Published in final edited form as:
Am J Phys Med Rehabil. 2008 December ; 87(12): 969–976. doi:10.1097/PHM.0b013e31818dfee5.

Leg Strength or Velocity of Movement Which Is More Influential on the Balance of Mobility Limited Elders?

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Abstract

Objective—To determine which component of leg power (maximal limb strength or limb velocity) is more influential on balance performance in mobility limited elders.

Design—In this cross-sectional analysis we evaluated 138 community-dwelling older adults with mobility limitation. Balance was measured using the Unipedal Stance Test, the Berg Balance Test (BERG), the Dynamic Gait Index, and the performance-oriented mobility assessment. We measured one repetition maximum strength and power at 40% one repetition maximum strength, from which velocity was calculated. The associations between maximal estimated leg strength and velocity with balance performance were examined using separate multivariate logistic regression models.

Results—Strength was found to be associated [odds ratio of 1.06 (95% confidence interval, 1.01–1.11)] with performance on the Unipedal Stance Test, whereas velocity showed no statistically significant association. In contrast, velocity was consistently associated with performance on all composite measures of balance [BERG 14.23 (1.84–109.72), performance-oriented mobility assessment 33.92 (3.69–312.03), and Dynamic Gait Index 35.80 (4.77–268.71))]. Strength was only associated with the BERG 1.08 (1.01–1.14).

Conclusions—Higher leg press velocity is associated with better performance on the BERG, performance-oriented mobility assessment, and Dynamic Gait Index, whereas greater leg strength is associated with better performance on the Unipedal Stance Test and the BERG. These findings are likely related to the intrinsic qualities of each test and emphasize the relevance of limb velocity.

Keywords

Balance; Strength; Velocity; Task Performance; Rehabilitation

Given the increasing elderly population and the high prevalence of injurious falls among these individuals, optimizing balance remains an important rehabilitative goal for older adults.[1] A

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Disclosures: No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit upon the author(s) or upon any organization with which the author(s) is/are associated. Supported by the American Geriatrics Society Dennis W. Jahnigan Scholars Career Development Award and a National Institute of Health Mentored Clinical Scientist Development Award (K23AG019663-01A2) (to JFB). This study also received support from the Department of Physical Medicine and Rehabilitation, Harvard Medical School and the Cable-Rubenstein Foundation. Input regarding design, conduct, and reporting for all entities were consistent with established NIH regulations. Mr. Mayson received the 2007 Electrode Store Best Paper Award-Medical Student Category for this study presented at the 2007 Association of Academic Physiatrists Meeting, San Juan, Puerto Rico.

person's ability to balance is coordinated by the complex interplay of various physiologic subsystems. The neuromusculoskeletal components of this balance system are important for maintaining balance, and if diminished, may lead to an increased risk of falling. Reduced muscle strength may decrease a person's ability to mount an adequate response to perturbations in balance.[3] Furthermore, strength has been linked to measures of balance that are predictive of falls[4] and fall-related fractures.[5] In addition to strength, studies have indicated that muscle power also plays an important role in the maintenance of balance and mobility.[6] Decreased power has also been linked to an increase in the incidence of falls.[7] Because muscle power is the product of the strength and velocity of movement (power = force × velocity), a decrease in either component may lead to a diminished capacity to generate power.

An association between muscle power and balance would not be surprising, considering the role muscle power plays in other functional activities. Specifically, skeletal muscle power is more predictive of performance in general mobility tasks than in strength among older adults.[8] It is not currently known, however, which of the two components of power (i.e., strength or velocity of movement) is more important in the maintenance of balance. In a recent article, Sayers et al.[9] indicated that limb velocity was more predictive of 400-m walk performance than was strength. Furthermore, Thelen et al.[10] suggested that the velocity of ankle torque development plays an important role in the ability to recover from a disturbance of balance. Taken together, these studies suggest that limb velocity may be an important factor in performance of clinically established balance tests that are predictive of falls.

To our knowledge, no published study has specifically looked at the role of limb velocity and strength in balance performance. Furthermore, there are few studies looking specifically at the role limb velocity plays in balance and falls. Finally, prior research has shown mobility limited older adults to be at an increased risk of falling on the basis of their short physical performance battery (SPPB) score.[11] Thus, we sought to evaluate clinically established balance measures in this population to determine the relative importance of limb strength and velocity of limb movement in good balance performance. Knowing which component of leg power is more strongly associated with balance will have important implications for the design and implementation of rehabilitative care.

METHODS

This study was a cross-sectional analysis of baseline data collected as part of a randomized, controlled trial of exercise among mobility-limited older adults. It was approved by the Spaulding Rehabilitation Hospital Institutional Review Board.

Recruitment of Subjects

Initially, 590 inquiries were solicited via advertising in newspapers, direct mailings, referrals from primary care providers, and telephone screenings. These inquiries identified 260 potentially eligible subjects who attended an initial screening assessment at our facility. Outcomes testing for the intervention study were completed over 1 to 2 subsequent visits depending on subject availability. Impairment and balance measures used for this analysis were all completed within the first two visits, which were scheduled within 1 wk of each other.

Screening Process

Subjects included in the study were mobility-limited, community-dwelling, older adults (age ≥ 65 yr) with SPPB scores between 4 and 10 and who were able to climb a flight of stairs independently or using a device (e.g., cane).[12] Exclusion criteria were unstable acute or chronic disease (e.g., uncontrolled diabetes), a score of <23 on the Folstein Mini-Mental State Examination (MMSE),[13] a neuromusculoskeletal impairment limiting participation in further outcomes testing (e.g., severe djd, avascular necrosis of the hip), or an exercise tolerance test with positive findings for unstable cardiovascular disease (e.g., unstable angina, supraventricular tachycardia, symptomatic aortic stenosis).[2] Further details regarding the study population are reported elsewhere.[14]

After providing informed consent, subjects underwent a comprehensive history and physical examination conducted by the principal investigator (J. F. Bean). Height and weight were measured during the initial physical examination using a calibrated scale and stadiometer. Body mass index (BMI) was calculated by the formula mass (kg)/height (m)^2 BMI status was characterized using standard National Heart, Lung, and Blood Institute cutpoints: with normal BMI < 25 kg/m^2, overweight BMI 25–30 kg/m^2, and obese as BMI > 30 kg/m^2.[15] At the completion of the physical examination, the total number of active medical conditions was recorded for each subject. Active medical conditions were defined as either (1) any condition for which a subject was actively receiving treatment or (2) any condition requiring medical treatment within the past 1 yr. Medical records were requested from subjects' primary care physicians to corroborate these findings. The total number of prescription and over-the-counter medications was also recorded.

On completion of the 260 potentially eligible subjects who attended an initial screening, 92 (35%) people could not participate in the study because of exclusion criteria, and 30 (11%) chose not to commit to the study, leaving 138 subjects.

Impairment Measures

Lower limb strength and power were measured in a seated position using a pneumatic double leg press resistance machine (Keiser Sports Health Equipment Inc., Fresno, CA) as previously described.[16] The machine calculates strength based on data from a pressure transducer mounted on a piston, which moves as force is applied to the lever arm. The leg press machine calculates the peak power during a repetition by sampling the position of the piston 64 times per second. Force production is calculated by the software at a set percentage of the range of motion representing a estimate of maximal leg strength.

The one repetition maximum (1RM) is a reliable measurement of a subject's strength, and was determined by progressively increasing resistance for successive repetitions until the subject could no longer move the lever arm through the full ROM while maintaining proper form.[3,17] The 1RM was determined as the highest resistance at which a full repetition could be completed. For the randomized, controlled trial from which this ancillary investigation was derived, power was measured as the best of five repetitions performed at 40% and 70% of the 1RM, in which subjects performed the concentric action of one repetition as quickly as possible. For this analysis, we analyzed data collected at 40% 1RM because it represents the higher velocity at which power was measured; and has higher associations with important functional tasks such as gait speed.[17] Estimated leg press velocity was derived by dividing the maximal power value for each individual, by the percentage of 1RM resistance at which the power was derived. Muscle power measurement and derivation of estimated leg press velocity using these methods has been used in previous studies using similar equipment with high reliability.[9,18] For the purposes of this manuscript, we will be using the terms maximal leg strength and maximal leg velocity, with the understanding that both represent reliable estimates of the true peak values.

Balance Measures

Four measures of balance were used in this study including one simple measure of balance and three composite measures. A simple measure of balance requires the subject to perform one specific task, whereas a composite measure requires the subject to perform multiple tasks and

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a composite score determines balance. The simple balance measure used was the Unipedal Stance Test (UST). The UST is a reliable and valid test associated with risk for injurious falls that measures the length of time that a person is able to maintain balance while standing on one leg.[19] The test was ended if the subject needed support to prevent a fall or was unable to continue, and the time was noted to the nearest 0.01 sec using a stopwatch. In contrast to the composite balance measures, the UST was introduced after the inception of the randomized controlled trial and, therefore, fewer subjects underwent testing.

The three additional tests of balance used in this study were the following: the Berg Balance Test (BERG), The Dynamic Gait Index (DGI), and the performance-oriented mobility assessment (POMA). In contrast to the UST, which requires only the maintenance of position over a base of support, the composite balance measures include a series of balance tasks. The BERG, POMA, and DGI are reliable and valid measures of balance in an elderly community-dwelling population, and scores from these tests have been shown to be associated with fall risk.[20–23] The BERG is a commonly used balance test in which the patient is asked to complete 14 tasks that are scored on a scale of 0 (cannot perform) to 4 (normal performance) with a maximum achievable score of 56. The BERG includes activities encountered in daily life such as sitting, standing, leaning over, and stepping.[22]

The second test used was the POMA, which evaluates position changes and gait maneuvers encountered in normal daily activities. Subjects perform tasks that are scored on a scale of 0 (cannot perform) to 2 (normal performance) with a maximum score of 28.[23] The final test used, the DGI, evaluates the study subject's ability to adapt his gait to changes in task demands. The subject completes eight tasks that are scored on a scale of 0 (cannot perform) to 3 (normal performance) with a maximum score of 24.[21]

To facilitate the clinical interpretation of our findings, we chose to evaluate our outcomes in terms of cut points, indicating a lower risk for falls. Values for the cut points were chosen after reviewing studies that examined relationships between each of these balance measures and fall risk, and also were chosen based on the distribution of our data.[20,23–25] For the BERG and DGI, scores ≥ 50 and >20, respectively, were associated with a lower falls incidence,[20,24] whereas a POMA score of >25 was indicative of good balance and lower fall risk.[21,24] A UST score ≥ 5 secs has a previously reported association with risk for falls.[19,27,4]

Data Analysis

To characterize the sample, we calculated frequencies and proportions for categorical variables and means and standard deviations for continuous variables. Given that the outcomes were not all normally distributed, Spearman correlations were calculated to compare performance on balance measures against leg strength and power. Next, we evaluated the bivariate relationships between each of the potential adjustment variables and the balance measures, to determine whether there was an association ($P < 0.20$). In addition, we inspected adjustment variables for colinearity, eliminating those colinear variables with a weaker association to the outcome. Next, we created four separate multivariate logistic regression models using clinically relevant cutoffs for each balance measure and including limb velocity, limb strength, and the adjustment variables to determine the factors associated with good balance performance (lower fall risk). In the multivariate logistic regression model, strength was standardized by dividing values by the subject's weight. We included in our final model only the adjustment variables with Spearman correlation P values < 0.20 with respect to the balance measures. Age, BMI status, gender, number of chronic conditions, and mental status met this criterion, whereas depression did not and was excluded from the final analysis. BMI status was characterized using standard cutpoints: overweight as a BMI $\geq$25-<30 kg/m^2 and obesity as BMI $\geq$ 30 kg/m^2 with normal BMI (<25 kg/m^2) as the reference category.[15] The number of chronic medical conditions and number of regular medications are both established measures characterizing health status.

Because a Spearman correlation coefficient of magnitude 0.71 ($P < 0.001$) indicates strong association between these two variables, we chose to use only the number of medical conditions as a covariate in multivariate regression models. SAS (SAS Version 9.1, Cary, NC) was used for all analyses.

RESULTS

Subjects had a mean age of 75.4 yrs, were predominantly female (69%), white (83% white; 15% black, 2% other), and overweight (mean BMI 27.8 kg/cm^2). As shown in Table 1, on average, subjects reported 5.6 chronic medical conditions and were prescribed 4.3 medications. Subjects had a mean score of 28.7 on the MMSE, and 13% were depressed as determined by the center for epidemiologic studies examination (> 16 is consistent with depression).[28] Subjects had an average SPPB of 8.7, and as such are characterized as having mobility limitation of moderate severity.[12] Consistent with this, mean values for performance measures were as follows: UST of 9.9 secs, DGI 21.3 of 24, POMA 25.7 of 28, and the BERG 50.6 of 56. Using our cutoff values, 68% of subjects had good balance scores according to the BERG and POMA, 69% had good balance according to the DGI, and 50% had good balance according to the UST. The associations among the respective balance measures were all statistically significant and are reported in Table 2. Associations were moderate to strong ($r = 0.49–0.60$) for all except for the association of UST with POMA and DGI which were 0.29 and 0.19, respectively. Subjects had an average leg press power of 491.4 W, velocity of 0.88 m/sec, and strength of 1423.7 N. The association between leg velocity per kilogram and leg strength per kilogram was $r = −0.32$; $P < 0.001$ (data not shown).

To better understand the relationship between these commonly used measures of balance and impairment measures, four separate multivariate logistic regression models were constructed to analyze what factors were associated with good balance performance. Results from these models include velocity, strength, and statistically significant adjustment variables and are presented in Table 3. Strength had a statistically significant association with performance on the UST, odds ratio 1.06 (95% confidence interval 1.01–1.11), so for every unit increase in strength, a subject was 6% more likely to be categorized as having good balance. Velocity did not play a significant role in UST performance. In contrast, velocity was consistently more associated with better performance on all composite measures of balance [14.23 (1.84–109.72), 33.92 (3.69–312.03), and 35.80 (4.77–268.71)] for the BERG, POMA, and DGI, respectively. Strength was significantly associated with the BERG 1.08 (1.01–1.14), but did not play a significant role in POMA or DGI performance. Age was associated with performance on UST [0.92 (0.86–0.99)] and BERG [0.90 (0.84–0.96).] The number of chronic conditions was associated with good performance on the DGI [0.78 (0.63–0.96)] and the UST [0.80 (0.67–0.96)]. Men had better performance on the POMA [6.87 (1.88–25.19)], but not on any other balance measures. Finally, subjects with higher MMSE scores performed better on the DGI [1.46 (1.11–1.92)].

DISCUSSION

In our analysis of balance measures predictive of falls, we found limb strength to be significantly associated with the UST and the BERG, whereas limb velocity was significantly associated with stronger performance on the composite balance measures. These findings add to existing knowledge of the association between muscle power and balance. Specifically, a 2005 study by Chan et al.[7] found that muscle power has a direct relationship with the risk of fall-related fractures in elderly adults. More recently, a study by Shigematsu et al.[5] suggested that although poor leg strength and low motor speed (as measured by upper extremity reaction time) were individually associated with fall-related fractures, a combination of these impairments dramatically increases the risk of a fall-related fracture.

In the context of this evidence, our findings support the roles that both limb strength and velocity play in the maintenance of balance. In addition, our study expands on this existing knowledge base by looking at the relative importance of strength and velocity across different balance measures. Mechanistically, the association between strength and UST performance, and the association between velocity and composite balance measures, can be explained by considering the dominant tasks involved in these balance measures.

The three composite balance tests, BERG, POMA, and DGI, require the subject to perform a variety of different tasks, most of which mimic activities performed in daily life. Each of these measures includes tasks that involve maintaining a fixed position, either seated or standing. In addition, these measures all include activities requiring movement, including such activities as walking, rising from a seated position, and transferring between chairs.[21–23] The BERG contains the fewest of these movement-related tasks, while the POMA and especially the DGI require a larger number of these tasks. In addition, the DGI contains some tasks in which a subject is asked to perform the required actions as quickly as possible. As such, the DGI rewards subjects who are able to move quickly. This may explain why an individual's measured velocity had the strongest effect on DGI performance (odds ratio, 19.91) as compared with BERG or POMA performance (odds ratio, 5.50 and 9.55, respectively).

Because of the large proportion of movement-related tasks that make up each of these balance measures, the BERG, POMA, and DGI may all be considered broader measures of mobility, rather than just "tests of balance." When our findings are considered in this context, the association of limb velocity with better performance on these tests is fully consistent with a previous report by Sayers et al.,[9] which suggested that the speed at which a person is able to generate force may have an important role in the performance of functional tasks. Furthermore, Thelen et al.[10] found that rapid generation of ankle torque plays an important role in the ability to recover from a balance disturbance, whereas van den Bogert et al.[29] found quick reaction time to be essential in recovery from a perturbation in balance. As such, good balance performance, and, consequently, lower fall risk, may depend on a person's ability to generate adequate limb velocity. Our findings do not negate the use of the BERG, POMA, and DGI as tests of balance but instead emphasize the link between balance and mobility. As a result, it seems likely that training programs that aim to improve limb velocity may positively affect both balance and mobility.

On the other hand, the physical demands of the UST are quite different from the demands of the composite tests. The UST, a measure of static balance, is dependent on the ability of the individual to support his weight on one leg. Because this activity does not involve movement of the base of support, it is not surprising that strength played a more dominant role than limb velocity. However, UST is a test which is largely influenced by muscle activity at the ankle, which we did not measure in our investigation.[10,30] It is conceivable that if an ankle measure were included, particularly one involving mediolateral motion that the findings would be similar to the other measures.

Though it has long been theorized that both optimal leg strength and leg velocity are very important for balance and potentially for fall prevention, our study is unique in that it measures both attributes among a relatively large cohort of mobility limited elders and that the findings are framed within a clinical context. The association between strength and velocity among our cohort was negative suggesting that our subjects tended to be either high or low in one of these attributes, but not both. It is likely that there is heterogeneity with respect to leg strength and leg velocity impairments and the true distributions would best be evaluated within a population-based study. Subjects in this study were identified as being mobility limited on the basis of their baseline SPPB score. The SPPB has been advocated as a primary care-based screening test and the mean score of our subjects is fully consistent with those who would be referred for rehabilitative services.[31–33]

An interesting finding of this study is that better performance on the MMSE was associated with DGI performance. Again, this association may be considered in light of the component activities of this balance measure. In comparison with the other measures of balance, the DGI includes a greater number of tests that require the performance of two tasks simultaneously, such as walking while turning one's head and looking up on command. Previous studies have shown that poorer cognitive performance is associated with worse performance in these types of dual-task physical activities,[34] so a positive association between performance on the MMSE and DGI is not necessarily surprising. In addition, recent reports have shown a direct link between dual-task performance and falls.[35,36] Though supported by the current literature, the association between MMSE performance and DGI performance needs to be confirmed in a larger study featuring a broader range of cognitive ability and measures of cognitive function.

Limitations

A potential limitation of this study is that fall status was not objectively measured among subjects, although we used cut points among balance measures that have been shown clinically to be predictive of falls. Furthermore, our subjects may be at a significantly higher risk of falls based on their SPPB scores as discussed previously[11] Another limitation is that limb strength and velocity were not measured for muscle groups other than the hip and knee extensors. The ankle, trunk, and hip abductors are all muscle groups that are important in the maintenance of balance,[10,30] so that strength and power output at these sites may affect performance measures. Also our values for limb velocity were not directly measured, but derived from the measure of leg press power. We were not able to acquire direct measurements of 1RM and limb velocity from our equipment only acquiring reliable estimates of the respective peak values, which from a physiologic perspective might be viewed as less optimal. Analytically, we did not have an equal distribution between the cut points of UST and the other balance measures, which could be theorized to account for our findings. However, a post hoc analysis using a purely statistical cut point did not reveal materially different point estimates. Finally, our study is a cross-sectional analysis evaluating older adults with mobility limitations. A larger and broader longitudinal study including healthy older adults and those with a significant fall history may allow us to better understand these relationships.

Despite the limitations of this study, the results presented in this paper highlight the potential importance of emphasizing enhancements in limb velocity in rehabilitative care. Clinical experience suggests that many rehabilitative therapists will emphasize strength training as the major component of balance rehabilitation.[4] However, despite intervention studies suggesting the benefits of limb power enhancement, use of high-velocity training among older adults is rarely used therapeutically. The findings of this study suggest that velocity of movement should be prioritized in rehabilitation.

In addition, the results of this investigation highlight differences between these four clinical measures of balance, indicating the context in which care providers and researchers may wish to use these respective measures. For example, if strength were to be prioritized, then the UST or BERG may be a measure of choice, or if speed of movement were prioritized, then a composite measure might be a better outcome measure.

CONCLUSION

Our study has demonstrated that higher leg press velocity is associated with better performance on BERG, POMA, and DGI measures, respectively, and that higher leg strength is associated with better UST and BERG performance. Although limited by certain methodological

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concerns, these findings underscore the importance of training both leg strength and velocity of movement when considering balance rehabilitation among mobility limited older adults and better characterize these four commonly used clinical measures of balance. Further investigation of these relationships through future longitudinal studies is warranted.

Acknowledgments

We would like to acknowledge Evelyn O'Neill, BS, for her assistance with the initial phases of recruitment and outcomes testing and Mary Alice Hanford, MA, for assistance with preparation of the manuscript.

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Table 1

Baseline Characteristics of 138 Community-Dwelling Older Adults

Characteristic	Mean (SD)	Range
Age (years)	75.4 (6.9)	65–94
Weight (Kg)	75.6 (16.3)	46.6–133.5
BMI (kg/m2)	27.8 (4.9)	19.8–42.1
Chronic Conditions (#)	5.6 (2.4)	1–14
Medications (#)	4.3 (2.8)	0–12
Mini Mental State Examination	28.7 (1.5)	24–30
SPPB	8.7 (1.5)	4.5–11
UST (seconds, n = 120)	9.9 (14.2)	0 – 82.4
DGI	21.3 (3.5)	5–24
POMA	25.7 (3.0)	15–28
BERG	50.6 (4.9)	34–56
Limb Power @ 40% 1RM (W)	491.4 (302.8)	94–1876
Limb Velocity @ 40% 1RM (m/s)	0.88 (0.30)	0.34–1.63
Maximum Limb Strength (N)	1423.7 (717.0)	252.0–3452.0

SPPB, Short Physical Performance Battery; UST, Unipedal Stance Test; BERG, Berg Balance Test; POMA, Performance-Oriented Mobility Assessment; DGI, Dynamic Gait Index.

SD = Standard Deviation

BMI = Body Mass Index

Table 2

Spearman Correlations between Balance measures among the 138 participants

r P-value	UST ≥ 5 seconds †	BERG ≥ 50	POMA > 25	DGI > 20
UST	1.00	0.53 <0.001	0.29 0.001	0.19 0.03
BERG		1.00	0.49 <0.001	0.51 <0.001
POMA			1.00	0.60 <0.001

UST = Unipedal Stance Test Time

BERG = Berg Balance Test Score

POMA = Performance-Oriented Mobility Assessment (Balance Section) Score

DGI = Dynamic Gait Index Score

r = Correlation coefficient

† = N=120

Table 3

Multivariate models showing the association between balance and maximal leg strength and leg velocity. Models include those covariates, which statistically achieved inclusion in the final models

Function	OR (95% CI)	*P* value
UST ≥ 5 seconds (N = 120)		
Velocity (m/s)	1.56 (0.39 – 6.22)	0.53
Strength (N/kg)	1.06 (1.01 – 1.11)	0.03
Age (Years)	0.92 (0.86 – 0.99)	0.02
Chronic Conditions (#)	0.80 (0.67 – 0.96)	0.01
BERG ≥ 50 (N = 137)		
Velocity (m/s)	14.23 (1.84 – 109.72)	0.01
Strength (N/kg)	.08 (1.01 – 1.14)	0.02
Age (Years)	0.90 (0.84 – 0.96)	0.002
POMA > 25 (N = 137)		
Velocity (m/s)	33.92 (3.69 – 312.03)	0.002
Strength (N/kg)	1.03 (0.97 – 1.09)	0.37
Age (Years)	0.97 (0.91 – 1.03)	0.28
Gender	6.87 (1.88 – 25.19)	0.004
DGI > 20 (N = 137)		
Velocity (m/s)	35.80 (4.77 – 268.71)	<.001
Strength (N/kg)	1.01 (0.96 – 1.06)	0.79
Age (Years)	0.95 (0.89 – 1.02)	0.18
Chronic Conditions (#)	0.78 (0.63 – 0.96)	0.02
BMI status	1.65 (.89 – 3.03)	0.11
Mini Mental Status Exam Score (#)	1.46 (1.11 – 1.92)	0.01

Velocity and strength UST, Unipedal Stance Test; BERG, Berg Balance Test; POMA, Performance-Oriented Mobility Assessment (Balance Section); DGI, Dynamic Gait Index

OR = Odds ratio

CI = Confidence interval

BMI Status: <25 (reference), 25-<30, ≥ 30 kg/m^2