Frequency spectrum differences in centre of pressure and centre of mass displacement between normal elderly people and patients with vascular higher-level gait disorders.

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Introduction
Patients with vascular higher-level gait disorders (HLGDs) have widely varying gait impairments. While some have start hesitation (gait ignition failure), with freezing and difficulty turning, others have no apparent difficulty with starting to walk. The anterior-posterior centre of pressure and centre of mass displacements in patients with HLGDs tend to fall outside the normal reference ranges for elderly people, while mediolateral values for these variables are within or close to normal values (Elble et al 1996). However, these differences seem to occur in patients with gait ignition failure as well as those with no apparent difficulty initiating gait, although, the values tend to be very variable within individual patients (Mickelborough 2001). As well as differences in displacement, the horizontal centre of pressure (COP) patterns during gait initiation of patients with HLGDs are less smooth than for normal elderly people, with erratic fluctuations (Elble et al 1996). It is not straightforward to quantify this difference in the ‘quality’ of COP displacement patterns within the time domain. There is some evidence that different control pathways are used for gait initiation and gait (Kirker 2000). It is expected that these differences will be reflected in differences between the preparatory and the stepping phases of gait initiation. It is hypothesised that: i) There are differences between the frequency characteristics of centre of pressure displacement in the preparatory and stepping phases of gait initiation in all subjects and ii) there are differences between patients with HLGDs and normal elderly people in the frequency characteristics of centre of pressure displacement during gait initiation.

Methods
Data were collected from twenty-one healthy elderly people, and eight patients with vascular HLGDs. Centre of pressure (COP) was measured using a force plate (Kistler 9281B11) collected at 500Hz. Subjects were each asked to perform at least ten trials of gait initiation at self-selected normal speed. For this study gait initiation is divided into a preparatory phase (onset of muscle activity to swing leg toe-off) and a stepping phase (swing leg toe-off to stance leg toe-off). Frequency domain analysis was performed on these COP data in both anteroposterior (x) and mediolateral (z) directions. Power Spectral Density was calculated using Welch's averaged, modified periodogram method. This uses an FFT with 256 points based on a hanning window, normalised by the mean for detrending. After the calculation of the power spectral density (PSD), the highest frequency contained in 99% of the PSD of the signal (PSD99) was calculated and used as the criterion.

To illustrate these differences the data were also examined with Time-Frequency domain analysis, using the Wigner function (Stergioulas 1997, Giakas et al 2000). These data are plotted in figure1a – d.

Results and discussion
There are significant differences between the frequency characteristics of x and z-axis centre of pressure displacement in the preparatory and stepping phases in both groups of subjects (p <0.01). In all cases the PSD99 values are lower during the preparatory phase, indicating that the signal contains a greater proportion of high frequency components during the stepping phase.
### Table 1  PSD99 values for normal elderly people and patients with HLGDs

<table>
<thead>
<tr>
<th></th>
<th>Normal elderly people (n=21)</th>
<th>Higher-level gait disorder patients (n=7)</th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>SD</td>
<td>95% CI for Mean</td>
</tr>
<tr>
<td>x preparatory</td>
<td>8.90</td>
<td>10.03</td>
<td>7.56-10.25</td>
</tr>
<tr>
<td>z preparatory</td>
<td>7.72</td>
<td>8.20</td>
<td>6.63-8.82</td>
</tr>
<tr>
<td>x stepping</td>
<td>21.07</td>
<td>19.75</td>
<td>18.42-23.70</td>
</tr>
<tr>
<td>z stepping</td>
<td>62.19</td>
<td>25.17</td>
<td>58.83-65.56</td>
</tr>
</tbody>
</table>

**Figure 1** Mesh graphs of the time-frequency domain (Wigner function) analysis of COP displacement for a single normal elderly subject (1a,1b) and a patient with HLGD (1c,1d) for gait initiation (onset to toe-off of the stance foot).
There are significant differences between these patients and normal elderly people in the frequency characteristics of centre of pressure displacement during gait initiation. The PSD99 is higher in patients than normal elderly people for both anteroposterior and mediolateral COP displacement during both preparatory and stepping phases of gait initiation (table 1, figure 1). In the frequency domain the COP signal of patients with HLGDs contains a greater proportion of high frequency components than for normal elderly people. Figures1a – d illustrate an example of the time-frequency domain analysis of COP displacement for a single normal elderly subject (1a,1b) and a patient with HLGD (1c,1d). It may be seen that the differences between the normal elderly people and patients with HLGDs are particularly marked in the x direction.

Previous analysis of frequency domain characteristics of gait patterns between normal subjects and patients has shown that this method is able to detect differences that are not apparent in the time domain (Giakas et al 1996). This method of analysis has potential as a novel method with which to identify the, often subtle, changes within gait initiation in patients with HLGDs compared with normal elderly people.

References
Giakas G. Baltzopoulos V. et al. Comparison of gait patterns between healthy and scoliotic patients using time and frequency domain analysis of ground reaction forces. Spine, 21, 2235-2242, 1996

Acknowledgements
JM. was funded by a training fellowship from the NHS NW R&D and by a project grant from Research into Ageing.