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Conventional And Robust Quantitative Gait Norms In Community Dwelling Older Adults

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Abstract

Objectives—While gait is widely used to assess health status in older adults, normative data is lacking. Our objective was to develop and compare norms for widely used gait parameters in adults age 70 and older using cross-sectional (conventional) and longitudinal (robust) approaches accounting for important confounders such as disease effects on gait.

Design—Cohort study

Setting—General community

Participants—Community-dwelling older adults (age>70, N=824) without dementia or disability

Measurements—Eight quantitative gait parameters measured using an instrumented walkway.

Results—Of the 824 subjects (conventional normal; CN sample), 304 were included in a ‘robust normal’ (RN) sample after excluding those with either prevalent or incident clinical gait abnormalities developing within one year of the baseline assessment to account for disease effects on gait performance. Descriptively, the RN sample showed better performance on all selected gait variables compared to the CN sample. For instance, mean gait velocity ($\pm$ standard deviation) was 105.9 $\pm$ 17.9 cm/sec in the RN sample compared to 93.3 $\pm$ 23.2 cm/sec in the overall CN sample. Applying a one standard deviation below the mean (70.1 cm/sec) derived from CN sample to define slow gait, 15.9% (131) in overall cohort were classified as abnormal whereas the RN cut-off (88.0 cm/sec) classified 39.7% (327) in the overall cohort as abnormal.

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Conclusion—Our findings suggest that cross-sectional conventional norms may under-estimate gait performance in aging. Longitudinal robust norms provide more accurate estimates of normal gait performance and thus may improve early detection of gait disorders in older adults.

Keywords

gait; reference values; elderly

INTRODUCTION

Gait is widely used in clinical practice to assess the health status of older adults.^{1–4} However, a clear consensus on normative gait values in older adults is lacking. A wide range of normal values is reported for gait parameters in older adults. For instance, mean gait velocity in older adults ranges from 89 cm/sec to 141 cm/sec in previous studies.^{5–8} There are a number of reasons for this lack of agreement among studies. All previous studies have been cross-sectional and were mostly based on small samples, which did not permit assessment of the effects of important confounders such as age, gender, and height.^{7–10} Applying norms for gait from younger populations to seniors will not take into account the morphological and functional changes that occur in gait with aging, and also result in misclassification of many independently living seniors as impaired.⁸

Another important variable unaccounted in previous normative studies is the effect of disease on gait, which may lead to underestimation of gait performance with normal aging. Clinical gait abnormalities are valid markers of disease.^{11, 12} Hence, excluding individuals with prevalent or in transition to developing clinical gait abnormalities from study samples will help develop robust quantitative gait norms that better reflect normal aging effects on gait. Robust norms also serve as a yardstick to judge effects of disease or interventions on gait. A previous study in our cohort showed that longitudinal robust norms (excluding individuals who developed dementia over follow-up) for neuropsychological tests provided better estimates of cognitive performance in normal aging and a more accurate prediction of those in transition to develop dementia than conventional norms.¹³

Previous studies have mostly reported normative data for gait velocity.^{6, 14} However, gait is a complex motor behavior with multiple other measurable facets. The increased use of instrumented techniques has allowed a more comprehensive assessment of gait.^{2, 15, 16}

Our objective is to provide conventional and ‘robust’ norms in community residing older adults without dementia or disability for widely used quantitative gait parameters measured using the GAITRite system (CIR systems, PA). The GAITRite system is an electronic walkway that automates collection of spatial and temporal parameters of gait.¹⁵ The walkway requires minimum setup and collection time, and does not require the placement of any devices on the patient.

In this study, the overall study population was termed the ‘conventional normal’ (CN) sample. To develop longitudinal robust norms, we excluded subjects with prevalent clinical gait abnormalities as well as those who developed clinical gait abnormalities over the first year of follow-up from the CN sample. Exclusion of individuals who developed incident abnormalities was done to account for the presence of clinically undetected (subclinical), misdiagnosed or subtle gait abnormalities at baseline. We compared both norming approaches to determine whether the longitudinal robust norms provide a more accurate representation of gait performance in normal aging than the cross-sectional conventional norms.

METHODS

Study population

We assessed gait in participants in the Einstein Aging Study (EAS).¹¹⁻¹⁷ The primary aim of the EAS was to identify risk factors for dementia. Recruitment and study procedures have been previously reported.^{11-17, 18} In brief, the EAS has used telephone-based screening procedures to recruit a community-residing Bronx County cohort identified from Health Care Finance Administration population lists from 1993 to 2003 and from Bronx county voter registration lists from 2004 to present. The EAS interview included verbal consent, brief medical history questionnaire, and telephone based cognitive screening tests.¹⁸ Inclusion criteria were age 70 and older, English speaking, and residing in Bronx County. Exclusion criteria include severe audiovisual loss, inability to ambulate even with the assistance of a walking aid, or institutionalization. Additional exclusion criteria for this study included presence of dementia (diagnosed at EAS case conferences¹⁹) or disability. Disability was defined as inability or requiring assistance to perform any one of the following seven activities of daily living: bathing, dressing, walking inside the house, chair transfers, toileting, feeding, and grooming.²⁰ Written informed consent was obtained at study entry. All study protocols were approved by the local institutional review board.

Quantitative gait assessment was introduced in the EAS in 2002. Of the 904 EAS subjects seen between February 2002 and May 2008, 824 (91.2%) subjects without dementia or disability received gait assessments. Reasons for not obtaining gait assessments included tester unavailability, subject illness, or refusal. Subjects who did and did not receive gait assessments were similar in terms of age. However, subjects with missing gait assessments had higher illness burden.

Quantitative gait assessment

Research assistants conducted quantitative gait assessments at study visits using a computerized walkway ($457 \times 90.2 \times 0.64$ cm) with embedded pressure sensors (GAITRite system). Subjects were asked to walk on the walkway at their “normal pace” for two trials wearing comfortable footwear. The walk was started and finished three feet from the recording field, indicated by markers on the floor, to allow for initial acceleration and terminal deceleration. Based on footfalls recorded on the walkway, the software automatically computes gait parameters as the mean of two trials. Based on our and other aging studies,¹⁻¹⁵ we selected eight gait parameters to norm: velocity (cm/sec), cadence (steps/minute), stride length (cm), swing time (sec), stance time (sec), and double support phase (%). Standard deviation (SD) of stride length and swing time was used as proxies for gait variability.²¹

The GAITRite system is widely used in clinical and research settings.¹⁵⁻¹⁷ It has high levels of concurrent validity compared with other systems²² as well as test-retest reliability.¹⁷⁻²³

Clinical gait assessment

Clinical gait abnormalities were diagnosed using a well established rating scale^{11-12, 17} at baseline and annual follow-up visits. Subjects were observed while they walked up and down a well lit hallway by study clinicians who rated gaits as normal or abnormal following visual inspection of walking patterns.¹¹⁻¹² Abnormal gaits were classified as non-neurological (e.g., gait limited due to pain from arthritis) or neurological (hemiparetic, unsteady, ataxic, spastic, neuropathic, Parkinsonian, and frontal).¹¹⁻¹⁷ More detailed descriptions and video weblinks of abnormal gaits are available.¹¹ Clinicians who evaluated gait were blinded to results of previous clinical gait examinations and quantitative gait

assessments. This clinical rating has established test-retest reliability and inter-rater reliability ($\kappa = 0.8$).^{12, 17}

Study samples

The overall dementia and disability free study cohort ($n = 824$) was the CN sample. The RN sample was the subset of subjects who were free of clinically diagnosed gait abnormality at baseline (prevalent sample) and at the one year follow-up visit (incident sample). Subjects in the incident sample had normal gait at baseline but were diagnosed with clinical gait abnormalities at the one-year follow-up visit. We also excluded 23 subjects awaiting follow-up as well as 87 subjects who did not have quantitative gait assessments at their one year follow-up from the RN sample. Reasons for missing evaluations at follow-up included death ($n=3$), refusal ($n=30$), relocation ($n=6$), developed dementia ($n=7$), serious medical illnesses ($n=17$), or lost contact ($n=24$). There were 304 subjects eligible for the RN sample following all exclusions.

Covariates

Research assistants collected demographic data, medical illness history, mobility, and medications (prescription and non-prescription) from subjects and caregivers at each visit using structured questionnaires. Consistent with our previous studies,^{2, 24} presence or absence of diabetes, congestive heart failure, hypertension, stroke, angina, myocardial infarction, chronic obstructive pulmonary disease, Parkinson disease, depression, and arthritis was used to calculate an illness index score (range, 0–10). Depressive symptoms were assessed by the Geriatric depression scale.²⁵ The Blessed Information-Memory-Concentration test²⁶ was used to assess general cognitive status.

Data analysis

The mean and standard deviation (SD) of the eight selected quantitative gait parameters are presented for the study samples. For RN and CN samples, gait parameters were tabulated per 5-year age stratum for each gender. Linear regression analysis adjusted for age and sex was used to assess differences in gait parameters among prevalent and incident samples compared to the RN sample as reference. Linear trend among age groups was examined for gait parameters in the RN and CN samples.

Linear regression analysis was used to assess the effect of disease on gait. Both prescription medication count and illness index score were examined as proxies for disease effects. However due to collinearity between these two variables in our models, we included only one of these variables at a time. A lower association of disease effect and gait velocity in RN sample would support use of RN method for defining normal aging gait performance.

To assess validity of robust and conventional norms in detecting gait abnormalities, cutoffs for 'slow gait' defined as a one SD below the mean were derived from CN and RN samples, and compared in the overall cohort. These cutoff scores were also compared in the incident sample to assess their role in early detection of gait impairment.

All data analysis was performed using STATA version 10.0 (StataCorp LP, College Station, TX).

RESULTS

Demographic and medical information for the CN and other samples are presented in Table 1. Of the 824 subjects, 321 (38.9%) had clinical gait abnormalities at baseline (prevalent sample) and 89 (10.8%) were diagnosed with clinical gait abnormalities at their one-year

follow-up visit (incident sample). Compared to the CN sample, the 304 RN subjects were younger, took fewer medications including psychotropics (6.6% versus 10.4%), and had lower depression²⁵ and cognitive scores²⁶. Illness index was not significantly different between samples. Of the RN sample, 85 % including 74 % in the oldest stratum (ages 85–97) were able to walk quarter mile or more without taking a break.

The quantitative gait parameters at baseline in various study samples are summarized in Table 2. Gait velocity (cm/sec) is also presented with values normalized for height (computed as velocity divided by height in centimeters) since height is a known predictor of velocity.²⁷ The RN sample descriptively showed better characteristics than the CN sample in all eight gait parameters. For example, mean gait velocity in the RN sample was 105.9 cm/sec compared to 93.3 cm/sec in the CN sample.

The two excluded subsamples (incident and prevalent) were compared to the RN sample for gait parameters using linear regression analysis adjusted for age and gender. The incident sample showed significantly reduced velocity ($p<0.001$), cadence ($p=0.014$), stride length ($p<0.001$) and increased double support ($p=0.010$) than the RN sample. The prevalent sample showed worse performance in all eight gait parameters compared to the RN sample ($p<0.001$). The results remained significant for six gait parameters except variability even after adjusting for velocity.

Normative gait values at baseline by age stratum and gender for RN and CN samples are also presented (Table 3). In the RN sample, gait velocity and stride length showed a decreasing trend with advancing age in both men and women. This trend remained significant even after excluding the oldest stratum with the smallest sample. An increasing trend in variability of stride length and swing time was seen only among women in the RN sample. On the other hand, worse performance on velocity, stride length, and swing time variability with advancing age was seen in both men and women in the CN sample. The RN approach also resulted in better gait characteristics than CN in older age groups. For instance, mean gait velocity for men and women combined was 101.0 cm/sec in the oldest stratum (age >85) of the RN sample compared to 82.4 cm/sec in the CN sample.

Prescription medication count was associated with gait velocity in the CN sample (regression coefficient; $\beta=-1.31$, CI $[-1.93, -0.69]$, $p<0.001$) but not in the RN sample ($\beta=-0.77$, CI $[-1.58, 0.04]$, $p=0.063$). Medications were also associated with cadence (β per medication increase = -0.40 , CI $[-0.74, -0.06]$, $p=0.020$), stride length ($\beta = -1.08$, CI $[-1.59, -0.57]$, $p<0.001$), and swing time ($\beta = 0.0019$, CI $[0.0003, 0.0034]$, $p=0.020$) in the CN sample. On the other hand, medications were not significantly associated with any of the seven other gait parameters in the RN sample. When illness index was included in the model instead of medications, illness index was associated with velocity ($p<0.001$), cadence ($p=0.004$), stride length ($p<0.001$), stance time ($P=0.014$), and double support phase ($p=0.019$) in the CN sample. In the RN sample, illness index was only significantly associated with velocity and stride length ($p<0.001$).

Applying a one SD below the mean cutoff (70.1 cm/sec) from CN to define slow gait, 131 subjects (15.9%) in the CN sample were classified as abnormal. The cutoff derived from the robust norms (88.0 cm/sec) classified 327 subjects (39.7%) in the CN sample as abnormal. Of these 327 subjects with ‘slow’ gait using the RN cutoff, 206 (64.2%) had clinical gait abnormalities. Among the remaining 121 subjects, 36 (29.8%) developed clinical gait abnormalities in one year and 31 (25.8%) did not return for follow-up. Among the 89 subjects in the incident sample, 36 (40.5%) had slow gait using the RN velocity cutoff score but only 5 (5.6%) has slow gait using the CN cutoff score. Applying a widely used 1.0 m/sec cutoff,³ 59.5% of CN and 37.2% of RN sample were classified as abnormal.

DISCUSSION

Our study provides 'robust' and conventional normative values for widely used gait parameters. The conventional norms for gait were derived at cross-section from a large and well characterized cohort of nondisabled and nondemented elderly individuals. These 'comparative norms' will help compare the gait performance of older individuals to a group of community-residing individuals with similar age and gender characteristics. An alternate approach to developing conventional norms would have been to exclude subjects with prevalent clinical gait abnormalities from the study sample. However, this method would limit comparisons with previous normative studies that did not account for clinical gait abnormalities.

We developed longitudinal robust norms to address the issue of disease effects on estimates of gait performance, which is a major limitation in cross-sectional normative studies. We used clinical gait abnormalities as a marker for disease effects on gait. The gait parameters were descriptively better in the RN sample compared to the CN. Gait characteristics were worse in the two excluded, prevalent and incident gait subgroups, supporting our RN approach. These findings lend support to our hypothesis that presence of clinical gait abnormalities leads to under-estimation of gait performance with normal aging. Our findings also suggest that the longitudinal RN norms may better reflect effects of normal aging on gait performance than the cross-sectional CN norms, which is more influenced by disease.

The longitudinal approach used to develop RN norms accounts for the effects of attrition in cross-sectional samples. Attrition in mobility studies can result from functional or mobility decline as well as worsening pathology. Hence, inclusion of subjects who subsequently drop out can lower mean gait performance similar to the lowering of performance seen with including subjects with clinical gait abnormalities. For instance, the 87 subjects with missing follow-up visits excluded from our RN sample had worse baseline gait characteristics (data not shown).

By using the velocity cutscore derived from RN norms (≤ 88.0 cm/sec), we identified 39.7% of our entire sample with slow gait. On the other hand, only 15.9% of entire sample were classified as slow gait using CN norms. Also, among the incident sample the robust velocity cutscore classified more than 40% as abnormal in contrast to 5.6% classified abnormal by conventional cutoff.

The concept of 'norms' is important from both theoretical and practical perspectives. The CN approach provides a picture of gait performance in community residing seniors that is influenced both by aging as well as disease. The RN approach, on the other hand, attempts to minimize the effect of disease. Most previous gait studies have not used RN procedures to select high functioning seniors though there are exceptions. For instance, the Dynamics of Health, Aging and Body Composition (Health ABC) study cohort was selected to be free of disability in activities of daily living and free of functional limitation (defined as any difficulty walking a quarter of a mile or any difficulty walking up 10 steps without resting) at baseline.³ Hence, this cohort is more akin to our RN sample. The mean gait velocity reported in the Health ABC study (1.17 m/sec) was higher than our RN sample (1.06 m/sec).³ This difference reflects the differences in criteria used for selecting high functioning samples. Also, the Health ABC cohort was restricted to ages 70 to 79 years and included equal numbers of men and women. The Three-City (3C) study, another large cohort study of community dwelling elderly, reported mean gait velocity of 1.08 m/sec.²⁸ Although the 3C study did not specifically use clinical gait abnormalities as an exclusion,²⁸ subjects with diagnoses that can affect gait (stroke, Parkinson's disease, hip fracture, and dementia) were excluded. Both these studies used approaches that were conceptually similar to our RN

procedure. The RN values can help derive ‘diagnostic norms’ or ‘target’ values for diagnosing abnormal performance or defining risk for adverse outcomes such as mobility disability or falls. Unlike RN derived values, target gait values may change depending on the nature and availability of new interventions for mobility.

While gait velocity is recommended as a clinical screen^{3, 6, 10}, there is growing interest in defining the role of other gait parameters such as temporal and spatial gait variables, which have been reported to predict risk of falls¹ and mobility disability¹⁶. Some of our variables such as swing or stance time are less well established in the context of risk assessment. We have reported that gait variability but not velocity predicts injurious falls in our cohort¹ supporting a role for a more comprehensive gait assessment. However, normative data for measures other than speed are limited especially in the elderly and our data will be useful as a yardstick to guide future investigations.

Several limitations need to be noted. This nested cohort study was necessarily restricted to subjects who received gait and fall assessments since 2002, but subjects seen previously were not differentially excluded. This is a community based sample but was not recruited as a representative population sample. While the demographic characteristics of this cohort were similar to that of older adults in our county, the lower illness burden and improved cognitive scores suggest that our sample is healthier. Disability was defined using a validated scale²⁰ but may not have captured all functional limitations. The cohort was restricted to adults 70 years and older due to EAS inclusion criteria, and similar procedures to develop RN norms for gait should be conducted in younger age groups. For parsimony and to report performance on variables most often associated with adverse outcomes in elderly, we selected eight gait variables. However, our CN and RN approaches can be applied to other gait variables derived from our quantitative assessments. Given the ubiquitous presence of disease in older adults, exclusion of everyone with disease or using medications would not be feasible as a strategy to obtain a representative RN sample. Only 73 subjects (8.9%) of our overall sample meet this criteria. Moreover, mere presence of disease may not result in gait dysfunction. While clinical gait abnormality is the disease proxy that is most directly related to gait performance, we acknowledge that we cannot completely exclude disease effects on gait in our RN sample.

The strengths of this study include our validated clinical gait classification, systematic quantitative gait assessments, and moderate attrition. Study physicians evaluating clinical gait abnormalities were blinded to quantitative gait data at baseline and at follow-up visits minimizing bias and diagnostic circularity. The longitudinal approach minimizes the possibility of misdiagnosis or under-recognition of subtle gait abnormalities. Prescription medications were not associated with any of the gait parameters in the RN sample; furthering supporting the notion that the RN approach separates out pathology from normal aging effects on gait.

This study provides robust and conventional norms for quantitative gait parameters in well defined cohort of nondisabled and nondemented community dwelling older adults age 70 and older. The RN approach provides better estimates of normal gait performance in the elderly, and will help derive target values for different gait variables to be used for the early diagnosis of gait impairment and in identifying individuals at risk of adverse outcomes in future studies.

Acknowledgments

Conflict of Interest:

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Table 1
Baseline characteristics of study populations

Continuous variables are presented as mean±SD.

	CN sample [*]	RN sample ^{**}	Incident sample	Prevalent sample
	(n=824)	(n=304)	(n=89)	(n=321)
Age	80.1±5.4	78.9±5.1	80.1±5.0	81.5±5.5
Gender (% female)	503 (61.0)	188 (61.8)	53 (59.6)	188 (58.6)
Ethnicity White (%)	574 (69.7)	213 (70.1)	68 (76.4)	213 (66.4)
Black (%)	211 (25.6)	70 (23.0)	17 (19.1)	97 (30.2)
Other (%)	39 (4.7)	21 (6.9)	4 (4.5)	11 (3.4)
Illness index score, (range 0–10)	1.2±1.0	1.1±1.0	1.2±1.0	1.3 ±1.0
Prescription medications (n)	3.3±2.5	2.8±2.4	3.6±2.8	3.6±2.4
Geriatric depression scale (range 0–15)	2.2±2.3	1.7±1.7	2.4±2.1	2.8±2.5
Blessed dementia scale (range 0–32)	2.3±2.5	1.9±2.1	2.3±2.6	2.6±2.6

* conventional normal sample,

** robust normal sample

Table 2
Quantitative gait parameters of study population at baseline

Values are mean $\pm$ SD. Incident and prevalent samples were compared to RN sample (reference) using linear regression analysis adjusting for age and gender. CN and RN sample represent conventional normal and robust normal sample.

	CN sample (n=824)	RN sample (n=304)	Incident sample (n=89)	Prevalent sample (n=321)
Velocity (cm/sec)	93.3 $\pm$ 23.2	105.9 $\pm$ 17.9	95.0 $\pm$ 19.7 [‡]	79.2 $\pm$ 22.3 [‡]
Normalized velocity*	0.58 $\pm$ 0.14	0.65 $\pm$ 0.11	0.58 $\pm$ 0.11	0.49 $\pm$ 0.13 [‡]
Cadence (steps/min)	101.2 $\pm$ 12.2	105.2 $\pm$ 9.8	101.7 $\pm$ 10.0 [‡]	96.5 $\pm$ 13.8 [‡]
Stride length (cm)	109.9 $\pm$ 20.2	120.9 $\pm$ 15.7	112.1 $\pm$ 17.1 [‡]	97.5 $\pm$ 19.2 [‡]
SD of Stride length (cm)	4.46 $\pm$ 2.61	4.02 $\pm$ 2.36	4.67 $\pm$ 2.90	4.85 $\pm$ 2.60 [‡]
COV** of Stride length (%)	4.34 $\pm$ 3.06	3.43 $\pm$ 2.17	4.29 $\pm$ 2.87	5.34 $\pm$ 3.46 [‡]
Swing time (sec)	0.44 $\pm$ 0.05	0.43 $\pm$ 0.04	0.43 $\pm$ 0.06	0.45 $\pm$ 0.06 [‡]
SD of Swing time (sec)	0.03 $\pm$ 0.03	0.02 $\pm$ 0.02	0.03 $\pm$ 0.03	0.04 $\pm$ 0.03 [‡]
COV** of Swing time (%)	6.49 $\pm$ 4.79	5.28 $\pm$ 4.06	5.86 $\pm$ 4.59	8.08 $\pm$ 5.37 [‡]
Stance time (sec)	0.77 $\pm$ 0.14	0.72 $\pm$ 0.08	0.76 $\pm$ 0.08	0.83 $\pm$ 0.18 [‡]
Double support (%)	27.1 $\pm$ 5.7	25.0 $\pm$ 4.2	26.6 $\pm$ 4.4 [‡]	29.5 $\pm$ 6.8 [‡]

* velocity (cm/sec)/height (cm),

** coefficient of variation; (standard deviation/mean) $\times$ 100

[‡] p value=0.01.

^{‡‡} p value<0.001

Table 3
Robust and Conventional norms for baseline quantitative gait parameters by age groups and gender

Values are mean $\pm$ SD.

Gait parameters of Robust Sample	Men by age group (n=116)					Women by age group (n=188)				
	70-74 (n=26)	75-79 (n=45)	80-84 (n=28)	>85 (n=17)	p for trend	70-74 (n=52)	75-79 (n=65)	80-84 (n=49)	>85 (n=22)	p for trend
Velocity (cm/sec)	112.1 $\pm$ 20.1	111.8 $\pm$ 17.8	107.9 $\pm$ 16.6	101.6 $\pm$ 18.4	0.048	110.3 $\pm$ 15.5	102.0 $\pm$ 18.9	100.2 $\pm$ 16.2	100.6 $\pm$ 15.1	0.005
Normalized velocity*	0.64 $\pm$ 0.10	0.65 $\pm$ 0.09	0.64 $\pm$ 0.11	0.61 $\pm$ 0.11	0.323	0.68 $\pm$ 0.10	0.65 $\pm$ 0.13	0.65 $\pm$ 0.10	0.65 $\pm$ 0.09	0.164
Cadence	99.9 $\pm$ 8.0	102.0 $\pm$ 10.1	101.8 $\pm$ 7.4	102.5 $\pm$ 12.4	0.391	108.0 $\pm$ 9.2	106.5 $\pm$ 9.7	107.0 $\pm$ 9.7	110.1 $\pm$ 7.7	0.601
Stride length (cm)	134.7 $\pm$ 15.8	131.6 $\pm$ 14.3	127.2 $\pm$ 14.5	118.9 $\pm$ 13.5	<0.001	122.7 $\pm$ 11.8	114.7 $\pm$ 14.6	112.2 $\pm$ 11.6	109.6 $\pm$ 11.5	<0.001
SD of Stride length	4.10 $\pm$ 2.07	3.96 $\pm$ 2.99	3.99 $\pm$ 1.97	4.27 $\pm$ 0.45	0.857	3.42 $\pm$ 1.51	3.66 $\pm$ 2.14	4.64 $\pm$ 2.44	5.06 $\pm$ 3.10	<0.001
COV** of Stride length	3.03 $\pm$ 1.44	3.06 $\pm$ 2.26	3.20 $\pm$ 1.67	3.64 $\pm$ 2.43	0.333	2.81 $\pm$ 1.28	3.34 $\pm$ 2.31	4.24 $\pm$ 2.39	4.69 $\pm$ 2.91	<0.001
Swing time (sec)	0.45 $\pm$ 0.03	0.44 $\pm$ 0.05	0.44 $\pm$ 0.04	0.45 $\pm$ 0.06	0.997	0.42 $\pm$ 0.04	0.42 $\pm$ 0.037	0.42 $\pm$ 0.04	0.41 $\pm$ 0.05	0.887
SD of Swing time	0.02 $\pm$ 0.01	0.02 $\pm$ 0.02	0.02 $\pm$ 0.03	0.02 $\pm$ 0.06	0.134	0.02 $\pm$ 0.01	0.02 $\pm$ 0.01	0.03 $\pm$ 0.02	0.03 $\pm$ 0.02	0.024
COV** of Swing time	4.61 $\pm$ 1.81	4.59 $\pm$ 4.31	4.99 $\pm$ 5.17	5.28 $\pm$ 4.05	0.161	4.69 $\pm$ 2.65	5.24 $\pm$ 2.86	6.19 $\pm$ 3.80	6.00 $\pm$ 2.98	0.015
Stance time (sec)	0.76 $\pm$ 0.08	0.74 $\pm$ 0.08	0.74 $\pm$ 0.07	0.74 $\pm$ 0.13	0.386	0.70 $\pm$ 0.08	0.71 $\pm$ 0.08	0.70 $\pm$ 0.08	0.68 $\pm$ 0.06	0.427
Double support (%)	25.6 $\pm$ 4.4	24.8 $\pm$ 3.7	25.1 $\pm$ 3.6	23.4 $\pm$ 4.1	0.141	25.5 $\pm$ 4.2	25.1 $\pm$ 4.3	24.8 $\pm$ 4.7	24.8 $\pm$ 4.5	0.383

Gait parameters of Conventional sample	Men by age group (n=321)					Women by age group (n=503)				
	70-74 (n=57)	75-79 (n=113)	80-84 (n=89)	>85 (n=62)	p for trend	70-74 (n=102)	75-79 (n=165)	80-84 (n=139)	>85 (n=97)	p for trend
Velocity (cm/sec)	104.6 $\pm$ 23.9	101.5 $\pm$ 22.4	95.7 $\pm$ 21.6	88.8 $\pm$ 22.9	<0.001	99.4 $\pm$ 21.6	93.9 $\pm$ 22.5	87.9 $\pm$ 21.7	78.3 $\pm$ 20.8	<0.001
Normalized velocity*	0.62 $\pm$ 0.13	0.60 $\pm$ 0.11	0.57 $\pm$ 0.13	0.54 $\pm$ 0.14	<0.001	0.63 $\pm$ 0.14	0.60 $\pm$ 0.14	0.57 $\pm$ 0.14	0.52 $\pm$ 0.14	<0.001
Cadence	98.5 $\pm$ 9.2	99.5 $\pm$ 11.8	99.9 $\pm$ 10.1	99.9 $\pm$ 12.9	0.478	104.0 $\pm$ 11.4	102.9 $\pm$ 12.2	102.5 $\pm$ 13.7	99.3 $\pm$ 13.1	0.012
Stride length	126.7 $\pm$ 20.3	121.7 $\pm$ 18.5	114.1 $\pm$ 19.5	106.0 $\pm$ 20.0	<0.001	114.1 $\pm$ 17.2	108.6 $\pm$ 18.1	102.0 $\pm$ 16.7	93.8 $\pm$ 16.2	<0.001
SD of Stride length	4.39 $\pm$ 2.44	4.58 $\pm$ 2.97	4.25 $\pm$ 2.10	4.45 $\pm$ 2.26	0.791	4.01 $\pm$ 2.78	4.22 $\pm$ 2.41	4.60 $\pm$ 2.55	5.21 $\pm$ 2.96	0.001
COV** of Stride length	3.64 $\pm$ 2.53	3.98 $\pm$ 3.06	3.91 $\pm$ 2.28	4.47 $\pm$ 2.68	0.138	3.71 $\pm$ 3.30	4.15 $\pm$ 2.88	4.76 $\pm$ 3.05	5.85 $\pm$ 3.70	<0.001
Swing time	0.45 $\pm$ 0.04	0.45 $\pm$ 0.05	0.44 $\pm$ 0.05	0.44 $\pm$ 0.05	0.088	0.42 $\pm$ 0.05	0.43 $\pm$ 0.06	0.43 $\pm$ 0.06	0.44 $\pm$ 0.06	0.014
SD of Swing time	0.02 $\pm$ 0.02	0.02 $\pm$ 0.02	0.03 $\pm$ 0.02	0.03 $\pm$ 0.04	0.031	0.03 $\pm$ 0.02	0.03 $\pm$ 0.02	0.04 $\pm$ 0.04	0.04 $\pm$ 0.03	<0.001
COV** of Swing time	4.87 $\pm$ 2.94	5.32 $\pm$ 4.43	5.58 $\pm$ 3.91	7.15 $\pm$ 6.30	0.006	5.78 $\pm$ 3.44	6.13 $\pm$ 3.49	7.79 $\pm$ 6.00	8.74 $\pm$ 5.68	<0.001
Stance time	0.78 $\pm$ 0.10	0.78 $\pm$ 0.13	0.77 $\pm$ 0.10	0.79 $\pm$ 0.15	0.855	0.75 $\pm$ 0.11	0.76 $\pm$ 0.15	0.76 $\pm$ 0.17	0.79 $\pm$ 0.13	0.033

Gait parameters of Conventional sample	Men by age group (n=321)				Women by age group (n=503)			
	70-74 (n=57)	75-79 (n=113)	80-84 (n=89)	>85 (n=62)	70-74 (n=102)	75-79 (n=165)	80-84 (n=139)	>85 (n=97)
Double support (%)	26.2±4.6	26.3±4.5	26.7±4.2	26.9±5.6	27.5±5.0	27.1±6.0	27.3±5.9	28.8±8.0

* velocity (cm/sec)/height (cm)

** COV (coefficient of variation, %); (standard deviation/mean) ×100