Ageing and gait variability—a population-based study of older people

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Abstract

Background: gait variability may be an important predictor of falls risk, but its characteristics are poorly understood.
Objective: to examine the relationship between age and gait variability in a population-based sample of older people.
Design: cross-sectional study.
Methods: in people aged 60–86 years (n = 412), temporal and spatial gait variability measures were recorded with a GAITRite walkway. Regression analysis was used to model the relationship between age and gait variability adjusting for height, weight and self-reported chronic disease. Further adjustment was made for gait speed to examine its influence on the associations.
Results: older age was associated with greater variability (P<0.05) in all gait measures. All relationships were linear, except that between age and step time variability, which was curvilinear in women. Adjusting for gait speed changed the magnitude of the age coefficient by 62–86% for temporal variability measures, 25% for step length variability and 5–12% for step width variability.
Conclusion: age is linearly associated with greater intra-individual gait variability for most gait measures, except for step time variability in women. Gait speed may mediate the association between age and temporal variability measures. Further study is needed to understand the factors responsible for the greater gait variability with ageing.

Keywords: ageing, gait variability, population-based, elderly

Introduction

The ability to walk efficiently and safely is important for older people to maintain independence and avoid falls [1]. Intra-individual gait variability refers to the fluctuation in the value of a gait measure from one step to the next. It is considered likely to reflect disruptions in intrinsic motor or postural control during walking resulting from age- or disease-related decline in the central and peripheral nervous systems [2, 3]. Gait variability measures have been described to be better predictors of falls and decline in mobility than absolute gait measures such as gait speed [4–8]. Given the high risk of falls and mobility problems in older people [9, 10], it is important to clearly characterise the relationship between ageing and gait variability. Such data may enhance the understanding of motor control in older age and assist in defining older people at particular risk of falling.

Although there have been previous studies examining the effect of age on gait variability [7, 11–20], significant gaps still exist in the literature. Firstly, the majority of previous studies have only compared younger with older adults [11–15, 17, 18, 20]. Their results have been inconsistent with some reporting greater gait variability [12, 14, 15, 17, 20] and others no differences in the younger versus older groups [11, 14, 15, 18, 20] probably reflecting the low subject numbers and different populations sampled. These studies do not provide data on whether age-related changes in gait variability continue in older age. A few small studies of older adults have reported increased variability with advancing age [7, 16, 19] but none have examined both spatial and temporal variables. Furthermore, no data are available on the relationship between age and gait variability at a population level, with prior studies being performed in either convenient samples of healthy volunteers or clinical samples [7, 16, 19]. Age may affect gait speed and other absolute gait measures in men and women [21], but it is unknown whether such an interaction between age and sex also occurs with regards to gait variability.

Walking speed slows in older age [12] and there is greater variability in some gait measures at slower speeds [20, 22]. Therefore, increased variability found with advancing age may simply be due to slower walking speeds [20] rather than an independent intrinsic phenomenon. Understanding the effect of speed in the relationship between age and gait variability may further clarify mechanisms underlying gait variability.

We conducted a population-based study to investigate the relationship between age and gait variability in older people. The aims were to: (i) study the magnitude and shape of associations between age and a range of gait variability measures; (ii) investigate whether sex modified these associations; and (iii) examine the effect of gait speed on these associations.

Methods

Study participants

Participants aged 60–86 years (n=412) were randomly selected from the Southern Tasmanian electoral roll (postcodes 7000–7199) to participate in the Tasmanian Study of Cognition and Gait, conducted at the Menzies Research Institute, Hobart, Tasmania, Australia. Southern Tasmania has a total population of 239,444 people including 46,159 persons aged at least 60 years [23]. Eligible participants were firstly sent an invitation to participate, followed by a phone call. Transport was provided if required. Data collection started in January 2005 and finished in November 2007. Participants were excluded if they lived in a nursing home, were unable to follow simple commands in English, were unable to walk without a gait aid or had any contraindications to magnetic resonance imaging as this was part of a larger study. The Southern Tasmanian Health and Medical Human Research Ethics Committee approved this study and written consent was obtained from all participants.

Gait analysis

Gait variables (step time, step length, step width and double support time (DST)) were measured at preferred speed using the 4.6-m GAITRite system (CIR Systems, Haver- town, PA, USA). Variables are defined in the GAITRite manual [24]. Participants started and finished walking 2 m before and after the mat to allow for acceleration and deceleration. After two practice trials, participants performed six walks [25]. These variables were chosen as they represent both temporal and spatial measures and have been examined in previous studies of falls risk [4–6]. The variability of each measure was calculated as the standard deviation [3, 6, 7, 17] across all step measures from the six walks.

Other measurements

Height (cm), weight (kg) and self-reported history of lower limb arthritis, hypertension, stroke, Parkinson’s disease,
diabetes mellitus, dementia and falls (in the preceding 12 months) were recorded using a standardised questionnaire. To allow estimation of potential non-response bias, non-responders completed a brief phone interview providing similar details about their medical history.

Date analysis

Differences in demographic, medical and gait characteristics between men and women were analysed using chi-square test, Student’s *t* tests and the two-sample Wilcoxon rank-sum test. Spearman correlation coefficients were used to measure the associations between gait variables, age, height, weight and speed. Linear regression methods were used to assess the relationship between gait measures and age. In multivariable linear regression, the association of gait variables with age independently of height, weight and each chronic disease was assessed. Stroke, dementia and Parkinson’s disease were grouped as one variable called central nervous system (CNS) disease due to low subject numbers in each group. Speed was added to determine its effect on the final regression models. At walking speeds other than preferred, temporal and spatial variability are higher, and there is less stability at the head and pelvis [26, 27]. We, therefore, chose a modelling approach including preferred speed as a covariate rather than introducing additional speed walking trials.

In the correlation and regression analysis, gait variables were transformed when required to remove skewness. One slow-paced woman was excluded from analysis after examination for outliers because her data were highly influential in increasing the value of the regression coefficients. This woman was severely physically and cognitively disabled. Statistical interaction between age and sex was assessed by a test of significance of a (age × sex) product term for men, and by a partial-*F* test for the inclusion of two product terms (age × sex, age² × sex) in the model for step time in women.

Finally, log-binomial regression analysis was used to determine whether gait variability measures increased the risk of self-reported falls after adjustment for age, sex, height and weight. For this analysis, step time and DST variability were converted to milliseconds. Analyses were performed using Stata 10.0 (StataCorp LP, TX, USA).

Results

The sample response proportion was 51% (412/804). Non-responders were older (*P* = 0.01) with a higher incidence of hypertension (*P* = 0.03). Demographic, medical and gait characteristics are summarised in Table 1. An average of 27.3 (SD 5.4) steps were recorded per person. There were no differences between left and right variability measures (*P* > 0.05), and results are based on the average of the left and right sides. Men walked faster (*P* = 0.01) and had greater variability in step length (*P* = 0.03), DST (*P* = 0.04) and step width (*P* = 0.003) than women. Associations between age, speed and the gait variability measures are shown in Table 1. Older age was associated with greater variability in all gait measures in both men and women (*P* < 0.05) and this was demonstrable for increasing age category as well (Appendix 1 in the supplementary data in Age and Ageing online). Faster speed was associated with less variability in all measures (*P* < 0.05) except for step width. All relationships were linear, except for a curvilinear association (*P* < 0.001) between age and step time variability for women (Appendix 2 in the supplementary data in Age and Ageing online).

Results of the multivariable linear regression of age with gait variability measures adjusting for height and weight are shown in Table 3. Age remained positively associated with all measures of gait variability in both men and women. In women, the association between age and step time variability was stronger in the older age groups. There was little change to the associations even after controlling for the presence of each chronic disease. Furthermore, chronic diseases were not associated with any of the gait variability measures except for self-reported history of arthritis, which was associated with greater step time variability in both sexes (*P* < 0.01). Adjusting for speed markedly reduced (range 62–86%) the magnitude of the age coefficient for temporal variability measures, but there was little change in the coefficient of the speed variable in the model with age when compared to its value in the model without age (range 4–10%). In contrast, adjusting for speed reduced the magnitude of the age coefficient by 25% in both sexes for step length variability. For step width

<table>
<thead>
<tr>
<th>Table 1. Sample characteristics (n=411)</th>
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<tbody>
<tr>
<td>Characteristic</td>
</tr>
<tr>
<td>Age, mean (SD)</td>
</tr>
<tr>
<td>Height [cm], mean (SD)</td>
</tr>
<tr>
<td>Weight [kg], mean (SD)</td>
</tr>
<tr>
<td>Self-reported medical history, n (%)</td>
</tr>
<tr>
<td>Hypertension</td>
</tr>
<tr>
<td>Diabetes</td>
</tr>
<tr>
<td>Stroke</td>
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<tr>
<td>Parkinson’s disease</td>
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<tr>
<td>Dementia</td>
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<tr>
<td>Arthritis</td>
</tr>
<tr>
<td>Falls in previous 12 months</td>
</tr>
</tbody>
</table>

SD, standard deviation; cm, centimetres; kg, kilogrammes; s, seconds.

*P* < 0.001.

*P* < 0.01.

*P* < 0.05.
Table 2. Correlations between subject characteristics and gait variables (n=411)

<table>
<thead>
<tr>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>Height</td>
<td>Weight</td>
</tr>
<tr>
<td>Women</td>
<td> </td>
<td> </td>
</tr>
<tr>
<td>Men</td>
<td> </td>
<td> </td>
</tr>
<tr>
<td>Age</td>
<td>−0.24</td>
<td>−0.37</td>
</tr>
<tr>
<td>Height</td>
<td>−0.31</td>
<td>−0.37</td>
</tr>
<tr>
<td>Weight</td>
<td>0.33</td>
<td>0.39</td>
</tr>
<tr>
<td>Speed</td>
<td>0.30</td>
<td>0.34</td>
</tr>
<tr>
<td>Step time variability</td>
<td>0.28</td>
<td>0.10</td>
</tr>
<tr>
<td>Step length variability</td>
<td>0.27</td>
<td>0.03</td>
</tr>
<tr>
<td>Step width variability</td>
<td>0.18</td>
<td>−0.01</td>
</tr>
<tr>
<td>Double support time variability</td>
<td>0.30</td>
<td>−0.13</td>
</tr>
</tbody>
</table>

**P < 0.001;***P < 0.01;*P < 0.05.

Table 3. Multivariable regression—cross-sectional effect of an additional year of age on gait variability measures (n=411)

<table>
<thead>
<tr>
<th>Gait measure</th>
<th>Regression coefficients (β) adjusted for:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1 (95% CI)</td>
<td>Model 2 (95% CI)</td>
</tr>
<tr>
<td>Step time variability*</td>
<td>0.254 (0.133, 0.375)*</td>
</tr>
<tr>
<td>Step length variability</td>
<td>0.022 (0.008, 0.036)**</td>
</tr>
<tr>
<td>Step width variability</td>
<td>0.016 (0.004, 0.027)**</td>
</tr>
<tr>
<td>Double support time variability*</td>
<td>0.257 (0.144, 0.371)*</td>
</tr>
</tbody>
</table>

Model 1, unadjusted; Model 2, adjusted for height and weight; Model 3, adjusted for height, weight and speed.

*P < 0.001; **P < 0.01; ***P < 0.05.

†Coefficient multiplied by 1,000.

‡Because of the non-linear association between step time variability and age for women, the cross-sectional effect of an additional year of age was different at each age. Here, we show estimates for 65-, 75- and 85-year-olds.

Discussion

This is the first population-based study to characterise in detail the relationships between age and a range of temporal and spatial gait variability measures in older people. We found greater age was associated with greater intra-individual variability in all gait measures, independent of height, weight and self-reported chronic disease. All relationships were linear, except for step time variability in women, which showed stronger associations in older age groups. Previous studies have suggested measures of gait variability are useful indicators of falls [4–7]. Screening of gait in people >60 years may, therefore, be valuable in identifying those at risk.

Adjustment for gait speed produced marked reductions in the estimated effect of age on temporal variability measures, suggesting that speed is an intermediate in the pathway between age and these measures. In contrast, speed is more likely to confound the relation between age and spatial variability measures. This finding has implications for how gait variability measures are analysed in future studies of ageing.
Our findings highlight that variability in step length and step time is greater in older adults in the general population and not just in those with disease [28]. This may represent decline in the automatic stepping mechanism or worsening central motor control [2, 11] and may contribute to an increased risk of falls due to poor foot placement or insufficient postural stability [6]. The greater step time variability with advancing age is consistent with results of other clinical studies of geriatric patients and functionally impaired older adults [7, 19]. However, we found that, although there were no significant differences between the sexes, stronger associations between step time variability and age were found in women of older ages. This may indicate that older women may increasingly require closer monitoring of their gait in relation to falls risk and also raises interesting questions about sex-related differences in mechanisms underlying step time variability. To our knowledge, there are no previous studies examining the associations between age and step length variability in older adults. Studies comparing much younger and older adults have been inconsistent, with some studies reporting greater step length variability in older groups [13, 17, 20] and others reporting no difference [11, 14, 15]. These seemingly conflicting findings may reflect the relatively healthy nature of the older participants or the limited statistical power associated with the small samples. Furthermore, these findings highlight that step length variability and step time variability are greater in older adults in the general population and not just in those with disease [28].

Greater step width and DST variability with advancing age may indicate impaired dynamic balance control during walking [11]. For example, in an attempt to control the centre of mass within their base of support, older people may continually adjust their step width or the duration of DST to compensate for poor balance. Our results are in agreement with a single study of older people finding greater step width variability in older age. Studies comparing step width variability between younger and older adults have found contrasting results, some reporting greater step width variability in older adults [13–15, 17] and others finding no difference by age [11, 20]. Moreover, it is unknown how much step width variability is optimal. There is limited evidence that either excessive or insufficient step width variability may be risk factors for falling [4, 6]. Indeed, Brach et al., hypothesised that a certain minimal level of variability may be needed to adjust step width to maintain stability [4]. Our findings, however, did not reflect this, with only linear relationships found between age and step width variability. Differences in results may be due to different definitions of step width or data collection methods used [4, 6, 20]. For example, data capture with metatarsal markers is likely to systematically vary from that collected with heel markers due to external foot progression [6]. Further work is needed to determine threshold values in each variability measure that are predictive of future risk of falls.

It is possible that mechanisms differ across variables [3]. Presence of chronic disease may have contributed to the associations between age and the gait variability measures. For example, diabetes may lead to peripheral neuropathy, possibly reducing stability whilst walking and resulting in greater gait variability [29]. However, the inclusion of self-reported chronic disease in the final models did not significantly alter the associations. This suggests other factors or diseases may explain the associations with age. The importance of the CNS in controlling rhytmical gait is reflected by the increased gait variability found in age-related changes or diseases of the CNS [28] and under dual task conditions [30]. Ageing is associated with changes in brain structure, involving regions that are important for intrinsic automaticity of gait such as the basal ganglia [28], potentially leading to greater gait variability. Psychological factors or age-related changes in strength and balance have also been found to be associated with an inconsistent walking pattern [3, 7, 19, 31]. In this study, arthritis was the only chronic disease associated with gait, and only with greater step time variability. This may have been due to impairments commonly associated with arthritis such as pain or decreased strength [32] interfering with timing of steps. The lack of association between other chronic diseases and gait variability in this study could have been due to low numbers, mildness of disease or the relatively unchallenging task.

To our knowledge, no previous studies have examined the effect of speed on the relationship between age and gait variability in the general older population. Our results suggest that speed is an intermediate in the pathway between age and temporal gait variables, indicating that age-related changes in temporal variability measures may be largely due to reduced walking speed. It is possible that, at slower walking speeds, the temporal automaticity of gait is impaired, resulting in reduced consistency from step to step. Spatial variability measures were less dependent on gait speed, and speed did not appear to mediate the relationship of spatial variability with age. These results suggest gait speed should be considered particularly when measuring temporal variability measures in further research and clinical practice.

The strengths of this study are its population-based design, the size of the sample, the use of sophisticated measurements by trained staff using standardised protocols and the range of measures of gait variability studied. The association of gait variability measures with retrospective recall of self-reported falls in our sample was consistent with previous reports [18], supporting the validity of the gait measures. The random selection of participants from a defined population enhances the generalizability of the findings to older people in general. In addition, we examined the effect of speed on these relationships and tested for non-linear associations and interactions, adding significantly to knowledge in the field. Our findings are, however, limited by their cross-sectional nature, with longitudinal follow-up needed to characterise actual changes in gait variability with ageing. In addition, we sampled a relatively small number of steps using a computerised mat. This restricted us to collect-
ing the magnitude of variability rather than examining the long-range correlations in these step fluctuations [2, 33]. However, it did allow us to collect both spatial and temporal variables, and participants were unlikely to be affected by fatigue over the short distance walked. Such simple measurement protocols have particular potential for inclusion in clinic-based screening.

Key points

• In this first population-based study of older adults, we found that older age was associated with greater temporal and spatial variability in both sexes.
• Step time variability was greater in women of older age.
• Gait speed should be considered particularly when measuring temporal variability measures in further research and clinical practice.
• Further research is needed to study optimal levels and determinants of each gait variability measure, and the role of gait variability as a component of falls risk screening programmes.

Conflicts of interest

There are no conflicts of interest.

Funding

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Supplementary data

Supplementary data mentioned in the text is available to subscribers in Age and Ageing online.

References

Prevalence and correlates of frailty among community-dwelling older men and women:
findings from the Hertfordshire Cohort Study

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Abstract

Background: frailty, a multi-dimensional geriatric syndrome, confers a high risk for falls, disability, hospitalisation and mortality. The prevalence and correlates of frailty in the UK are unknown.

Methods: frailty, defined by Fried, was examined among community-dwelling young-old (64–74 years) men (n = 320) and women (n = 318) who participated in the Hertfordshire Cohort Study, UK.

Results: the prevalence of frailty was 8.5% among women and 4.1% among men (P = 0.02). Among men, older age (P = 0.009), younger age of leaving education (P = 0.05), not owning/mortgaging one’s home (odds ratio [OR] for frailty 3.45 [95% confidence interval {CI} 1.01–11.81], P = 0.05, in comparison with owner/mortgage occupiers) and reduced car availability (OR for frailty 3.57 per unit decrease in number of cars available [95% CI 1.32, 10.0], P = 0.01) were associated with increased odds of frailty. Among women, not owning/mortgaging one’s home (P = 0.02) was associated with frailty. With the exception of car availability among men (P = 0.03), all associations were non-significant (P > 0.05) after adjustment for co-morbidity.

Conclusions: frailty is not uncommon even among community-dwelling young-old men and women in the UK. There are social inequalities in frailty which appear to be mediated by co-morbidity.

Keywords: frailty, prevalence, older people, social inequalities, co-morbidity, elderly