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Validity of the Gait Variability Index in older adults: Effect of aging and mobility impairments

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Abstract

Gait variability, defined as the fluctuation in spatiotemporal characteristics between steps, is suggested to be a sensitive indicator of mobility deficits with aging and pathological processes. A challenge in quantifying gait variability is the decision of which spatiotemporal parameters to assess because gait parameters may exhibit different amounts of variability and may differentially relate to mobility performance. The Gait Variability Index (GVI), a composite measure of variability across several gait parameters, was previously developed to overcome this challenge. The present study seeks to validate the use of GVI in the older adult population. A retrospective analysis of gait and clinical data was conducted using data pooled from five prior studies. The final data set included 105 younger adults (YA, age < 65) and 81 older adults (OA, age ≥ 65). The GVI of OA (91.92 ± 8.75) was significantly lower compared to the GVI of YA (100.79 ± 7.99). Within OA, the GVI was significantly lower ($p < 0.0001$) in individuals with mobility deficits (84.35 ± 9.03) compared to those with high mobility function (96.35 ± 8.86). Furthermore, GVI was associated with mobility function, including walking speed and performance on the Berg Balance Scale. Our findings imply that the GVI is a valid assessment for gauging spatiotemporal gait variability in older adults, is sensitive to differentiate between high-functioning older adults and those with mild to moderate mobility deficits and is associated with some clinical measures of functional mobility and balance.

Keywords

Gait; Variability; Spatiotemporal; Aging; Mobility

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1. Introduction

Gait variability, defined as the fluctuation in spatiotemporal characteristics between steps, is a sensitive indicator of mobility deficits [1]. For example, variability in spatiotemporal parameters is reported to predict mobility deficits and future falls better than the mean of spatiotemporal parameters in older adults [2]. Gait variability is altered by pathological conditions of disease and injury [3]. An investigation of the magnitude of these fluctuations has received considerable attention and is the focus of the current study. Particularly, the magnitude in gait variability is an important outcome measure in older adults since altered gait variability has shown to be associated with advancing age, mobility deficits, cognitive impairments and fall risk [4–7]. A majority of the literature in older adults report that gait variability is increased in older adults [1]. However, decreased gait variability has also been reported in some spatiotemporal parameters (such as step width) and related to mobility deficits [8]. Despite the mounting evidence supporting use of gait variability as an outcome measure in the older adult population, there has been limited use of gait variability measures in clinical settings or in randomized controlled trials.

The lack of widespread use of gait variability as an outcome measure may, in part, be due to methodological challenges [9]. First, it is unclear which spatiotemporal measures are of greatest importance when assessing gait variability. Variability has been reported for at least 11 spatiotemporal parameters, but it is unclear which are most relevant to mobility function and the deficits that they reflect. For instance, step width variability was associated with age-related sensory impairments in a study by Brach et al. [10], whereas Richardson et al. reported that step time and not step width variability was associated with sensory impairments [11]. Second, there is a lack of consensus regarding how best to quantify gait variability [e.g., standard deviation (SD), coefficient of variation (CV)]. Some researchers have proposed that until a consensus can be reached, gait variability should be analyzed multiple ways [9]. Third, for individuals with impaired mobility the increase in gait variability can be observed across many different spatiotemporal parameters. This inter-dependence confounds statistical analysis because it is not clear which parameters are the best indicators of mobility deficits.

These methodological issues motivated the development of the Gait Variability Index (GVI). The GVI is a conglomerate measure of gait variability derived from nine spatiotemporal parameters and was developed to improve objective quantification of gait variability [12]. Preliminary validity was demonstrated by a decrease in GVI for individuals with Friedreich's Ataxia, suggesting that the GVI was linked to mobility function [12]. While the GVI seems to be a promising outcome measure because it avoids some of the methodological problems surrounding variability measures, it is not yet validated as an outcome measure in older adults. Therefore, the purpose of this study was to investigate the validity of the GVI as an outcome measure of mobility deficits in older adults.

2. Methods

2.1. Participants

This study retrospectively analyzed data pooled from 5 studies (Table 1). Participants aged 18–90 years (n = 186) were included. Participant data was categorized into two broad categories: younger adults (YA) less than 65 years of age and older adults (OA) greater than or equal to 65 years of age. Study protocols were approved by the Institutional Review Boards at the respective institutions and all participants gave their informed consent before participation.

2.2. Procedures

Procedures of included studies have been described in detail elsewhere [12–15]. Here we report only those procedures that impacted the data analysis for the current study (Table 1). Our primary data of interest were the spatiotemporal gait measures acquired by an instrumented walkway (GAITRite), a valid and reliable tool to evaluate spatiotemporal gait measures [16].

Selected clinical measures of functional mobility and balance were retrospectively available from some included studies and were used to further validate the GVI. These included the Berg Balance Scale (BBS), Timed Up and Go Test (TUGT), Dynamic Gait Index (DGI), Community Balance and Mobility Scale (CB&M), Activities-specific Balance Confidence (ABC) scale, Short Physical Performance Battery (SPPB) and Functional Reach Test (FRT). Each of these measures have shown to be valid and reliable to assess functional mobility and balance in older adults [17–21].

2.3. GVI calculation

Data were exported from the GAITRite software, version 4.7.4 and GVI was calculated if a minimum of five absolute differences (at least 13 consecutive steps for a walk) were available.

The GVI was calculated using the macro that was available as supplemental material provided by Gouelle et al. [12]. The parameters used for GVI computation is based on the weighting identified using a PCA that determines the main correlation pattern among multiple measures of gait variability. Step time (0.930) and stance time (0.919) are the most contributing parameters, but the majority of the parameters have weighting above 0.80. A lower factor value indicates that either the parameter is contributing less to overall gait variability and/or showing naturally more variance within an asymptomatic gait.

The GVI quantifies the distance between the amount of variability observed for a reference group and the amount of variability observed for an individual [12]. To enhance applicability, GVI is transformed into a score with 100 representing the mean score for the reference group. The standardized mean score and SD of the reference population are defined as 100 and 10, respectively [12]. GVI ≥ 100 indicates that the individual has a similar level of variability as the reference group. For GVI < 100, each 10-point difference corresponds to a separation of 1 SD from the reference group score. For instance, an

individual with a GVI of 70 would have gait variability that deviates from the control group mean by 3 standard deviations. In contrast, an individual with a score greater than 100 would have gait variability that is closer to the control group's mean variability than is the average member of the control group.

2.4. Statistical analyses

Parameteric *t*-tests investigated whether the GVI (1) differed in OA from YA and (2) discriminated high-functioning older adults (HFOA) from older adults with mild to moderate mobility deficits (MDOA) in a subset of the pooled sample. The area under the curve (AUC) of an ROC curve was computed to further assess the discriminatory power of the GVI. Discriminatory power $0.7 \leq AUC \leq 0.8$ is suggested to be acceptable [22]. Sensitivity and specificity of the GVI were also calculated. Pearson correlation coefficients investigated the relationship between GVI and clinical measures of functional mobility and balance. Correlational analyses were also replicated with regression models adding study as the dummy variable to test if combining data sets may have confounded the results. The results were similar so findings from the correlational analyses are presented. Data were analyzed using SPSS (19.0).

3. Results

Data reduction steps (i.e., ensuring enough steps to compute variability through GVI) resulted in a reduced data pool of 105 individuals in the YA group and 81 individuals in the OA group. The characteristics of the study pool and relevant characteristics of sub-groups of participants from each study are presented in Table 2.

3.1. Effect of aging on GVI

The GVI of OA (91.93 ± 8.75) was significantly lower ($p < 0.0001$) when compared to the GVI of YA (100.79 ± 7.99). An inspection of the raw data suggested that the relationship between age and GVI is likely not linear throughout the age continuum (Fig. 1). Visual inspection of the raw data suggested that the relationship between age and GVI changes at approximately age of 50 years. Prior to 50 years, there seemed to be no clear association between GVI and age but after 50 years there was a negative association such that GVI reduced with advancing age (Fig. 1). Linear regression modeling confirmed these visual analyses and demonstrated a modest but significant proportion of variance explained by GVI in adults aged 50 years and older ($r = 0.39$, $R^2 = 0.15$, $p < 0.001$).

3.2. Ability of GVI to discriminate older adults based on their level of mobility function

GVI in MDOA (84.35 ± 9.03) was significantly lower ($p < 0.0001$) compared to the GVI in HFOA (96.35 ± 8.86). The discriminatory power of the GVI was also acceptable (AUC = 0.841, $p = 0.002$, Table 3).

3.3. Relationship between GVI and clinical measures of functional mobility and balance

In the OA group, GVI was significantly correlated with walking speed ($r = 0.42$, $p < 0.001$) and BBS ($r = 0.49$, $p < 0.001$). Relationships between GVI and other clinical data were not statistically significant ($p > 0.05$), as shown in Table 4. However, there were trends

supporting an association between GVI and falls history (r=—0.315, p = 0.061) and GVI and TUG (r=−0.330, p = 0.057).

4. Discussion

The GVI was previously developed as a composite measure to quantify the magnitude of variability in spatiotemporal parameters and demonstrated preliminary validity as an indicator of mobility deficits [12]. In the present study, GVI was validated as an indicator of age-related deficits in mobility function. Our study had 4 important findings: (1) GVI was significantly lower in older adults (age ≥ 65 years) compared to younger adults (age < 65 years), (2) decrements in GVI appeared to become prominent in the 6th decade of life and continued to deteriorate with advancing age, (3) GVI discriminated higher-functioning older adults from those with mobility deficits in a sub-set of the study sample, and (4) lower GVI was associated with poorer outcomes in some clinical measures of functional mobility and balance.

4.1. GVI is lower in older adults compared to younger adults

The effect of aging on gait variability has earlier been investigated in several studies but conflicting results have been reported. For example, Gabell and Nayak were among the first to investigate the effect of age on gait variability [23]. They quantified variability as the CV in stride time, double-support time, step length and stride width and reported no difference in gait variability between younger and older adults. Similarly, others reported no effect of age on gait variability when quantifying variability in selected spatiotemporal gait parameters [24]. Contrary to these studies, some others reported differences in gait variability between younger and older age groups [25,26]. For example, Grabiner et al. quantified variability as the SD in stride width, stride time, stride length and velocity and reported an increase of gait variability selectively in stride widths in older adults when compared to their younger counterparts [25]. Similarly, another study investigated the effect of age on gait variability (quantified as SD) in several spatiotemporal parameters, such as step time, step length, step width and double support time, but unlike Grabiner et al., this study reported an association of age with all spatiotemporal gait measures [4].

While differences in sample size and characteristics are issues that typically need to be considered when comparing results across studies, the lack of consistent methods, such as the choice of spatiotemporal parameters and the use of SD or CV to analyze the magnitude of variability, is apparent in these studies with conflicting results. Since the GVI resolves some of the existing methodological problems encountered when quantifying the magnitude of gait variability, the use of GVI may serve to clarify the association between gait variability and age. Note that, an increase in the magnitude of gait variability leads to a reduction in the value of the GVI because the construction of the GVI is such that any deviation from a reference group is calculated in units of standardized SD and subtracted from the reference group value. Therefore, a reduction in the GVI scores in older adults reflects an increase in the gait variability.

4.2. Around 50 years of age, GVI decreases with advancing age

An interesting finding of this study was that the relationship between GVI and age did not seem to be linear. First, visual inspection and later regression modeling confirmed that the relation between GVI and age seemed to be specific to age-groups and was not uniform across the age continuum. We found that at age ≥ 50 years, GVI changes its pattern and seemed to decrease with advancing age. While our results in this area are preliminary due to the small sample size and retrospective nature of the data, these preliminary findings are promising in light of a recent population-based study [27]. Verlinden et al. recently reported that variability measures may be amongst the first 'gait factors' that capture deteriorating gait [27]. Specifically, they studied adults 50 years and older and found that gait variability was the gait factor that associated with the youngest age group (50 years) suggesting gait variability measures as early screening markers [27]. Therefore, our preliminary findings suggest that the GVI could serve as an accurate composite measure of variability further supporting the validity of the index. Nonetheless, our results in this area require further validation using prospective longitudinal designs. Future studies should investigate cut-off scores of GVI to determine screening thresholds to detect mobility deterioration with advancing age.

4.3. GVI discriminated higher-functioning older adults from those with mobility deficits

Not only was the GVI lower in older adults, the index discriminated older adults with mild to moderate mobility deficits from those who were higher-functioning. Gait variability has earlier shown to be effective in discriminating older adults with a wide range of mobility deficits and cognitive impairments from their healthier counterparts [5,6]. Therefore, our finding of lower GVI in higher-functioning older adults compared to those with mild to moderate mobility deficits is not surprising. However, when compared to the prior study by Gouelle et al., which reported that GVI was lower in individuals with ataxic gait compared to healthy adults [12], the two older adult groups used for comparison in the current study had relatively subtle differences in mobility function. Furthermore, the acceptable AUC index suggests good discriminatory power of the GVI.

It is important to note that, the GVI was originally proposed as a 'global' or 'conglomerate' index of gait variability that is inclusive of several aspects of variability [12]. Therefore, while we suggest that the researcher or clinician may first use a global index like the GVI to determine how variable an individual is compared to an asymptomatic/reference population or to differentiate the levels of variability alteration, specific spatiotemporal parameters (e.g., step length or step width variability) may need to be additionally examined to understand the motor control deficits specific to the clinical condition.

4.4. GVI associated with some clinical measures of functional mobility and balance

GVI demonstrated strong correlation with walking speed in older adults. The positive strong linear correlation of GVI with walking speed suggests higher functioning level for those with greater GVI. Walking speed is reported to be a clinically meaningful indicator of physical health status in the older adults [28]. For instance, because of its strong clinimetric properties to predict future health status and functional decline, walking speed has been associated with survival rates in community-dwelling older adults aged 65 years and older

and suggested to be the 6th vital sign of health [29]. Therefore, the strong correlation of GVI with the gold standard measurement of walking speed further validates GVI as an indicator of mobility function in older adults.

GVI significantly and positively correlated with the Berg Balance Scale, which is a widely used assessment of balance performance in older adults [30]. The relationship between GVI and other clinical measures of functional mobility and balance were not statistically significant, although the strength of the correlation coefficients suggest a moderate to strong effect for some measures. It is likely that the interrelationships between GVI and clinical measures were not statistically significant due to the small sample size of the sub-sets used for these analyses. Despite the fact that statistical significance was not achieved, the direction of relationship was consistent with GVI decreasing with poorer outcomes (i.e., greater number of falls, lower scores on functional mobility assessments like DGI, ABC and CB&M and greater time on the TUGT). Our methods should be replicated with larger sample sizes to better establish the strength of associations between GVI and functional mobility and balance.

Of importance, is the relationship between number of falls in the past year and GVI that demonstrated a trend for association but was not statistically significant. The type of falls reported for this sub-set of the study included several unusual falls in high-level functions like running and sporting activities. Falls were also recorded retrospectively. Prospective reporting of fall events is a more accurate approach and minimizes recall bias. Despite these concerns with the falls data, the trend for an association between GVI and falls history is encouraging. Future studies should replicate these analyses with prospective falls data collection.

4.5. Study limitations

First, while retrospective analyses were sufficient to discriminate GVI of older adults from younger, prospective data are required to further explain our findings on the relationship between age and GVI. Second, different lengths of walkways were used for data collection. Using shorter walkways can induce the need for more walks resulting in sources of external variability. Nevertheless, the GVI can be robustly constructed from several walks on a walkway minimizing inter-trial variability. Third, a limited number of steps were used to compute the GVI. The effect of using a limited number of steps is unknown, as no prior study has investigated the relationship between number of steps and resultant GVI. For the present study, the number of steps used is generally consistent with that expected for gait testing in a clinical setting.

5. Conclusions

The GVI is a valid assessment for gauging the magnitude of spatiotemporal gait variability in older adults because (1) it is lower in older adults compared to younger, (2) seems to reduce with advancing age during the critical years where mobility deficits begin to emerge, (3) is capable of differentiating older adults who are high-functioning from those with mild to moderate mobility deficits, and (4) associates with some clinical measures of functional mobility and balance performance. Future research should further develop the clinimetric

properties of the GVI for its potential use in clinical practice. Of particular importance is the ability of the GVI to predict future falls and to quantify the therapeutic effects of behavioral or pharmacological interventions.

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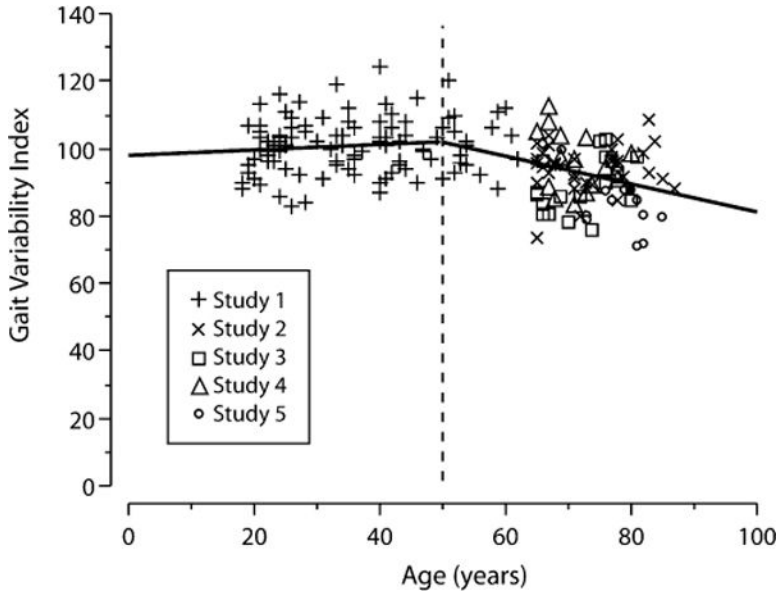

Fig. 1.

Relationship between Gait Variability Index and age. There is no relationship between Gait Variability Index (GVI) and age before 50 years of age. After 50 years of age, GVI reduces with advancing age.

Table 1

Description of data sets included in the current study.

Study	Inclusion/exclusion criteria	GAITRite specifications	Relevant study methodology	Clinical assessments
Study 1 Younger adults [YA]	No evidence of muscle, bone, joint, and brain or nerve dysfunction; no history of lower limb and/or dorsal surgery	GAITRite Platinum 4, 88m and 6.10m 3–5 trials at comfortable speed	Institution data collected: Robert Debré Hospital, Assistance Publique – Hôpitaux de Paris, France Participants were instructed to walk at their usual/comfortable/ self-selected speed Participants started walking 2m before and continued to walk 2m after the walkway	N/A
Study 2 Older adults [OA]	Age 65–80 years; able to walk without an assistive device; no report of past or current trouble in gait and equilibrium; no cardiovascular conditions; no history of neurological diseases with influence on walking capacities; no history of vestibular or orthopedic (lower limb) disorders and no amblyopia	GAITRite Platinum 4, 88m 3 trials at comfortable speed	Institution data collected: Robert Debré Hospital, Assistance Publique – Hôpitaux de Paris, France Participants were instructed to walk at their usual/comfortable/ self-selected speed Participants started walking 2m before and continued to walk 2m after the walkway	N/A
Study 3 Older adults [OA]	Adults aged 65 years or older residing independently in the community; able to walk at the minimum indoors and outdoors with supervision or independently; ambulate without assistive devices; able to follow verbal requests for movement or tasks, no unstable acute or chronic disease; Mini-Mental State Examination (MMSE) score less than 23 suggestive of no severe cognitive impairments; and no severe neurologic, cardiorespiratory orthopedic impairments that limit balance and mobility	GAITRite Platinum Plus 18.0 ft, 5.49m active length 3 trials at comfortable speed	Institution data collected: University of North Florida, Jacksonville, FL Participants were instructed to walk at their “usual/ comfortable/self-selected speed” Participants started walking 2m before the walkway in response to a “go” signal and continued to walk 2m after the walkway	Performance-based assessments; BBS, TUGT, DGI, CB&M, ABC, SPPB, and FRT Self-report measures; ABC scale and a self-report of falls questionnaire that documented number of falls in the past year
Study 4 High-functioning older adults [HFOA]	Age 65–80 years; no use assistive device for walking; no fall within the previous year; a response of ‘NO’ to the question “Do you find walking, climbing stairs or performing daily household chores to be physically challenging?”; no pain, stiffness, numbness or range of motion limitations of the back or legs; no involuntary weight gain or loss exceeding 10 lbs within the past 6 months; no myocardial infarction or symptomatic cardiovascular disease in the past year; no bone fracture in the past year; no medical condition affecting movement; no terminal illness; or no contraindications to magnetic resonance imaging assessment. Resting blood pressure below 160/95; body mass index within the range of 19–32; BBS ≥ 50; MMSE ≥ 25 and usual 10 m walking speed ≥ 1.0 m/s	GAITRite Gold 12 ft, 3.66 m active length 5 trials at comfortable speed	Institution data collected: Brain Rehabilitation Research Center, Gainesville, FL Participants were instructed to walking at “normal/comfortable/ everyday speed” Participants started walking 2m before and continued to walk 2m after the walkway	Performance-based assessments; BBS, SPPB
Study 5 Mobility deficits older adults [MDOA]	Age 65–85 years; included 400m walking speed<1.1m/s, BBS score>41, MMSE score>21, body mass index within the range of 19–35 and agreement with the statement “You find it physically	GAITRite Gold 12 ft, 3.66 m active length 5 trials at comfortable speed	Institution data collected: Brain Rehabilitation Research Center, Gainesville, FL Participants were instructed to walking at “normal/comfortable/ everyday speed”	Performance-based assessments; BBS, SPPB Self-report measures; ABC scale

Study	Inclusion/exclusion criteria	GAITRite specifications	Relevant study methodology	Clinical assessments
	tiring to walk a quarter mile, or climb two flights of stairs, or perform household chores." Exclusion criteria included use of an assistive device for walking; lower extremity pain while walking; involuntary weight gain or loss exceeding 10lbs within the past 6 months; myocardial infarction or symptomatic cardiovascular disease in the past year; bone fracture in the past year; injury or illness to the central nervous system; uncontrolled hypertension exceeding 160 systolic and/ or 95 diastolic; or terminal illness		Participants started walking 2m before and continued to walk 2m after the walkway	

Table 2

Characteristics of the study sample.

	Study 1 Younger adults [YA]	Study 2 Older adults [OA]	Study 3 Older adults [OA]	Study 4 High functioning older adults [HFOA]	Study 5 Mobility deficits older adults [MDOA]	Older adults data pooled (study 2–5)
Sample recruited	123	30	40	20	16	106
Sample analyzed	105	19	34	15	13	81
GVI	100.79±7.99	89.32±7.96	94.30±6.86	96.35±8.86	84.35±9.03	91.93±8.75
Age	35.39±12.41	72.47±5.49	73.29±6.81	71.20±4.41	77.23±5.60	73.34±6.12
Gender	54F/51M	12F/7M	22F/12M	10F/5M	7F/6M	49F/30M
BMI	22.92±3.43	24.71±3.77	27.37±4.69	26.46±2.21	29.47±2.59	26.19±3.34
Falls past year	n/a	0.0±0.0	1.35±1.65	n/a	n/a	n/a
BBS (54)	n/a	n/a	53.21±2.40	54.47±1.25	51.08±3.52	53.06±2.69
SPPB (12)	n/a	n/a	10.47±1.66	11.31±0.95	9.40±2.38	10.38±1.84*
ABC (100)	n/a	n/a	86.48±12.50	n/a	83.27±14.58	84.87±13.54*
TUGT (s)	n/a	n/a	10.28±2.28	n/a	n/a	n/a
CB&M (96)	n/a	n/a	47.97±18.34	n/a	n/a	n/a
DGI (24)	n/a	n/a	20.03±3.42	n/a	n/a	n/a
FRT (inches)	n/a	n/a	10.88±2.20	n/a	n/a	n/a
Gait speed (m/s)	n/a	1.10 ± 0.18	1.18±0.24	1.28±0.16	0.97±0.13	1.15±0.21

Abbreviations: GVI, Gait Variability Index; BMI, body mass index; BBS, Berg Balance Scale; SPPB, Short Physical Performance Battery; ABC, Activities-specific Balance Confidence; TUGT, Timed Up and Go Test; CB&M, Community Balance and Mobility Scale; DGI, Dynamic Gait Index; FRT, Functional Reach Test; n/a, not applicable.

*Data pooled from available studies.

Table 3

Discriminatory power of GVI in discriminating older adults who are high functioning (HFOA) from those with mobility deficits (MD0A).

AUC	95% confidence interval	*p*-Value	Sensitivity	Specificity
0.841±0.078	(0.689, 0.993)	0.002	66.6%	84.6%

Abbreviation: AUC, area under the curve.

Table 4

Relationship between Gait Variability Index and clinical measures of mobility and balance.

Clinical data	Gait variability index	
	r	***p*-Value**
Number of falls (n=36)	−0.315	0.061
BBS (*n*=62)	0.492**	0.000
SPPB (*n*=62)	−0.081	0.533
ABC (*n*=47)	0.202	0.174
TUG (*n*=34)	−0.330	0.057
CBM (*n*=34)	0.036	0.839
DGI (*n*=34)	0.275	0.115
FRT (*n*=34)	0.088	0.620
Walking speed (*n*=81)	0.415**	0.000

Abbreviations: BBS, Berg Balance Scale; SPPB, Short Physical Performance Battery; ABC, Activities-Specific Balance confidence; TUGT, Timed Up and Go Test; CB&M, Community Balance and Mobility Scale; DGI, Dynamic Gait Index; FRT, Functional Reach Test.

** $p < 0.01$; r =Pearson correlation coefficient.