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ACCURACY OF POSTURAL SWAY IN GAIT MEASURED WITH ACCELEROMETERS

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SUMMARY

Falls often occur during ambulation. Measuring postural sway during walking may further our understanding of why some older people fall. Scale differences make it impractical to measure postural sway (in centimetres) while walking over extended distances with optical motion capture. Direct measurement of three-dimensional linear displacement in remote settings may be best achieved with accelerometers. We used accelerometer data to measure and visualise small linear displacements relative to a moving base of support while walking. Agreement between the accelerometer system and an optical system was moderate to excellent (ICC(2,1) 0.77 to 0.99).

INTRODUCTION

In laboratory settings, the relationships between the pelvis and lumbar spine angular displacements have been measured during walking with optical motion capture [1]. Centre of mass displacements during walking have also been measured with optical motion capture [2, 3], an extended force platform [4], an instrumented treadmill [5], and with shoes fitted with force platforms [6].

Accelerometer data have previously been integrated to obtain vertical displacements in gait and these measures have then been used to predict step length using various inverted pendulum models [7-9]. Alternatively, band-pass filtering has been proposed as a method to obtain vertical foot displacements from accelerometer data [10]. High pass filtering with a very low cut-off frequency (0.1 Hz) has also been proposed as a method of obtaining horizontal pelvis displacements [11].

Finally, gyroscopes have also been used to measure angular displacement of the trunk during gait [12]. During gait angular displacement of the trunk is measured relative to the nearest (lumbar) joint centre.

Using accelerometers only, here we investigate how to best measure linear displacements relative to the moving base of support in three dimensions.

METHODS

Thirteen healthy people, 9 female and 4 male participated; mean age 32 ±6 years, height 169 ±10cm, and weight 63 ±16Kg. Each participant completed 2 walks at self-selected fast, normal and slow walking speeds over a 5.76 meter GaitRite mat. Two walks were rejected because of missing data leaving a total number of 76 walks for analysis. Tri-axial accelerometers were attached to the participants head and sacrum (Opal™ by APDM, sampling frequency 128Hz). Pilot data were collected simultaneously with an optical motion capture system (OptiTrack by NaturalPoint, sampling frequency 100Hz).

While walking, changing sensor orientation could cause acceleration associated with gravity to swamp 'true' horizontal acceleration. Therefore, a continuously changing pitch and roll correction was used to obtain the corrected acceleration ($\mathbf{A}_{\mathbf{Corr}}$, Equation 1). Assuming zero mean global acceleration over the walk, the correction matrix (**R**) was found by low-pass filtering the measured acceleration (**A**) with a cut-off of 0.25 times the step frequency.

Equation 1: $$\mathbf{A}_{\mathbf{Corr}} = \mathbf{RA}$$

Relative displacement from the accelerometers (Figure, dotted lines) was found by twice integrating the corrected acceleration ($\mathbf{A}_{\mathbf{Corr}}$). Data were filtered using a high-pass 4th order Butterworth filter. The cut-off frequencies depended on the sensor axes and step frequency (Fo)

1. Head and sacrum anterioposterior (AP) and vertical (VT) cut-off; 0.5×Fo
2. Sacrum mediolateral (ML) cut-off; 0.25×Fo
3. Head ML cut-off; 0.43×Fo

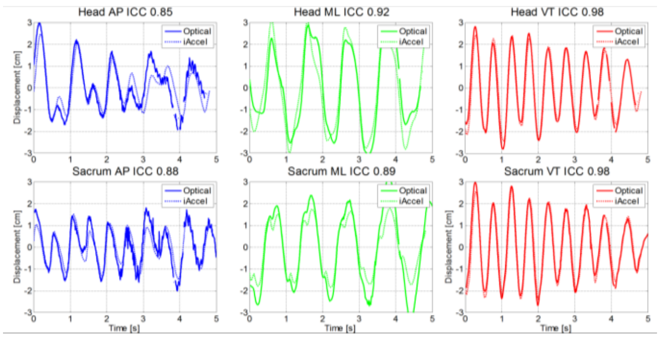

Figure 1: Comparison of relative displacement during normal walking as measured by optical motion capture (solid lines) and accelerometers (dotted lines).

The optical option capture system used 6 cameras in pairs, each side of the walkway. The optical relative displacement (Figure 1, solid lines) was found by high-pass filtering to remove global movements. The root mean square statistic (RMS) was used to quantify the magnitude of each parameter in the AP, ML and VT axes. Optical measurement of relative displacements during gait was compared to accelerometer measurement of relative displacement during gait. The intra-class correlation co-efficient for criterion referenced reliability ICC(2,1) was used.

RESULTS AND DISCUSSION

Postural sway while walking was measured accurately with accelerometers. Agreement was good between RMS displacement measured by optical motion capture and that calculated by integrating accelerometer data (ICC 0.76 to 0.99, Table 1). Agreement was best along the vertical axis.

Relative displacements may be conceptualised as similar to global head and sacrum movements if the participant were walking on a treadmill. In healthy walking they appear to sweep out a highly regular and controlled pattern through space (Figure 2).

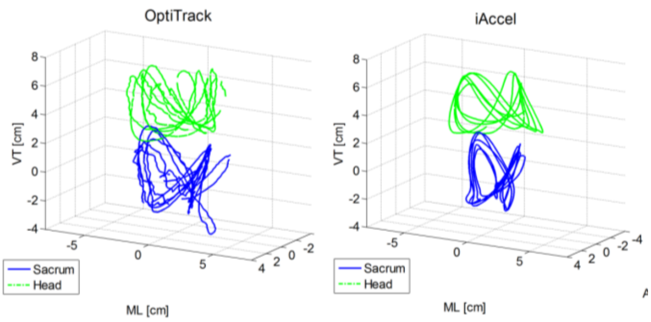

Figure 1: Displacement of the head and sacrum relative to the moving base of support. Optical measurements (left panel) contain more noise. The head trajectory is off-set 5cm vertically.

The range of RMS displacements we observed (see Table 1) agrees with previously reported ranges for lower trunk, pelvis, and centre-of-mass displacements. Vertical excursions of the center-of-gravity from 3.88cm to 5.53cm were previously measured with an accelerometer attached close to the L3 vertebra [7]. Harmonic decomposition was also used to obtain the amplitude of first harmonic of ML pelvis displacement; from 1.5cm to 2.7cm [11].

Centre of mass excursions have been previously calculated using optical analysis and a 15 segment kinematic model [3]. That study reported excursions from 3.85cm to 6.99cm along the ML axis, and from 2.74cm to 4.83cm along the VT axis. Our measurements are also within the ranges of centre of mass displacements reported using an instrumented treadmill [5] and pelvis motion measured using an instrumented treadmill in combination with optical motion capture [8].

CONCLUSIONS

Postural sway while walking can be measured accurately with accelerometers. The highly regular cyclic sway patterns were successfully visualised using three-dimensional cyclograms (Figure 2). Displacements were presented relative to the moving base of support. We are currently investigating how relative displacement patterns change with increased age and frailty.

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Table 1: The observed 95% range of RMS displacements measured by accelerometers. Agreement between the optical and accelerometer systems for the RMS magnitude of sway.

	Relative Sacrum Displacement			Relative Head Displacement		
	AP	**ML**	**VT**	**AP**	**ML**	**VT**
RMS sway, 95% Range [cm]	0.36 - 1.83	0.66 – 5.81	0.33 – 2.81	0.19 – 2.57	0.40 – 6.96	0.36 – 2.81
Agreement of RMS values [ICC]	0.82	0.81	0.99	0.77	0.92	0.99