A population-based study of sensorimotor factors affecting gait in older people

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Abstract

Background: the study of factors associated with age-related gait decline may assist in developing methods to preserve mobility in older people.
Objective: to examine the associations between sensorimotor factors relevant to ageing and gait in the general older population.
Design: cross-sectional population-based study.
Methods: participants aged 60–86 years (n = 278) were randomly selected using electoral roll sampling. Sensorimotor factors (quadriceps strength, reaction time, postural sway, proprioception and visual contrast sensitivity) were measured using the Physiological Profile Assessment. Gait variables (speed, cadence, step length, double support phase and step width) were recorded with a GAITRite walkway. Linear regression was used to model relationships between sensorimotor and gait variables.
Results: mean age of participants was 72.4 (7.0) years with 154 (55%) males. Better quadriceps strength, reaction time and postural sway (in men) predicted faster gait speed due to their effects on step length and/or cadence. Body weight (in men) and visual contrast sensitivity (in women) were modifying factors in these relationships. Better postural sway, reaction time (in men) and quadriceps strength (in women) predicted reduced double support phase. Modifying factors were quadriceps strength (in men) and proprioception (in women). Postural sway was the sole predictor of step width and in women only.
Conclusion: potentially modifiable sensorimotor factors were associated with a range of gait measures, with a different pattern of individual associations and interactions seen between the sexes. These results provide further mechanistic insights towards explaining age-related gait decline in the general older population.

Keywords: ageing, gait, sensorimotor, population-based study, elderly

Introduction

Approximately 30% of older adults have a gait disorder that is associated with loss of independence, falls, hospitalisation, institutionalisation and mortality [1–3]. Age may affect several characteristics of gait including speed (and its contributors, stride length and cadence), step width and double support phase (DSP) [4]. These effects of age on gait may be partly due to deterioration in sensory and motor systems that are important for safe walking. For example, muscle strength, reaction time, balance, sensation and vision have been shown to decline with age [5] or as a consequence of clinical and sub-clinical disease [6]. Decline in sensorimotor abilities are individually associated with slower gait speed and cadence, shorter steps, longer DSP and wider step width in older people [1, 7–10].

Age-related gait decline is more likely to be due to a number of sensorimotor factors, rather than one single factor [11]. Few population-based studies have comprehensively examined the relationships between multiple sensorimotor factors and gait [1, 7, 12, 13]. Furthermore, these studies have tended to examine only one variable such as gait speed [7, 12] or step length [13], included only women [1] and have failed to explore potential interactions involved in these relationships. Examining interactions between such factors may add to knowledge about mechanisms by which older adults maintain mobility. A good understanding of these relationships may inform the development of specific interventions.
to prevent age-related decline in gait speed (due to shorter steps, increased DSP and/or slower cadence) or wide based gait. Such data would also provide clinicians with an evidence base for community-based programmes designed to maintain mobility.

The aim of this population-based study was to examine the relative contributions of multiple sensorimotor factors to a range of gait variables. Specifically, we hypothesised that better performance on sensorimotor tests would be associated with faster gait speed and cadence, greater step length, shorter DSP and a smaller step width. Given our previous findings of sex differences in age-related changes in gait [4], we examined this hypothesis separately in men and women.

Methods

Study participants

Individuals aged 60–86 years (n = 278) living in Southern Tasmania were randomly selected from the electoral roll to participate in the Tasmanian Study of Cognition and Gait (TASCOG). Southern Tasmania has a total population of 239,444 people including 46,159 persons aged at least 60 years [14]. Individuals were excluded if they lived in a nursing home or were unable to walk without a gait aid. The Southern Tasmanian Health and Medical Human Research Ethics Committee approved this study and written consent was obtained from all participants.

Gait measures

Gait was measured using a 4.6 m GAITRite walkway (CIR Systems Inc., Clifton, NJ, USA). Speed, cadence, step length, step width and DSP were recorded at preferred speed. Participants started and finished walking 2 m before and after the mat to ensure constant walking speed across the mat [15]. After two practice trials, participants performed six walks and gait measures were averaged over those. The GAITRite has been validated against a gold standard three-dimensional motion analysis system [16], and has excellent test–retest reliability in older adults [17].

Sensorimotor factors

Sensorimotor function was assessed using the short form of the Physiological Profile Assessment (PPA). The PPA is a validated battery of the following sensorimotor measurements used to identify those at risk of falling [18]: (i) visual contrast sensitivity (VCS) (dB) using the Melbourne Edge Test; (ii) proprioception (cm) using a lower limb matching task, with an inscribed vertical protractor placed between the seated participant’s legs; (iii) maximal isometric quadriceps strength (kg) measured in sitting using a spring gauge; (iv) simple reaction time (ms) using a light stimulus and a finger press of a switch as the response; (v) postural sway (mm) using a sway-meter to measure body displacement at the waist level with the participant standing on a foam rubber mat for 30 s under two conditions—eyes open and closed. Maximal medial–lateral and anterior–posterior sway (mm) were summed to calculate the final score for each condition. Better performance was indicated by larger scores of VCS and quadriceps strength and lower scores of proprioception, reaction time and sway.

Other measurements

Height (cm), weight (kg) and self-reported history of lower limb arthritis, stroke, Parkinson’s disease, dementia, hypertension, angina, ischaemic heart disease, diabetes mellitus and falls (in the preceding 12 months) were recorded using a standardised questionnaire. Non-responders completed a brief phone interview providing their medical history and history of falls in the previous 12 months to estimate potential non-response bias.

Data analysis

Chi-square and Student’s t-tests were used to compare gait and sensorimotor variables between men and women. In correlation and regression analyses, DSP was log transformed. Partial correlations were first used to estimate the relationships between the sensorimotor and gait variables adjusting for age. Multivariable regression was used to model the effect of each sensorimotor factor on individual gait variables adjusting for age, height and weight. Other sensorimotor factors were also included in models if their association with the gait measure was statistically significant (P < 0.05) or if their inclusion changed the coefficient estimates of the other co-variates by >10%. Statistical interaction between co-variates was assessed by including the product of those co-variates in the regression. We carefully checked the scale of the co-variates and investigated the model fit particularly with respect to the interaction terms. Analyses were conducted using STATA version 9.0 (StataCorp, TX, USA).

Results

The sample response proportion was 53% (278 of 428). People who did not participate (non-responders) were older (P = 0.001) but did not differ from participants with respect to sex (P = 0.17), history of hypertension (P = 0.36), diabetes mellitus (P = 0.46), stroke (P = 0.53), ischaemic heart disease (P = 0.61) and previous falls (P = 0.89). Compared with women, men were taller (P < 0.001), heavier (P < 0.001), walked faster (P = 0.04), had a larger step length (P < 0.001) and step width (P < 0.001) but a slower cadence (P < 0.001) (Table 1). Men had stronger quadriceps strength than women (P < 0.001), but poorer proprioception (P = 0.02).

Adjusting for age, reaction time and quadriceps strength were the factors most strongly associated with gait speed in both men and women (Table 2). For both sexes, quicker reaction time was associated with longer steps, faster cadence and speed and a shorter DSP. Stronger quadriceps strength was associated with longer steps and faster speed in both sexes and faster cadence in men. Smaller sway (eyes open or closed) was associated with faster speed and longer steps.
in both sexes, and shorter DSP and smaller step width in women. VCS and proprioception were not associated with any of the gait variables independently of age.

In final multivariable models (please see the table in the table of Appendix 1, available on Age and Ageing online), reaction time was an independent predictor of speed and its determinants cadence and step length. The effect of quadriceps strength on step length and speed was modified by body weight in men \( (P \text{ for interaction } = 0.01) \) and VCS in women \( (P \text{ for interaction } = 0.02) \), with stronger associations seen in men with lower body weight and women with better VCS. Quadriceps strength predicted cadence independently of other factors in men, but was a confounder in the relationship between reaction time and cadence in women. Postural sway (eyes closed) independently predicted step length and speed, but only in men. An interaction was found between VCS and proprioception \( (P \text{ for interaction } = 0.02) \) in predicting speed in women, with weaker associations between proprioception and speed seen in women with better vision.

Postural sway (in both sexes) and quadriceps strength (in women only) were independent predictors of DSP. In men, the effect of reaction time in predicting DSP was modified by weight \( (P \text{ for interaction } = 0.004) \) and quadriceps strength \( (P \text{ for interaction } = 0.04) \) such that stronger associations were found in taller men with poorer strength. In women, the effect of postural sway (eyes closed) on DSP was modified by proprioception \( (P \text{ for interaction } = 0.06) \) with a stronger association seen for women with poorer proprioception. Postural sway with eyes closed was the sole predictor of step width and only in women. The footnotes in Appendix 1 provide information on the critical values of height, weight and the sensorimotor variables that are effect modifiers in the interaction effects.

The strength of the associations between sensorimotor measures and each gait variable are summarized in Table 3 as partial \( R^2 \) values from the final multivariable models.

### Discussion

In this sample from the general older population, several important and modifiable sensorimotor factors were associated with gait speed, its determinants (step length and cadence) and DSP, but only postural sway was associated with step width. Among the sensorimotor factors, quadriceps strength and reaction time explained the greatest proportion of variance. The pattern of these associations varied between the sexes.

Quadriceps strength explained the greatest proportion of variance of gait speed, with greater strength predicting faster speeds for all but the heaviest men \( (>93 \text{ kg}) \) and the women with poorest vision \( (<17 \text{ dB}) \) (using the results provided in the table of Appendix 1, available on Age and Ageing). Other significant co-variates of faster speed were quicker reaction time in both men and women, smaller postural sway for men and better proprioception in all women except those with better vision. These results are generally in agreement with those from the few previous population-based studies showing that multiple sensorimotor factors are associated with postsural sway in both sexes and poorer gait speed in women with poorer proprioception.
with speed, with muscle strength being of particular importance [1, 7, 12]. Our study extends previous findings [1, 7, 12] by reporting on both men and women and carefully examining for interaction effects. To illustrate and further explore these interactions, we calculated the gain in quadriceps strength required to increase speed by 5 cm/s (using the results provided in the table of Appendix 1, available on Age and Ageing), a value described as the smallest clinically meaningful change [19]. For example, a woman with a VCS of 21 (50th percentile) would need an estimated 9 kg increase in strength to increase speed by 5 cm/s, whereas a woman with a VCS of 23 (75th percentile) would only require an estimated 6 kg increase in strength. A man weighing 80 kg (50th percentile) would need an estimated 18 kg increase in quadriceps strength to increase speed by 5 cm/s, whereas a man weighing 92 kg (75th percentile) would require an impractical 167 kg gain in strength. Interventions designed to improve mobility may therefore be more effective if multifactorial. For example, interventions to increase speed ideally would involve a weight loss programme in men and visual education strategies in women to complement muscle strengthening.

Clinicians routinely examine whether slower speed is the result of shorter steps, a slower cadence or a combination of both. We therefore examined the associations between sensorimotor variables and each of these gait variables. Faster cadence contributed to faster gait speed through its associations with quicker reaction time (in both sexes) and stronger quadriceps strength (in men only). Reaction time and quadriceps strength equally explained the greatest proportion of variance for cadence in men.

Quadriceps strength explained the greatest proportion of variance for step length with greater strength predicting longer steps for all but heavier men and women with the poorest vision. Such interactions were not observed in previous studies in which strength and vision were found to be independent predictors of step length in women [1, 8]. Quicker reaction time in both sexes and smaller postural sway (in men only) also were independent predictors of longer steps. This information may be useful clinically. For example, in a community programme designed to improve walking speed, older adults with both reduced cadence and step length may benefit from a programme designed to improve reaction time and muscle strength. In addition, those with reduced step length may also benefit from a balance and weight loss programme (in men) or a visual education programme (in women).

The associations between sensorimotor factors and DSP [8] or step width [9] have been explored in very few studies and only in convenience samples. These gait variables have been associated with falls in older people [20, 21] and may be measures of dynamic balance during gait [22]. Consistent with this concept we found that smaller postural sway, also a measure of standing balance control, was associated with reduced DSP (in both sexes) and narrower step width (in women only). However, the variables explaining the greatest variance were stronger quadriceps strength for women and reaction time for men. Postural sway (in women only) was the sole sensorimotor predictor of step width, and this finding is consistent with that of the only previous study examining associations between balance and step width in women [9].

The mechanisms by which each sensorimotor factor affects gait may be different. Poorer quadriceps strength may reduce the propulsive forces and stability required to maintain sufficient cadence, step length and DSP. Slower reaction time may reflect reduced central processing speed due to age-related changes in the brain, and its association with reduced speed may reflect the direct effects of the declining central cognitive control of gait. Alternatively, people with slow reaction times may reduce their cadence and step length and increase DSP (men) as a strategy to compensate for unexpected perturbations and obstacles. The association between sway and DSP may simply reflect the fact that they measure the same construct, with the former indicating static balance and the latter a more dynamic balance during gait. However, it is also possible that older people may widen or shorten their steps, and increase their DSP to improve stability and compensate for poor balance.

Some sex differences were observed in the associations between sensorimotor factors and gait variables, possibly

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**Table 3. Partial $R^2$ values for the regression of gait variables on sensorimotor variables**

<table>
<thead>
<tr>
<th></th>
<th>Better visual contrast</th>
<th>Quicker reaction time</th>
<th>Better proprioception</th>
<th>Stronger QS (eyes open)</th>
<th>Smaller sway (eyes open)</th>
<th>Smaller sway (eyes closed)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Men</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Faster speed</td>
<td>0.05</td>
<td></td>
<td></td>
<td>0.07</td>
<td>0.02</td>
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<tr>
<td>Faster cadence</td>
<td>0.03</td>
<td></td>
<td></td>
<td>0.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longer step length</td>
<td>0.04</td>
<td></td>
<td></td>
<td>0.06</td>
<td>0.03</td>
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<tr>
<td>Reduced DSP</td>
<td>0.09</td>
<td></td>
<td></td>
<td>0.03</td>
<td>0.02</td>
<td></td>
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<tr>
<td>Narrower step width</td>
<td></td>
<td>0.03</td>
<td>0.04</td>
<td>0.03</td>
<td>0.03</td>
<td>0.08</td>
</tr>
<tr>
<td><strong>Women</strong></td>
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<tr>
<td>Faster speed</td>
<td>0.05</td>
<td>0.03</td>
<td>0.04</td>
<td>0.07</td>
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<td>Faster cadence</td>
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<td>Longer step length</td>
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<td>Reduced DSP</td>
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<td>Narrower step width</td>
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</table>

QS, quadriceps strength; DSP, double support phase.
reflecting a reliance on different physiological systems. It is also possible that men and women compensate for impairment in physiological systems differently. For example, poor balance (sway) may lead women to increase step width, men to shorten step length and both to increase DSP to improve stability when walking. Alternatively, hormonal differences may also play a role. For example, menopause can lead to a rapid decline in muscle strength [23], leaving women to rely more heavily on other factors such as vision. Further research is needed to confirm the sex differences found in this study.

Although a wide range of sensorimotor factors were studied, the models explained only up to 49% of the variance in gait. Other factors such as loss of range of movement, vestibular function, cognition, pain, fear of falling, depression or other sensorimotor factors are also likely to contribute to impaired gait. Further research is needed, particularly into the factors contributing to step width considering its association with falling in older adults [21].

Other limitations of this study need to be considered. Firstly, it was cross sectional in nature. The true causal nature of these associations need to be further explored and determined in alternate study methodology or in longitudinal analyses. Secondly, whilst the sample response proportion (53%) was much higher than that in previous population-based studies [7, 12], the possibility of non-participation bias cannot be discounted.

This study adds significantly to knowledge of the sensorimotor factors associated with walking ability by providing data on a wide range of quantitative gait measures in a large population-based sample. In addition to providing novel data for men, this study extends previous work by exploring interaction effects between the sensorimotor variables. Furthermore interventions are available to improve strength, balance, reaction time [24] and vision [25]. Therefore, these results provide clinicians with potential factors for a more focussed assessment or intervention in those with specific temporal or spatial gait changes.

Key points
- This population-based study provides new insights into the relative contributions of key sensorimotor factors associated with a wide range of gait variables.
- Sensorimotor factors contributed up to 49% of the variance of gait variables.
- Quadriceps strength in both sexes and reaction time in men were the strongest predictors of speed-related gait variables. Postural sway was the only predictor of step width in women only.
- Men and women may rely on different sensorimotor variables to maintain walking.
- The results may assist in designing effective prevention and intervention strategies towards maintaining or improving walking in older people.

Conflicts of interest
There are no conflicts of interest.

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Supplementary data
Supplementary data are available at Age and Ageing online.

References


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