Published in final edited form as:

Gait Posture. 2011 January ; 33(1): 98–101. doi:10.1016/j.gaitpost.2010.10.004.

Predisability And Gait Patterns In Older Adults

Joe Verghese, M.D. and Xiaonan Xue, Ph.D.

¹Department of Neurology, Albert Einstein College of Medicine, Yeshiva University, Bronx, NY, USA

²Department of Epidemiology and Population Health, Albert Einstein College of Medicine, Yeshiva University, Bronx, NY, USA

Abstract

Presence of performance inconsistency during repeated assessments of gait may reflect underlying subclinical disease, and help shed light on the earliest stages of disablement. We studied inter-session fluctuations on three selected gait measures (velocity, stride length, and stride length variability) during normal pace walking as well as during a cognitively demanding ‘walking while talking’ condition using a repeated measurement burst design (six sessions within a 2-week period) in 71 nondisabled and nondemented community residing older adults, 40 with predisability (does activities of daily living unassisted but with difficulty). Subjects with predisability had slower gait velocity and shorter stride length on both the normal and walking while talking conditions at baseline compared to nondisabled subjects. However, there was no significant pattern of fluctuations across the six sessions on the three selected gait variables comparing the two groups during normal walking as well as on the walking while talking conditions. Our findings support consistency of gait measurements during the earliest stages of disability.

Keywords

gait; elderly; measurement; variability; disability

INTRODUCTION

Intra-individual variability on cognitive and motor functions has been traditionally ascribed to measurement error. However, more recent studies have proposed that intra-individual variability reflects neurobiological disturbance,¹ and investigators have related variability in individual cognitive and motor measures to risk of developing various adverse health outcomes in older adults.^{2, 3} There is also growing interest in understanding the role of intra-individual variability in specific gait measures in the geriatric literature.⁴ Intra-individual gait variability has been described as a clinical marker for high risk elderly. For instance, subjects with mild cognitive impairment syndrome have been reported to have

© 2010 Elsevier B.V. All rights reserved.

Corresponding Author: Joe Verghese, M.D., Division of Cognitive & Motor Aging, Department of Neurology, Albert Einstein College of Medicine, 1165 Morris Park Avenue, Rousso 301, Bronx, New York 10461, USA. Tel: 718 430 3808, Fax: 718 430 3829, joe.verghese@einstein.yu.edu.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Conflict of interest statement

There are no conflicts of interest associated with this study.

greater variability in stride or swing time compared to healthy controls.⁵ In other studies, nondisabled and nondemented older adults who showed increased stride to stride or stance time variability at baseline assessments were reported to be at increased risk of falling,⁶ developing mobility disability,⁷ or dementia.⁸

Intra-individual gait variability represents performance inconsistency of individuals from one measurement occasion to the next, and is usually measured over seconds to minutes within a single session. In contrast, the nature and role of longer-term fluctuations in gait measured in multiple sessions across several days or weeks has received less attention.^{9–12} This relatively longer-term between-session fluctuation in gait measures is referred to as ‘consistency’ in this report to avoid confusion with within-session ‘variability’ in gait measures. This consistency in gait over days to weeks is different from the decline in gait performance typically reported over yearly intervals or more in cohort studies.¹³ In the cognitive literature, increased fluctuations on cognitive test scores measured over multiple sessions on the same day (lower consistency) distinguishes subjects with mild cognitive impairment syndrome from healthy elderly.¹⁴ On the other hand, Ferrucci and colleagues reported that weekly assessments of gait velocity over six months in 99 disabled older women in the Weekly Disability Substudy of the Women’s Health and Aging Study were relatively consistent (high consistency), even when examined across different age groups and disability levels as well as accounting for changes in the severity of medical illnesses or the occurrence of new medical events during the study period.¹¹ In contrast, self-reports of disability by women in this same cohort was consistent over one week but not over longer time intervals.¹⁰ These findings suggest that, unlike cognitive performance, objective gait velocity measurements are consistent between-sessions even when measured over weeks or months in both disabled and healthy elderly controls.

Whether this consistency of gait performance applies to variables other than velocity or extends to older adults in the earliest stages of disablement has not been established. Furthermore, underlying mechanisms for consistency in gait over longer periods still remains to be determined. Hence, we proposed to build on previous findings by examining within-session ‘variability’ as well as between-day ‘consistency’ on gait measures using a repeated measurement burst design over a two-week period in 71 nondisabled and nondemented community residing older adults, 40 with predisability. We defined predisability as self-reported difficulty in performing activities of daily living. Predisability represents the earliest stages of the disablement process,¹⁵ and has been shown to predict risk of developing disability.¹⁶ We compared gait variability and consistency in individuals meeting this criterion with nondisabled subjects. Performance inconsistency between sessions in gait if demonstrated may reflect underlying subclinical disease, and help shed light on the nature of functional reserve during the earliest stages of disablement.¹⁷

METHODS

Study population

Subjects were participants in a longitudinal aging study who agreed to take part in this substudy. The primary aim of the parent study was to identify risk factors for dementia, and study design has been previously reported.^{8, 18} In brief, potential subjects (age 70 and over) identified from Bronx County population lists were contacted by letter explaining the purpose and nature of the study, and then by telephone. Subjects who gave verbal consent on the telephone were invited for further evaluation at our research center. Exclusion criteria included severe audiovisual loss, bed bound due to illness, and institutionalization. Additional exclusion criteria for this substudy included presence of dementia (diagnosed by study clinicians at consensus case conferences⁸) or disability. The following seven activities of daily living were assessed based on a disability scale developed for use in community-

based cohorts¹⁹: bathing, dressing, grooming, feeding, toileting, walking around home, and getting up from a chair. Subjects who self-reported difficulty in doing any one of the seven activities were termed predisabled. Subjects who required another person's assistance or were unable to do one or more of the seven activities were defined as disabled. None of the 71 eligible subjects met the disability criteria; 40 subjects had predisability. Written informed consents were obtained according to protocols approved by the local institutional review board.

Gait

Quantitative gait assessments were conducted using a computerized walkway ($180 \times 35.5 \times 0.25$ inches, $4.572 \times 0.902 \times 0.006$ meters) with embedded pressure sensors (GAITRite, CIR systems). Subjects were asked to walk on the mat at their usual pace for two trials in a quiet well-lit hallway wearing comfortable footwear and without any attached monitors. Start and stop points were marked by white lines on the floor, and included three feet from the walkway edge for initial acceleration and terminal deceleration.

Cognitive processes, especially attention and executive functions, have important associations with gait in older adults.^{20, 21} Hence, we also used a cognitively demanding 'walking while talking'²² (WWT) task as a stressor to accentuate fluctuations in gait performance, especially in predisabled subjects. Gait velocity during the WWT condition was a stronger predictor of falls than velocity when walking while reciting all alphabets or during normal pace walking without talking in our previous study.²⁰ For the WWT task,^{20, 22} subjects were asked to walk on the computerized mat reciting alternate letters of the alphabet for two trials. Subjects were asked to pay attention to reciting letters and not to concentrate on their walking.²² The order of the initial letter on the interference task was randomly varied between 'A' (A-C-E) and 'B' (B-D-F) between the two trials of WWT. To reduce learning effects, subjects were given practice trials as required on both the single and dual task conditions, but were not taught strategies.²²

Based on footfalls recorded on the walkway, the software automatically computes gait parameters. While a number of gait parameters are obtained following these assessments, to limit multiple comparisons we a priori selected three gait parameters to define gait performance for this study: velocity (m/s), stride length (m), and stride length variability (SD). These three gait variables have consistently shown strong associations with adverse health outcomes such as falls,⁶ dementia,⁸ nursing home placement,¹⁸ and mortality¹⁸ in the same cohort. The GAITRite system is widely used in clinical and research settings, and excellent validity and test-retest reliability for gait velocity is reported in our and other studies.^{6, 22, 23} The intraclass correlation coefficient (ICC) between two sessions completed on the same day in the current study sample for the normal pace condition (velocity 0.96, stride length 0.95) and WWT (velocity 0.96, stride length 0.90) was high, suggesting good reliability.²⁴ Other gait variables are highly correlated with these measures supporting reliability of the assessments.

Study design

Subjects had gait assessments done at six separate sessions (two sessions per day) over a 2-week period. The sessions were all done during the morning hours at approximately the same times. The interval between gait tests done on the same day varied from 2 to 3 hours. In between the two sessions on the same day subjects had rest breaks with refreshments, completed health questionnaires, and took part in other experimental neuropsychological tests. The interval between testing days varied from 1 to 4 days.

Baseline clinical assessments

Clinical assistants used structured questionnaires to elicit history of medical illnesses, and depressive symptoms at study visits.⁸ Presence of depression, diabetes, heart failure, hypertension, angina, myocardial infarction, strokes, Parkinson's disease, chronic obstructive lung disease, and arthritis was used to calculate a summary illness index as previously described.^{8, 25} We consulted medical records and contacted subjects' family members or physicians to verify or obtain further details. General cognitive status was assessed by the Blessed-Information-Memory concentration test.²⁶

Data analysis

Demographic variables and gait characteristics were compared between predisabled and normal subjects using either chi-square test (categorical variables) or a two-sample t-test (continuous variables).²⁷ Then consistency (fluctuations) across the six sessions on the selected three gait variables on the two walking conditions (normal pace and WWT) was measured using standard deviation as well as coefficient of variation (ratio of the standard deviation to the mean).⁸ Group comparisons of inter-session gait consistency between predisabled and normal subjects were first examined by non-parametric Wilcoxon rank sum test, two-sample t-test, and then with multiple linear regression to adjust for potential confounders including age and sex.²⁷ We further examined if the inter-session consistency on the selected gait variables during WWT was lower (increased fluctuation) for the predisabled group than the normal group by including an interaction term between group presence (predisabled or normal) and walking condition (normal or WWT) in a linear mixed effects model.^{28, 29} The linear mixed effects method is similar to multiple linear regression, but allows correlation between observations (gait performance in normal and WWT conditions are correlated because they are from the same subjects) and accommodates unbalanced data resulting from missing data.^{28, 29}

RESULTS

All subjects who took part in this substudy completed all six sessions giving a 100% participation rate. Comparisons of the baseline characteristics between the 40 subjects with predisability and 31 healthy controls are presented in Table 1. There were no significant demographic differences between the two groups. As expected, subjects with predisability had slower gait velocity and shorter stride length on both the normal and WWT conditions at the first baseline assessment compared to the remaining nondisabled subjects (see Table 1). There were no significant group differences on stride length variability on both walking conditions, even after accounting for one outlier in the nondisabled normal group on WWT (Table 1).

Consistency on the three selected gait variables across the six sessions, summarized by standard deviation and coefficient of variation, was compared between the normal and predisabled groups. The findings were essentially the same using these two summary measures. Hence, only results using standard deviation are presented in Table 2. Furthermore, since non-parametric test, two-sample t-test and linear regression models controlling for age and gender gave consistent results, Table 2 only shows the results for the linear regression analysis, which is adjusted for age and sex. Both the walking conditions, normal pace walking and WWT, failed to show any significant fluctuations on the selected gait variables across the six sessions between the two groups (high consistency).

Within a person, as expected, the inter-session fluctuations on the gait variables during the WWT were higher than that during normal pace walking. However, the degree of fluctuations in the three selected gait parameters during WWT was not significantly higher

for the pre-disabled group compared to the normal group when tested using a linear mixed effects model.^{28, 29}

DISCUSSION

Our findings show that elderly individuals with predisability have slower velocity and stride length at baseline during normal pace walking compared to the nondisabled controls. The difference on velocity and stride length between the two groups was more pronounced during the WWT condition. However, fluctuations in the three selected gait variables measured during normal pace walking across six sessions over a two week period was consistent when comparing older adults with and without predisability. The inter-session consistency on the selected gait variables in both groups remained even when stressed by the WWT condition. Our findings, hence, corroborate the consistency of gait measurements previously reported in disabled women,¹¹ and extend the findings to nondisabled and predisabled elderly populations. The consistency of gait measurements over multiple sessions in our and other studies also suggests that irrespective of the degree of disability gait measurements are reliable indicators of treatment effects following mobility rehabilitation that typically takes place over days to weeks.

Our findings of consistency in gait patterns when measured over days to weeks in older adults including those that were predisabled is supported by previous studies conducted in different populations and using other analytical approaches. Ferrucci and colleagues used a mixed effects model and autocorrelation function to measure the consistency of gait velocity measured weekly over six months in 99 disabled women.¹¹ These investigators found that the correlation in measurements of gait speed remained above 0.6 in all age and disability subgroups.¹¹ Another study found that intra-individual fluctuation in gait velocity was consistent when measured every two weeks over a 7-month period in 24 nondisabled older adults.¹²

It has been proposed that the consistency of gait velocity measurements at self selected usual pace might reflect an 'internal memory' for the walking activity or relative automaticity of walking processes in humans,¹¹ which is preserved even in those with disability. However, automaticity of walking processes would be less applicable to the more cognitively demanding WWT condition. We have reported that attention executive function processes are strongly associated with walking while talking.²¹ Subjects slow down more while walking when reciting alternate letters of the alphabet than when walking without talking or reciting all letters of the alphabet.²⁰ These results suggest increasing involvement of cognitive control processes in the WWT condition, and support its role as a cognitive stressor of gait.²¹ Execution of customary motor tasks is said to require a substantially greater effort in older adults compared with young adults, and even normal older adults perform activities of daily living such as walking close to their maximal capabilities.³⁰ Hence, another possible explanation for our findings is that the WWT taxes cognitive and functional reserves in both normal and predisabled seniors to such an extent that further fluctuations in gait performance over the short-term are minimized. It is less likely that progression of disability may be independent of gait performance as speed and other gait measures have been shown to be predictive of disability over long term follow-up.^{7, 31} However, a definitive explanation for gait consistency over long periods is still lacking.

Limitations

The repeated measurement burst paradigm requires significant commitment of time and resources.¹⁷ This burst design has been used to document intra-individual variability in other measures such as sensorimotor function and cognition in prior studies.^{3, 9, 10, 12} This design was utilized in our study to provide insights into physiological changes in early stages of

disability. It was not our intention to validate this procedure as a diagnostic tool for disability to be implemented in clinics. We restricted the gait variables analyzed to limit comparisons. Furthermore, it was not our intent to compare the validity of different gait variables as markers for predisability but to provide a broad representation of gait performance. The slowing in gait speed between the normal pace and WWT conditions suggests that the WWT condition is a sufficient stressor. However, it is possible that other more stressful cognitive-motor conditions might have revealed subtle group differences on inter-session variability in gait performance. Training or practice effects are a consideration in any study involving multiple assessments. We attempted to minimize training effects by allowing practice trials.²² Moreover, all subjects had performed both the gait tests using the same equipment on one or more previous occasions as part of the parent study procedures prior to their enrollment in this substudy.^{6, 8} The good test-retest reliability of the selected gait variables in the current study and also for gait velocity examined over short durations in other studies using the same instrumented walkway^{22, 23} makes it less likely that measurement error accounts for the observed results.

Our findings extend the observations of gait consistency made in disabled subjects, and support the consistency of gait parameters measured over short intervals in community residing older adults.

Acknowledgments

Disclosures: Supported by grants from the National Institute on Aging (grant AG03949 and RO1 AG025119). The study sponsors had no role in the study design, in the collection, analysis and interpretation of data; in the writing of the manuscript; and in the decision to submit the manuscript for publication.

REFERENCES

1. Li, S.; Lindenberger, U. Cross-level unification: A computational exploration of the link between deterioration of neurotransmitter systems and dedifferentiation of cognitive abilities in old age. In: Nilsson, L-G.; Markowitsch, H., editors. Cognitive neuroscience and memory. Toronto, Canada: Hogrefe & Huber; 1999.
2. Burton CL, Strauss E, Hultsch DF, Moll A, Hunter MA. Intraindividual variability as a marker of neurological dysfunction: a comparison of Alzheimer's disease and Parkinson's disease. *J Clin Exp Neuropsychol* 2006;28:67–83. [PubMed: 16448976]
3. Dixon RA, Garrett DD, Lentz TL, MacDonald SW, Strauss E, Hultsch DF. Neurocognitive markers of cognitive impairment: exploring the roles of speed and inconsistency. *Neuropsychology* 2007;21:381–399. [PubMed: 17484601]
4. Hausdorff J. Gait variability: methods, modeling and meaning. *J Neuroengineering Rehabil* 2005;2:19.
5. Verghese J, Robbins M, Holtzer R, et al. Gait Dysfunction in Mild Cognitive Impairment Syndromes. *J Am Geriatr Soc* 2008;56:1244–1251. [PubMed: 18482293]
6. Verghese JHR, Lipton RB, Wang C. Quantitative Gait Markers and Incident Fall Risk in Older Adults. *J Gerontol A Biol Sci Med Sci* 2009;64:896–901. [PubMed: 19349593]
7. Brach JS, Studenski SA, Perera S, VanSwearingen JM, Newman AB. Gait variability and the risk of incident mobility disability in community-dwelling older adults. *J Gerontol A Biol Sci Med Sci* 2007;62:983–988. [PubMed: 17895436]
8. Verghese J, Wang C, Lipton RB, Holtzer R, Xue X. Quantitative gait dysfunction and risk of cognitive decline and dementia. *J Neurol Neurosurg Psychiatry* 2007;78:929–935. [PubMed: 17237140]
9. Mendes de Leon CF, Guralnik JM, Bandeen-Roche K. Short-term change in physical function and disability: the Women's Health and Aging Study. *J Gerontol B Psychol Sci Soc Sci* 2002;57:S355–S365. [PubMed: 12426444]

10. Rathouz PJ, Kasper JD, Zeger SL, et al. Short-term consistency in self-reported physical functioning among elderly women: the Women's Health and Aging Study. *Am J Epidemiol* 1998;147:764–773. [PubMed: 9554418]
11. Ferrucci L, Guralnik JM, Salive ME, et al. Effect of age and severity of disability on short-term variation in walking speed: the Women's Health and Aging Study. *J Clin Epidemiol* 1996;49:1089–1096. [PubMed: 8826987]
12. Li S, Aggen SH, Nesselroade JR, Baltes PB. Short-term fluctuations in elderly people's sensorimotor functioning predict text and spatial memory performance: The Macarthur Successful Aging Studies. *Gerontology* 2001;47:100–116. [PubMed: 11287736]
13. Rolita L, Holtzer R, Wang C, Lipton RB, Derby CA, Verghese J. Homocysteine and mobility in older adults. *J Am Geriatr Soc* 58:545–550. [PubMed: 20158558]
14. Darby D, Maruff P, Collie A, McStephen M. Mild cognitive impairment can be detected by multiple assessments in a single day. *Neurology* 2002;59:1042–1046. [PubMed: 12370459]
15. Verbrugge LM, Jette AM. The disablement process. *Soc Sci Med* 1994;38:1–14. [PubMed: 8146699]
16. Fried LP, Young Y, Rubin G, Bandeen-Roche K. Self-reported preclinical disability identifies older women with early declines in performance and early disease. *J Clin Epidemiol* 2001;54:889–901. [PubMed: 11520648]
17. Nesselroade JR, Jones CJ. Multi-modal selection effects in the study of adult development: a perspective on multivariate, replicated, single-subject, repeated measures designs. *Exp Aging Res* 1991;17:21–27. [PubMed: 1936098]
18. Verghese J, LeValley A, Hall CB, Katz MJ, Ambrose AF, Lipton RB. Epidemiology of gait disorders in community-residing older adults. *J Amer Geriatr Soc* 2006;54:255–261. [PubMed: 16460376]
19. Gill TM, Allore HG, Holford TR, Guo Z. Hospitalization, restricted activity, and the development of disability among older persons. *Jama* 2004;292:2115–2124. [PubMed: 15523072]
20. Verghese J, Buschke H, Viola L, et al. Validity of divided attention tasks in predicting falls in older individuals: a preliminary study.[see comment]. *J Amer Geriatr Soc* 2002;50:1572–1576. [PubMed: 12383157]
21. Holtzer R, Verghese J, Xue X, Lipton RB. Cognitive processes related to gait velocity: results from the Einstein Aging Study. *Neuropsychology* 2006;20:215–223. [PubMed: 16594782]
22. Verghese J, Kuslansky G, Holtzer R, et al. Walking while talking: effect of task prioritization in the elderly. *Arch Phys Med Rehabil* 2007;88:50–53. [PubMed: 17207675]
23. Menz HB, Latt MD, Tiedemann A, Mun San Kwan M, Lord SR. Reliability of the GAITRite walkway system for the quantification of temporo-spatial parameters of gait in young and older people. *Gait Posture* 2004;20:20–25. [PubMed: 15196515]
24. Cohen, J. Statistical power analysis for the behavioral sciences. 2nd ed. New Jersey: Lawrence Erlbaum; 1988.
25. Holtzer R, Friedman R, Lipton RB, Katz M, Xue X, Verghese J. The relationship between specific cognitive functions and falls in aging. *Neuropsychology* 2007;21:540–548. [PubMed: 17784802]
26. Blessed G, Tomlinson BE, Roth M. The association between quantitative measures of dementia and of senile change in the cerebral grey matter of elderly subjects. *British Journal of Psychiatry* 1968;114:797–811. [PubMed: 5662937]
27. Altman, DG. Practical Statistics for Medical Research. 2 ed. Chapman & Hall/CRC; 2006.
28. Cnaan A, Laird NM, Slasor P. Using the general linear mixed model to analyse unbalanced repeated measures and longitudinal data. *Stat Med* 1997;16:2349–2380. [PubMed: 9351170]
29. Laird NM, Ware JH. Random-effects models for longitudinal data. *Biometrics* 1982;38:963–974. [PubMed: 7168798]
30. Hortobagyi T, Mizelle C, Beam S, DeVita P. Old adults perform activities of daily living near their maximal capabilities. *J Gerontol A Biol Sci Med Sci* 2003;58:M453–M460. [PubMed: 12730256]
31. Abellan van Kan G, Rolland Y, Andrieu S, et al. Gait Speed at Usual Pace as a Predictor of Adverse Outcomes in Community-Dwelling Older People An International Academy on Nutrition and Aging (IANA) Task Force. *J Nutr Health Aging* 2009;13:881–889. [PubMed: 19924348]

Table 1

Baseline demographic and gait characteristics of subjects with and without predisability

Variable	Normal (n = 31)	Pre-disability (n = 40)	p-value *
Age, y	80.3 ± 5.8	79.7 ± 5.8	0.29
Female, %	46.7	53.3	0.22
Education, y	14.3 ± 3.1	13.4 ± 2.8	0.21
Illness index score (0–10)	1.4 ± 1.2	1.3 ± 1.2	0.91
Blessed test score (0–32)	2.1 ± 2.1	2.5 ± 2.1	0.45
Normal pace walking			
Velocity, m/s	1.04 ± 0.12	0.83 ± 0.21	<0.001
Stride length, m	1.18 ± 0.11	1.03 ± 0.18	<0.001
Stride length variability, SD	4.5 ± 2.0	3.8 ± 2.1	0.17
WWT			
Velocity, m/s	0.74 ± 0.22	0.61 ± 0.26	0.03
Stride length, m	1.11 ± 0.17	0.94 ± 0.19	<0.001
Stride length variability, SD	8.1 ± 14.0	6.0 ± 3.3	0.45

* P values are for comparisons of categorical variables by chi-square test and continuous variables by t-test.²⁷

Table 2

Comparison of inter-session variability in gait parameters between subjects with and without predisability. Variability in three parameters is expressed as standard deviation across six sessions, and values reported as means $\pm$ SD.

Variable	Normal (n = 31)	Pre-disability (n = 40)	p-value *
Normal pace walking (inter-session variability)			
Velocity	4.6 $\pm$ 2.1	5.2 $\pm$ 2.8	0.49
Stride length	3.5 $\pm$ 3.5	4.2 $\pm$ 2.7	0.59
Stride length variability	2.9 $\pm$ 8.5	2.5 $\pm$ 4.5	0.47
WWT (inter-session variability)			
Velocity	7.4 $\pm$ 3.9	6.7 $\pm$ 3.7	0.35
Stride length	4.7 $\pm$ 3.8	6.3 $\pm$ 5.4	0.28
Stride length variability	3.3 $\pm$ 7.4	5.9 $\pm$ 12.5	0.46

* p-values derived from linear regression adjusted for age and sex.²⁷