AN INVESTIGATION OF THE GAIT OF ELDERLY FALLERS WITH ORTHOSTATIC HYPOTENSION USING FOOTSWITCHES

K.M. Culhane*, M. O'Connor**, A.M. Finucane**, D. Lyons** and G.M. Lyons*

* Biomedical Electronics Laboratory, Department of Electronic and Computer Engineering, University of Limerick, Limerick, Ireland
** Rehabilitation Centre, St. Camillus' Hospital, Limerick, Ireland

Karen.Culhane@ul.ie

Abstract: Gait abnormalities are a recognised risk factor for falling in the elderly and variability in gait has been shown to be a measurable predictor of falls. Orthostatic Hypotension (OH) has a high prevalence in the elderly and is also a common cause of falling in that population. The objective of this study was to evaluate gait variability of older adult fallers with a diagnosis of OH and to compare it to the gait variability of older adult fallers without an OH diagnosis and a healthy control group of older adult non-fallers. Using footswitches the temporal parameters of gait of these subjects were examined; stride time, swing time, stance time, percent stance time and walking speed, and the variability of these parameters from stride-to-stride was determined. Results showed that the OH fallers walked significantly slower than the control group, spending significantly longer in the stance phase of the gait cycle. Despite the reduction in walking speed, the OH faller group demonstrated increased variability in the temporal parameters of gait measured when compared with the controls. This study demonstrates measurable gait abnormalities in those who fall due to OH that may further increase their risk of falling.

Introduction

Gait abnormalities are a recognized risk factor for falling in the elderly and variability in gait has been shown to be a measurable predictor of falls (Hausdorff, Rios & Edelberg, 2001; Maki, 1997). Variability in gait is a reflection of the inconsistency and irregularity of gait. With falls as a leading cause of accidental death in the elderly (Lilley, Arie & Chilvers, 1995) and with their debilitating consequences such as significant injury, fractures, hospital admission and fear of recurrence, many techniques have been used to evaluate gait patterns with a view to predicting fall risk (Auvinet, Chaleil & Barrey, 1999; Guimares & Isaacs, 1980; Hausdorff et al., 2001).

Temporal gait parameters have been previously analysed in elderly fallers and gait variability has been shown to predict falls (Hausdorff et al., 2001; Haussdorff et al., 1997). Using footswitches, Hausdorff et al. (Haussdorff et al., 1997) examined the stride-to-stride variability of stride time, stance time and swing time of elderly fallers, elderly non-fallers and young people. The elderly fallers in Hausdorff's studies were selected based on the criteria that the falls they experienced were not due to a major intrinsic event (e.g. syncope). They observed that all measures of gait variability were significantly greater in the elderly fallers compared to both the elderly non-fallers and young controls. A prospective study of community-dwelling older adults confirmed that stride time variability was indeed a predictor of falls with increased gait variability clearly associated with subsequent falls during a 12-month follow-up period (Hausdorff et al., 2001).

Certain medical conditions are also associated with an increased risk of falling. In a further study by Hausdorff et al. (Haussdorff et al., 1994), elderly subjects with congestive heart failure were found to have significantly greater walking variability when compared with elderly controls and young subjects. When the walking patterns of patients with Parkinson's disease and Huntington's disease were investigated, Hausdorff et al. found that gait variability measures were two and three times that observed in healthy subjects, respectively (Haussdorff et al., 1998). Therefore, a feature of gait that can be used to identify people at risk of falling is variability.

Othostatic hypotension (OH) has a high prevalence in the elderly, reported to be as high as 30% in elderly, home-dwelling subjects (Luukinen et al., 1995) and is a significant risk factor for falls (Heitterachi et al., 2002). OH causes falls by transiently reducing cerebral perfusion pressure. This can cause loss of consciousness, loss of postural tone or unsteadiness. Regional cerebral blood flow during head-up tilting has been measured in patients with symptomatic OH using a 133-Xenon inhalation technique. Lower mean hemispheric blood flow was demonstrated with a significant redistribution of regional blood flow. Reduction of blood flow to the frontal lobes was noted while an increase in blood flow to the post-central areas was seen (Passaunt et al., 1993). The frontal lobes contain the motor, pre-motor and supplementary motor areas. These areas are important in the planning and execution of movement and in postural stability.

The objective of this study was to evaluate gait variability of older adult fallers who were falling due to orthostatic hypotension (OH fallers) and to compare it to the gait variability of older adult fallers in whom OH

ISSN: 1727-1983 © 2005 IFMBE

was excluded as a cause (NOH fallers) and a healthy group of older adult non-fallers (Control). We hypothesised that persons with OH might have subtle underlying gait abnormalities as a result of repeated episodes of cerebral hypoperfusion.

Using footswitches we investigated the stride-to-stride variability, measured using the standard deviation, of stride time, stance time, percent stance time and swing time while walking, as well as walking speed. Gait has not been previously assessed in patients with OH using quantitative electronic devices.

Materials and Methods

27 elderly subjects were recruited from the medical database in St. Camillus' Hospital Limerick. All subjects were over 60 years of age, lived in the local community and were capable of independent ambulation. Chart review was undertaken to correctly divide the subjects into three distinct groups: elderly fallers with a primary diagnosis of OH, referred to as OH fallers (n = 9; mean age: 77 yrs; SD 8 yrs:), elderly fallers without a diagnosis of OH, referred to as NOH fallers (n = 9; mean age: 76 yrs; SD: 5 yrs) and a healthy elderly group of non-fallers, referred to as the control group (C) (n = 10; mean age: 69 yrs; SD: 5 yrs).

A faller was defined for the purpose of this study as a person who had fallen from vertical to horizontal on at least two occasions over the preceding 12-month period (Gabell & Nayak, 1984). OH was diagnosed using tilt-table and finometer technology. This is a well-established technology that allows accurate assessment of transient postural blood pressure changes involving the use of a head-up tilt table, which is a mechanised table that allows patients to undergo passive posture change from a horizontal beginning point to 70°. This is combined with phasic blood pressure assessment using digital artery photoplethysmography, which allows 'beat-to-beat' recording of blood pressure changes using a volume clamp technique. Exclusion criteria consisted of the use of pacemakers and cognitive impairment.

Ethical approval for the study was obtained from the University of Limerick Research Ethics Committee and the Mid-Western Health Board Scientific Research Ethics Committee. Informed consent was obtained from all subjects before participating.

Using footswitches the temporal parameters of gait of these subjects were examined; stride time, swing time, stance time, percent stance time and walking speed, and the variability, measured using the standard deviation (SD), of these parameters from stride-to-stride was then determined. All subjects walked for 18m along a level walkway.

The hardware used during testing consisted of a combined heel and toe footswitch sensor and a portable (Biomedical Monitoring BM42[1]) data-logger. The temporal parameters of gait were detected using the footswitch embedded in the subjects' left shoe and then connected to the battery-powered, pocket-sized (75mm x 56mm x 18mm) data-logger attached to a belt around the waist. The monitoring device and associated cabling was lightweight, portable and easy to attach.

The footswitch sensor provided a measure of the force applied to the floor by the heel and toe from which heel and toe contact events were obtained by determining when the footswitch signal exceeded a certain voltage threshold. The footswitch signals were sampled at 1000Hz at a resolution of 12 bits and stored on the data-logger's memory card. After each trial the data-logger data were downloaded to a computer using a USB memory card reader.

While wearing the equipment, subjects walked independently at a self-selected pace along an 18m level walkway. As a precautionary measure, due to the high risk of falling within this population, subjects walked between parallel bars with two investigators on either side at all times. This walk was repeated twice or until the subject was comfortable with wearing the equipment. This facilitated recording of the subjects' natural walking pattern. Once the subject was familiar with the equipment, three walks were recorded for analysis.

The data were analysed using a custom-designed Matlab®[2] program. The middle three strides of each of the three walks were analysed. For each stride cycle, stride time, stance time, percent stance time and swing time were calculated. The variability of these parameters from stride to stride was then calculated using the standard deviation (SD). Definitions of these gait parameters are listed in Table 1.

Table 1: Gait Cycle Definitions

	Definitions
Stride time	Time from heel-strike to the next heel-strike of the same foot
Stance time	Time from heel-strike to end contact (typically toe-off)
Swing time	Time from end contact to the following heel-strike
Percent stance time	100 x stance time / stride time
Standard deviation	The absolute magnitude of the variability
Stride cycle	The movements and events that occur between successive heel strikes of the same foot. It contains the two phases of stance and swing.

For statistical analysis the distribution of all data was first tested for normality. For normally distributed data, analysis of variance (ANOVA) was used to test for significant differences between the three groups. Post-hoc multiple t-test comparison was then performed to determine which groups were significantly different and

[1] Biomedical Monitoring Ltd., Wolfson Centre, Glasgow, G4 ONW, U.K.

[2] MATLAB, The Mathworks Inc., 24 Prime Park Way, Natick, MA, USA

a Bonferroni correction was applied to adjust for the problem of inflating the type-I error. For non-normal data the Kruskal-Wallis test was used to test for statistical difference between the three groups. For pair-by-pair comparison Mann-Whitney U tests were used. An α level of $p \leq 0.05$ was used as the level of statistical significance. All statistical analyses were performed using SPSS 10[3] for Windows.

Results

On average both faller groups were older than the control group. When statistically analysed this was shown to be significant only for the OH fallers and the control group (p=0.039). Table 2 displays the subjects' ages.

Table 2: Subjects' Ages

Age (yrs)	OH fallers	NOH fallers	Control
Mean (SD)	77 (8)	76 (5)	69 (5)

Table 3 summarises the mean values of the temporal parameters of gait obtained from the footswitches. Table 4 displays the statistically different pairs.

Table 3: The Mean Values of the Temporal Parameters of Gait for the Groups.

Variable	OH fallers	NOH fallers	Controls (C)
Stride time (s)	1.41	1.40	1.11
Stance time (s)	0.76	0.80	0.56
% Stance time	53	54	42
Speed (m/s)	0.68	0.58	1.15

Table 4: Significantly Different Groups and p-Values for the Temporal Parameters of Gait. (* denotes near significance).

Variable	Significantly Different Pairs	p-values
Stride Time	Controls v OH Fallers Controls v NOH Fallers	p=0.004 p=0.028
Stance Time	Controls v OH Fallers Controls v NOH Fallers	p=0.000 p=0.010
% Stance Time	Controls v OH Fallers Controls v NOH Fallers	p=0.109* p=0.089*
Speed	Controls v OH Fallers Controls v NOH Fallers	p=0.004 p=0.001

Mean stride times of the OH fallers and the NOH fallers were significantly longer than the control group. This was reflected in the swing time and stance time results with both phases of the stride cycle proving to be significantly longer for the OH fallers and NOH fallers when compared to controls. Consequently both faller groups were found to walk significantly slower than the control group.

Percent stance time showed that both the OH and NOH faller groups spent a greater proportion of the gait cycle with the foot in contact with the ground than did the control group with the differences nearly reaching significance for both groups (p=0.109, p=0.089) when compared with the controls (Table 4).

Table 5 summarises the variability results (standard deviation SD) of the temporal gait data obtained from the footswitches. Table 6 shows the statistically significant pairs.

Table 5: The Mean Values of the Variability of the Temporal Parameters of Gait for the Groups.

Variable	OH fallers	NOH fallers	Controls (C)
Stride Time SD	0.094	0.112	0.045
Stance Time SD	0.06	0.06	0.04
Swing Time SD	0.058	0.067	0.028
Percent Stance SD	1.63	3.47	1.58

Table 6: Significantly Dfferent Groups and p-Values for Gait Variability Measures. (* denotes near significance).

Variable	Significantly Different Pairs	p-values
Stride Time SD	Controls v OH Fallers Controls v NOH Fallers	p=0.010 p=0.004
Stance Time SD	Controls v NOH Fallers	p=0.006
Swing Time SD	Controls v OH Fallers Controls v NOH Fallers	p=0.079* p=0.008

On average, both faller groups displayed greater variability than the control group. This increased variability was found to be statistically significant for stride time and swing time when compared to controls. Significant difference was also noted between the NOH fallers and the control group for stance time variability. Percent stance time variability did not reach significance between groups (Table 6).

Discussion

Orthostatic hypotension has a high prevalence in the elderly and is an important risk factor for falls in the elderly with its symptoms of dizziness, weakness and blurred vision. Using footswitches the temporal parameters of gait can be measured. Variability from stride to stride, can then be calculated as a reflection of inconsistency and irregularity of gait. Hausdorff et al. have shown that gait variability is associated with falling in the elderly. They have shown that all measures of gait variability were significantly greater in elderly fallers compared to both elderly non-fallers and healthy

[3] SPSS Ltd., 1st Floor, St. Andrews House, West Street, Woking, Surrey, GU21 1EB, U. K..

controls (Haussdorff et al., 1997). In prospective studies, both Hausdorff et al. (Hausdorff et al., 2001) and Maki (Maki, 1997) have proven that gait variability is a predictor of falls. Certain medical conditions are also associated with an increased risk of falling and significantly greater gait variability has been found in subjects with conditions such as congestive heart failure, Parkinsons disease and Huntington's disease when compared with controls (Haussdorff et al., 1998; Haussdorff et al., 1994).

In this study we evaluated the gait variability of older adult fallers who were falling due to Orthostatic Hypotension (OH) and compared it to the gait variability of older adult fallers without OH and a healthy control group of older adult non-fallers. Using footswitches we examined the stride-to-stride variability, using standard deviation (SD) of stride time, stance time, percent stance time and swing time.

It is considered that persons with OH fall as a result of transient cerebral hypoperfusion causing loss of consciousness, loss of postural tone or unsteadiness rather than any persistent musculoskeletal cause. Therefore, assuming this, their gait pattern would not be similar to that of regular fallers but instead would resemble that of the controls. We postulated that due to repeated episodes of cerebral hypoperfusion there might be persistent neurological effects, which could modify neural outflow causing subtle gait abnormalities in patients with OH.

The results showed that overall both faller groups were found to walk at a significantly slower speed than the controls. This confirms results of previous studies on elderly fallers (Cho & Kamen, 1998; Guimares & Isaacs, 1980) and is considered to be a conservative measure or adaptation to improve gait stability.

Percent stance time showed that both faller groups also spent a greater proportion of the gait cycle with the foot in contact with the ground compared to the control group. The stance phase is perceived as the more stable part of the gait cycle. Reduced walking speed and spending a greater proportion of the gait cycle in the stance phase are gait adaptations that are frequently observed in fallers (Guimares & Isaacs, 1980; Maki, 1997). It has been suggested that these may be compensatory measures related to fear of falling (Maki, 1997).

On average, both faller groups displayed greater variability in all tempero-spatial parameters measured compared to the control group. Variability in gait is a known predictor of falls. This study has documented that fallers with OH have significantly greater gait variability compared to controls. This finding supports the hypothesis that fallers with OH have subtle underlying gait abnormalities, which may be as a result of permanent neurological damage due to repeated episodes of cerebral hypoperfusion.

Falls are a leading cause of accidental death in the elderly. Common consequences of falling include significant injury, fractures, hospital admission and fear of recurrence (Maki & Fernie, 1996). There is a huge cost associated with falls, with the cost of hip fractures alone in the United Kingdom estimated at 726 million pounds per annum (Parrot, 2000). Furthermore, fear of falling can result in a loss of confidence, restricting domestic and social activities, leading to isolation and loneliness (Tinetti et al., 1994). Therefore, any preventative measures that can be undertaken to reduce falls and fall risk in the elderly have many health and economic benefits.

Patients presenting with OH are normally solely treated with medication for improving the symptoms of OH. This study has revealed biomechanical irregularities in addition to the known vascular abnormalities of this group. Treatment procedures may now need to incorporate physiotherapy and participation in falls prevention programmes in an effort to further reduce the risk of falling in this vulnerable group.

A limitation of this study are the low numbers involved, therefore, these analyses are just exploratory and would need to be confirmed in a definitive more highly powered study in the future.

Conclusion

This pilot study demonstrates that like conventional fallers, measurable gait abnormalities also occur in those who fall due to OH that may further increase their risk of falling. This technique is clinically feasible as the instrumentation is portable allowing gait assessments to be conducted in a range of hospital and rehabilitation settings.

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ISSN: 1727-1983