161.1 ± 7.8	165.9 ± 10.1	158.7 ± 5.2	0.003
Weight (kg)	68.9 ± 11.5	74.9 ± 11.2	66.1 ± 11.1	0.01
Body mass index (kg/m^2)	26.9 ± 3.4	27.1 ± 3.8	26.5 ± 3.2	0.04
Foot length (cm)	23.4 ± 1.4	24.4 ± 1.5	22.9 ± 1.1	0.001
Two-point discrimination (mm)	12.4 ± 2.8	12 ± 1.6	12.6 ± 3.2	0.4
Number of disease	4.0 ± 1.8	3.9 ± 2.2	4.1 ± 1.6	0.68
Number of medications	4.3 ± 2.1	4.2 ± 2.6	4.35 ± 1.8	0.82
Mini-Mental State Examination	29.0 ± 1.0	28.8 ± 1.0	29.1 ± 0.98	0.33
Limits of stability test				
AP displacement (cm)	8.9 ± 3.8	10.6 ± 4.5	7.7 ± 3.1	0.007
Functional base of support (%)	37.2 ± 0.15	41.7 ± 0.17	35 ± 0.14	0.05
CoP measures in narrow stance				
95% elliptical area of sway (cm^2)	5.1 ± 2.5	5.5 ± 2.9	4.9 ± 2.1	0.53
CoP velocity (cm/s)	1.9 ± 0.6	2.0 ± 0.6	1.9 ± 0.6	0.51
ML sway (cm)	2.9 ± 1.0	3.0 ± 1.0	2.9 ± 1.0	0.79
AP sway (cm)	2.3 ± 0.5	2.3 ± 0.5	2.3 ± 0.6	0.91
Isometric muscle strength				
Dorsiflexion isometric strength (N m)	22.5 ± 7.8	26.8 ± 8.6	20.6 ± 6.6	0.01
Plantar-flexion isometric strength (N m)	53.6 ± 22.7	68.6 ± 22.8	43.7 ± 14.4	0.001

The second, third and fourth columns show averages and standard deviation. The last column shows the significance values (P) of the differences between male and females.

properly detect when the centre of gravity approaches the LOS.

To our knowledge, no one has studied how postural control during LOS relates to ankle strength and foot sensation among older adults.

The aims of this study are to investigate how two specific tests of postural control, LOS and postural stability, relate to ankle muscle strength and foot sensation in older adults. Identification of sensorimotor factors associated with both types of balance control can help us to understand better the balance problems facing older adults. Given that LOS likely requires highly active muscular control and that postural stability requires careful sensory monitoring of stance, we hypothesised that ankle muscle strength (and not foot sensation) will be significantly correlated with LOS and that foot sensation (and not ankle muscle strength) will be significantly correlated with postural stability. Data from this study may lead to a better understanding of the mechanisms underlying falls that occur during reaching and bending movements.

Subjects and setting

Forty-three participants (77.8 ± 6.2 years) were recruited from two protected retirement homes (Table 1). Participants had to be at least 65 years of age and ambulate independently. Individuals with neurological disorders (for example, stroke, Parkinson and multiple sclerosis), psychiatric disorders, cognitive dysfunction (Mini-Mental Status Examination score <24) or blindness were excluded. All participants provided informed consent, in accordance with approved procedures by the Helsinki ethical committee.

Testing protocol

Limits of stability

Participants stood upright on a force plate (AMTI, Newton, MA, USA) with their unshod feet as close together as possible and arms at their sides. The instructions were to keep the body rigid and lean forward, backward, left and right as far as possible, maintain the full plantar surface of the feet in contact with the force plate and hold in each extreme position for ~2 s. The dependent LOS variables included the maximum anteroposterior displacement of centre of pressure (CoP) (AP-LOS, defined as anterior minus posterior CoP displacement). To control for foot length, the functional stability limits (FSLs) were calculated and computed as the peak AP-LOS as a per cent of foot length. The LOS test in older adult fallers is consistent and reliable [19]. The average of five trials was used in the analysis.

Postural stability (PS)

Participants stood upright on a force plate for 30 s as still as possible, with their unshod feet as close as possible. Dependent variables were the maximum CoP sway distance in the medio-lateral direction (ML sway) and in the anterior–posterior direction (AP sway), the average velocity of CoP sway and the CoP sway area. Given that two trials of PS are thought to be a reliable estimate of PS [20], the average of two trials was used for the analysis.

Ankle plantar (PF) and dorsiflexor (DF) strength

Maximum isometric PF and DF strength were measured in semi-sitting position on a dynamometer chair (Biodex System 2, Shirley, NY, USA) with the ankle in a neutral position.

Table 2. Pearson correlation coefficients to measure associations between limits of stability (AP-LOS), functional limits of stability (FSL), ankle muscle strength, two-point discrimination (TPD) and postural stability parameters

Partial Pearson correlations	AP-LOS (cm)	FSL (%)	TPD (mm)	ML sway (cm)	AP sway (cm)	Sway area (cm^2)	Sway velocity (cm/s)	Dorsiflexors isometric strength (N m)	Plantarflexors isometric strength (N m)
AP-LOS (cm)	1								
FSL (%)	0.98*	1							
TPD (mm)	0.05	0.03	1						
ML sway (cm)	−0.03	−0.01	0.3*	1					
AP sway (cm)	0.09	0.11	0.10	0.23	1				
Sway area (cm^2)	0.06	0.07	0.10	0.81*	0.74*	1			
Sway velocity (cm/s)	−0.05	−0.1	0.26*	0.65*	0.42*	0.51*	1		
Dorsiflexors isometric strength (N m)	0.3*	0.27	−0.33*	−0.07	−0.11	−0.05	−0.12	1	
Plantarflexors isometric strength (N m)	0.55*	0.4*	0.029	0.11	−0.003	0.12	0.03	0.52*	1

*Significant at $P < 0.05$.

Participants held the contraction up to 3 s. The absolute values (in Nm) and the average of three trials were used in the analysis.

Static two-point discrimination (TPD) test is a crude clinical evaluation of the innervation density of the slowly adapting mechanoreceptors. A two-pronged instrument firmly contacted the sole of the distal end of the first toe and participant determined whether one or two prongs were touching them. The smaller the detectable distance between the two prongs, the more sensitive the sense of touch. The measurements for TPD obtained with this protocol have high interobserver reliability [21].

Data analysis

Associations between all variables (LOS, FSLs, ankle muscle strength, TPD and PS parameters) were determined using Pearson's r. Because PF strength is essential to anterior leans and DF strength is essential to posterior leans, correlations between PF strength and peak anterior CoP displacement and between DF strength and peak posterior CoP displacement were also evaluated. Because AP-LOS and FSLs were significantly correlated with age ($r = -0.67$, $P < 0.001$ and $r = -0.68$, $P < 0.001$, respectively), we ran partial correlations on all variables while controlling for age. All analyses were run using SPSS with statistical significance determined at $P < 0.05$.

With gender as a covariate, four stepwise regression analyses models were run for each postural control dependent variable (AP-LOS, FSLs, sway velocity and AP sway) to identify which independent variables (ankle muscle strength or TPD) best predicted the dependent variable. Because DF strength correlates with PF strength ($r = 0.52$) (e.g. variables were collinear), separate models, DF and PF strength models, were examined. Age and muscle strength could not be simultaneously included in the model because they have previously been shown to be correlated.

Results

AP-LOS was significantly correlated with both DF ($r = 0.3$, $P < 0.05$) and PF strength ($r = 0.55$, $P < 0.001$). FSLs were significantly correlated with only PF strength ($r = 0.4$, $P < 0.01$). The relationship between PF strength and the anterior CoP displacement was also highly significant ($r = 0.65$, $P < 0.001$), while the correlation between DF strength and peak posterior CoP displacement was borderline significant ($r = 0.38$, $P = 0.09$). In males, the correlations between PF strength and AP-LOS and FSLs were even higher ($r = 0.69$, $P = 0.003$ and $r = 0.63$, $P < 0.01$, respectively). Ankle muscle strength and postural sway measures were not significantly correlated. Postural sway was not correlated with LOS or FSLs (Table 2).

AP-LOS was not significantly correlated with TPD (Table 2). However, TPD was significantly correlated with sway velocity and ML sway ($r = 0.3$, $P < 0.001$; $r = 0.26$, $P < 0.01$, respectively).

In the stepwise regression analyses, PF was the only significant predictor of AP-LOS ($\beta = 4.8$, $R^2 = 0.28$, $P < 0.001$; βs for gender and TPD were −0.49 and 0.14, respectively). In a separate model, DF strength did not significantly predict AP-LOS. In other separate regression models, ankle muscle strength and TPD did not significantly predict PS measures.

Discussion

The capacity to control one's balance while leaning or bending is critical to daily living. A measure of leaning or bending, AP-LOS, may be influenced by (i) ankle muscle strength; (ii) ankle range of motion and (iii) mechanoreceptor sensitivity in the feet.

The present analyses show that PF strength is more strongly associated with AP-LOS than DF strength but neither are associated with PS. Perhaps the contribution of plantarflexors is larger simply because the anterior lean distance (controlled by PF) is larger than the posterior lean distance (controlled by DF) within the LOS test. However, the correlation between DF strength and posterior CoP displacement did not reach significance, suggesting that PF strength may be more critical to preventing falls during reaching or bending activities. Previous studies also found moderate to strong relationships between lower-limb muscle strength and functional balance [12], stair climb time [22–25], short physical performance battery [22, 24], 4 m walk time [22], chair-stand time [24] and tandem gait [24].

Regarding ankle range of motion, it is unlikely that LOS in the present study was limited due to decreased ankle dorsiflexion range of motion. In a previous study [25] and using a motion analysis system, the extent of dorsiflexion range of motion used in older adults when leaning forward during the AP-LOS was 3.8°. Mean dorsiflexion values for older adults is much higher, ranging from 13.5° to 10.1° [26].

Loss of cutaneous sensation is correlated with impaired postural control and an increased risk of falling [7, 17] and instability [9, 27]. Results of the present study show that TPD was not correlated with AP-LOS, but correlated significantly with PS. Forefoot anaesthesia appears to be important in postural control mainly when eyes are closed [28]. Thus, plantar insensitivity may affect PS in patients with sensory deficits [28], which is found commonly impaired in older adults [10, 29].

Previously, PS was weakly correlated with LOS and FSLs [5, 30]. We found no significant associations, suggesting that postural sway more likely captures sensorimotor deficits rather than dynamic movements requiring more intensive muscle contraction. This suggests that two different balance-control mechanisms may be used to control stability, one during standing and the other during reaching movements. Reduced muscle strength may lead to a fall during a more dynamic task, including reaching or bending movements, and is a relatively less important contributor to quiet stance. Thus, we suggest that balance training should incorporate exercises that closely mimic extreme reaching tasks, thereby providing the muscle activation and functional challenge to maintain balance when nearing the LOS.

In conclusion, plantarflexors muscle strength plays a more significant role in decreased AP-LOS in older adults than TPD and may thus help us to explain fall that occur during reaching tasks. The results suggest the importance of training plantarflexor strength among elderly persons during exercise-based fall prevention programmes.

Key points

- Plantarflexor muscle strength is important in fall prevention given its key contribution to reaching tasks in older adults.
- Ankle muscle strength is not as important as foot sensory function in contributing to postural stability in quiet stance.
- Training to avoid falls should consider functional ankle strength training, and in particular mimicking reaching tasks such as reaching and bending.

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Conflicts of interest

None.

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Relationship between serum preheparin lipoprotein lipase mass, plasma glucose and metabolic syndrome in older subjects

SIR—The biomarkers regarding the pathophysiology of metabolic syndrome (MetS), a risk factor for atherosclerosis, remain to be explored. Recently, low serum levels of preheparin lipoprotein lipase mass (preLPL) in MetS have been reported in a wide range of ages. Although the associations between MetS, metabolic measures including MetS components and preLPL among older people can differ from younger adults, the specific correlations in older individuals have not been examined. In the present study, 125 Japanese subjects (37 men and 88 women, mean 76.9 years) were investigated to observe the association between preLPL, MetS and metabolic measures, such as body mass index, blood pressure, lipid panels and plasma glucose (PG). In simple correlation and multiple regression analysis, among metabolic measures, only PG was significantly and inversely correlated to preLPL. Additionally, MetS subjects showed significantly lower preLPL levels than non-MetS subjects, even after adjustments for age and sex. These results suggest that the significant correlation of PG to preLPL might be reflective of age-related metabolic features, and that preLPL might be a biomarker connected with the pathophysiology of MetS, even in older subjects.

Introduction

Recently, obesity/obesity-based disorders and ageing have become two overlapping and mounting public health problems. In particular, MetS, a cluster of metabolic