Breadth of base whilst walking:
effect of ageing and parkinsonism

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Abstract

Background: the effect of healthy ageing and of parkinsonism on breadth of base whilst walking had not been adequately documented.

Design: height-specific reference ranges for mean foot separation at mid-swing were derived for males and females, age not proving to be a significant influence.

Method: normative data were obtained from 164 healthy volunteers, and foot separation in idiopathic parkinsonism (99 patients) was characterized by comparison.

Results: parkinsonism was associated with significantly greater within- and between-subject variability in foot separation. There was a linear trend from increased separation in those with bilateral signs but little functional impairment, to decreased separation in the severely impaired but not yet chair or bed bound. Foot separation was best explained by two clinical signs, rigidity and anatomical postural abnormality. A flexed posture was associated with increased separation, rigidity with decreased, the separation manifested being determined by the net effect.

Conclusion: in early idiopathic parkinsonism, falling may depend on abnormal posture, and increased breadth of base be compensatory. Later, the decrement in foot separation may become a primary determinant of falls.

Keywords: ageing, foot separation, parkinsonism, walking

Introduction

Falls occur primarily during activity [1-4]: walking is essentially an unstable condition [4, 5]. The centre of gravity projects outside the base of support for most of the gait cycle [4], the breadth of base, position of the centre of gravity and its distance from the base being critical to stability [6]. But just how good is our clinical judgement of what constitutes a normal breadth of base or, indeed, the gait of normal ageing? Clinical opinion is that the “characteristic type of gait in old age” has a “slight widening of the base” [7], “the gait of the elderly...is frequently wide-based” [6] and walking in “a classical wide-based manner...can reasonably be attributed to age rather than to current disease” [8]. Assuming that the swing paths are parallel to the line of progression, foot separation in the coronal plane can readily be estimated by monitoring foot/ground contact using talcum powder or in a fixed gait laboratory. The ‘pocket gait laboratory’ [9] gives foot separation as one foot passes the other. Alternatively, the relative position of the ‘tagged’ left and right feet can be sampled during the cycle. Reference ranges are presented, by which the ‘unusualness’ [10] of foot separation at mid-swing can be assessed in relation to personal characteristics. The gait of sufferers from idiopathic parkinsonism is characterized by comparison.

Subjects and methods

The 164 healthy volunteers (at least 12 men and 12 women from each decade, 30-89 years) were Caucasian, living independently and able to walk for over 40 m or 60 s, without fatigue, dyspnoea, angina, claudication or musculoskeletal pain. They did not normally use a walking aid. There was no history of parkinsonism or other specific neurological or musculoskeletal disorder. Those with a mental test score ≤8 on the 16-point Modified Tooting Bec scale [11] or with clinical depression or other mental illness were excluded, as were those with overt abnormalities of spine, lower limbs or posture—e.g. isolated findings of a ‘walking stick posture’ (see below), previous orthopaedic surgery to spine or lower limbs or pain in relevant joints.
Ninety-nine volunteers with idiopathic parkinsonism (up to a maximum of 12 men and 12 women in each decade between 40 and 89 years) were also recruited. Parkinsonism had been diagnosed by the presence of two or more cardinal signs: brady/hypokinesia, 'resting' rigidity, tremor and postural abnormality. There was evidence of at least three of the UK Brain Bank supportive criteria [12] for diagnosis of definite Parkinson's disease. Clear-cut, non-idiopathic parkinsonism was excluded [12, 13], as were patients in whom there were reservations about the idiopathic nature (e.g. where arteriosclerotic pseudoparkinsonism was suspected of coexisting with idiopathic [14]). All were independently mobile and without orthostatic symptoms. Those with other physical or mental disorders that might affect assessment (as above) were excluded. All but six were receiving antiparkinsonian medication. Those whose performance fluctuated in relation to individual doses were assessed in their 'therapeutic window', i.e. the period in the dosage interval when optimal effects of medication occur.

All gave informed consent to participate in the study, which had local ethics committee approval.

Assessments were as follows:

1. Mid-heel separation at mid-swing was measured over 40 m or 60 s, in a 2.5-m-wide empty corridor, using the computerized, pocket-sized, infrared telemetric 'shoestring' device [15]. Rested subjects walked 'at their own speed', following the command "go".

2. Physiological postural correction—body sway, standing at ease with shoes on and eyes open—was measured as total angular movement in the sagittal plane [16], during three consecutive 1 min periods.

3. Anatomical postural abnormality in parkinsonism was assessed by measuring forward displacement [17] of occiput, with knees extended and buttocks and heels against a wall, but otherwise standing at ease (scoring: \( \leq 10.2 \) cm, 0; >10.2-12.7 cm, 1; >12.7-15.3 cm, 2; >15.3 cm, 3).

4. Rigidity in parkinsonism: resting mid-line rigidity [17] was rated (scoring: none detectable in neck, 0; detectable, 1; moderate, 2; severe, 3).

5. Functional impairment in parkinsonism was assessed using the Hoehn and Yahr staging (stage 1 representing unilateral involvement with minimal or no functional impairment and stages II to IV increasing incapacity, with the first signs of impaired righting reflexes—evident in unsteadiness as the patient turns or demonstrated when he or she is pushed from standing equilibrium with feet together and eyes closed—appearing at stage III) [18].

6. Cognitive inefficiency was measured using the time required to lift the left or right index finger in response to visual signals. An alerting signal did or did not warn the subject in advance whether the imperative signal would be to lift the left or right index. A practice of four replicates of the four combinations (from random permuted blocks) preceded the test proper (15 replicates). A fixed delay of 2 s was used between alerting and imperative signals. The smaller the ratio of unwarmed to warned reaction time (i.e. the lesser the ability to make use of a warning), the more inefficient the cognitive processing [19].

Statistical analysis

Analysis of variance was used to select, from characteristics of the healthy volunteers, the set which best determined the primary dependent variable, mean foot separation at mid-swing. A reference range for foot separation, specific for key influencing variables, was calculated [10]. Analysis of covariance was used to compare (i) foot separation and (ii) body sway between those with parkinsonism (sub-divided according to functional impairment, anatomical posture and rigidity) and those without. Covariates (including those of potential biological importance, but not reaching statistical significance at the 0.05 level) were fitted for the combined subject group. Single and multiple linear regression was used to construct explanatory models for the between-parkinsonian variability in foot separation. The proportion of the variability so explained (\( R^2 \)) was estimated and adjusted to remove the chance contribution made by each variable in the model.

The assumptions of normally distributed residuals [20] and equality of variance [21] were investigated. To ensure their validity, a log transformation was required for the SD in foot separation, sway and cognitive inefficiency. (For transformed variables, mean differences are expressed as ratios and magnitude of effects as percentage changes.)

Results

Relationship of subject characteristics to foot separation whilst walking

In the healthy volunteers, two key determinants of mean foot separation at mid-swing were identified: gender \((P < 0.001)\) and height \((P = 0.04)\). Separate height-specific reference ranges for men and women are given (Figure 1). Foot separation tended to increase with body weight, but this additional effect \([0.18, 95\% \text{ confidence interval (CI)}: -0.10, 0.47 \text{ mm kg}^{-1}\) failed to reach statistical significance \((P = 0.2)\).

There was no compensatory increase in foot separation at mid-swing (Figure 2a) for the age-associated increase in sway (Figure 2b). Rather, foot
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separation, after adjustment for the above covariates, decreased with age, but the change, \(-0.15 (-0.34, 0.04)\) mm.year\(^{-1}\), reached statistical significance only at the 0.1 level. The population as a whole is, of course, becoming taller, but there was no evidence that this was masking an age-associated increment in foot separation \((P = 0.8\) for interaction between age and height). The magnitude of the change in foot separation during adult life is, thus, small and comparable with the within-subject standard deviation during a walk (Figure 3). In contrast, the increase in mean standing body sway with age was large, 17.3 % (12.0, 22.8) per decade \((P < 0.005)\). Sway increased with body weight \((P = 0.002\), with no significant interaction between age and weight) and tended to increase with height \((P = 0.06\), after adjustment for weight).

Effect of parkinsonism on foot separation whilst walking.

The variability in mean foot separation at mid-swing was greater \((P = 0.0009, F\) test\) in those with a diagnosis of idiopathic parkinsonism than in those without \((147 (95\%\) data interval 88, 206) and 149 (110,}

Figure 1. Height-specific reference range for separation between the mid-point of the two heels, at mid-swing, in (a) 79 male and (b) 85 female healthy volunteers. —, regression line; —, 80% range; —, 95% range; —, 99% range and •, individual data points.

Figure 2. Effect of age on (a) mean mid-heel separation, after adjustment for height, gender (as if all subjects were male) and weight and (b) mean standing body sway, adjusted for weight and height, in 164 healthy subjects. —, regression line; —, 95\% data intervals; •, individual data points.

Figure 3. Reference range for the within-subject standard deviation in mid-heel separation in health, the interrupted lines indicating the 95\% range for 164 volunteers (■). Data from 99 patients with parkinsonism (□) are shown for comparison.
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Table 1. Effect of parkinsonism, categorized according to functional disability, postural abnormality and rigidity on foot separation at mid-swing and standing body sway

<table>
<thead>
<tr>
<th>Categorization</th>
<th>n</th>
<th>Mean foot separation (mm)</th>
<th>Body sway (% increment)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Contrast (95% CI)</td>
<td>P</td>
</tr>
<tr>
<td>Hoehn and Yahr staging</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>32</td>
<td>8.6 (-0.2, 17.0)</td>
<td>0.045</td>
</tr>
<tr>
<td>III</td>
<td>37</td>
<td>-2.0 (-9.9, 5.9)</td>
<td>0.6</td>
</tr>
<tr>
<td>IV</td>
<td>29</td>
<td>-11.8 (-2.6, -20.9)</td>
<td>0.01</td>
</tr>
<tr>
<td>Score for posture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>40</td>
<td>-3.8 (-11.4, 3.8)</td>
<td>0.3</td>
</tr>
<tr>
<td>1</td>
<td>42</td>
<td>7.0 (-0.6, 14.6)</td>
<td>0.07</td>
</tr>
<tr>
<td>≥2</td>
<td>17</td>
<td>-16.2 (-4.5, -27.9)</td>
<td>0.007</td>
</tr>
<tr>
<td>Score for rigidity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>3</td>
<td>16.7 (-8.5, 41.9)</td>
<td>0.2</td>
</tr>
<tr>
<td>1</td>
<td>53</td>
<td>3.8 (-3.3, 10.8)</td>
<td>0.3</td>
</tr>
<tr>
<td>≥2</td>
<td>43</td>
<td>-8.3 (-16.1, -0.6)</td>
<td>0.03</td>
</tr>
</tbody>
</table>

*a* Of values in 99 patients with parkinsonism to those in 164 without. They are expressed for foot separation as the mean difference (mm), with parkinsonism minus without, and for sway as the percentage increment, with parkinsonism over without.

*b* Significance of the difference from 0.

Adjustment made for covariates determined in the entire group of subjects: for foot separation these are, gender, height, age and weight (last at age-adjusted [19]). For body sway, age, weight and height.

187) mm, respectively, values being adjusted to grand means for covariates, but there was no overall difference in group means [mean difference -1.6 (95% CI: -8.4, 5.2) mm, p = 0.6, t-test, assuming unequal variances]. The precision with which the gait cycle was repeated (Figure 3) was slightly less in the parkinsonian patients [mean difference in within-subject SD in separation 3.0 (1.9, 4.1) mm, P < 0.001].

Could progressive, post-diagnosis changes in foot separation explain the greater between-subject variability in the parkinsonian group? Time since diagnosis and duration of levodopa therapy were not determinants of separation (adjusted for covariates), but rate of progression of the condition and timing of medicinal intervention relative to progression, do vary. However, by comparison with controls (Table 1), foot separation of parkinsonian patients was less in stage IV functional impairment, not significantly different in stage III and greater in stage II. Indeed, there was a significant inverse, linear relationship between separation and functional impairment (P = 0.01, R² = 32% for the model containing staging and relevant personal characteristics).

A narrow foot separation was also seen in severe disease, as judged by a score of ≥2 for anatomical posture or by a score of ≥2 for rigidity (Table 1). Those with a postural score of 1 tended to have broadness of base. Foot separation in parkinsonian patients with no anatomical postural abnormality (score 0) was like that of controls: they, presumably, had no stimulus to broadening of base per se or as a result of treatment. There was no significant overall association (P = 0.35) between body sway and foot separation in parkinsonism (even after adjustment of each for covariates). The table shows a significant increase in sway, even when functional impairment and disease were mild. Those whose increased perturbations were likely to be centred upon or include the vertical position, because of minimal anatomical postural abnormality, had no significant increase in foot separation. Any compensatory increase, provoked by less symmetrical perturbations, may either fail as the disease progresses or be overridden by other pathological processes: sway was greater in stage III functional impairment than in II, breadth of base present in stage II but absent in III. It might be expected that the decreased foot separation of severe impairment or disease (stage IV or a score ≥2 for posture or rigidity) would, itself, result in a further increment in sway: this was not the case. Indeed, sway ranked lower in those parkinsonian patients with more severe anatomical postural abnormality or rigidity, being, perhaps, inhibited centrally or blocked peripherally by rigidity.

Perhaps cognitive inefficiency [19] might impede a compensatory increase in foot separation? The ratio of unwarned to warned reaction time was less in parkinsonian patients (mean 1.36 (95% CI 1.28, 1.45)) than in controls (1.50 (1.46, 1.55)): the patients were, indeed, more inefficient [contrast of ratio in patients to that in controls = 0.91 (0.85, 0.97), i.e. significantly different from 1, P = 0.004]. However, within the parkinsonian group, extent of inefficiency (age-adjusted [19]) did not significantly influence foot separation.
In the multivariate analysis, the candidate variables, body sway, time since diagnosis of parkinsonism and efficiency of cognitive processing, were rejected serially, having failed to contribute significantly to explaining the between-parkinsonian variability in foot separation. Foot separation in the parkinsonian group was best explained ($R^2 = 37\%$) by a model containing the two remaining candidate variables, the rigidity and anatomical posture scores ($P = 0.03$ in each case), in addition to relevant personal characteristics. The two were associated with opposing effects, flexed posture with increased separation and rigidity with decreased (no significant posture–rigidity interaction). Foot separation at mid-swing was determined by the net effect.

**Discussion**

The proportion of people who have fallen in the preceding year [22] increases disproportionately with age from the late sixties. Work on healthy volunteers, including the present study, suggests that the explanation might lie in an age-related increase in perturbations [24–26] and inadequacy of protective reflexes [19, 27], but not in decreased breadth of base [28]. Altered foot separation is likely to be a risk factor in older people with musculoskeletal, ophthalmic, vestibular and neurological disorders.

In treated patients with idiopathic parkinsonism [9], narrow foot separation at mid-swing was associated with a greater risk of falls. In these fallers, any compensatory broadness of base has, presumably, been overcome by a pattern of rigidity, characterized by pronounced effects on the hip adductors and/or by decreased pelvic transverse rotation [30] and tilt [31]. Isolated activation of rigidity is described in otherwise healthy elderly people [29]: it may reduce foot separation whilst walking and, thereby, cause falls.

In parkinsonism, fallers are over-represented at the time of presentation [23], compared with the same age group in the general population. Similar risk factors (more body sway and psychomotor slowing) were implicated, but an additional one emerged, the beginning of a "poker" spine with the head flexed forward. With increasing forward displacement of the centre of gravity, sway may not just add to the instability, but potentiate it. Foot separation was not measured [23]: any compensatory increase in foot separation may offset overt disturbance of balance during linear gait, but not suffice in combating the increased risk of falls. It could even add to the difficulty in turning.

Pharmacological intervention, targeted at decreasing rigidity and its activation by walking [29] and improving psychomotor responses [32], may avert falls in parkinsonism. Tailored physiotherapy, aimed at combating the walking-stick posture, preventing reduced range of movement and stiffness of joints [33, 34] (in order to facilitate motor responses) and maintaining foot separation and out-pointing of toes, seems important [23]. Training in alternative motor strategies, such as the *en bloc* turn [35, 36], may avoid falls associated with hazardous manoeuvres for those with a narrow base.

**Acknowledgement**

The spirit, kindness, generosity and support of local parkinsonian patients and their carers, in particular that of the late Mr John Chambers and his wife Anne, has been an inspiration to the authors.

**Key points**

- Broadness of base during walking is not a feature of normal ageing.
- In parkinsonism, breadth of base is widened early in the disease process, as a result of flexed posture, and then later narrowed, as a result of overriding rigidity.

**References**


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