Correlation of accelerometry with clinical balance tests in older fallers and non-fallers

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Abstract

Background: falls are a common cause of injury and decreased functional independence in the older adult. Diagnosis and treatment of fallers require tools that accurately assess physiological parameters associated with balance. Validated clinical tools include the Berg Balance Scale (BBS) and the Timed Up and Go test (TUG); however, the BBS tends to be subjective in nature, while the TUG quantifies an individual’s functional impairment but requires further subjective evaluation for balance assessment. Other quantitative alternatives to date require expensive, sophisticated equipment. Measurement of the acceleration of centre of mass, with relatively inexpensive, lightweight, body-mounted accelerometers is a potential solution to this problem.

Objectives: to determine (i) if accelerometry correlates with standard clinical tests (BBS and TUG), (ii) to characterise accelerometer responses to increasingly difficult challenges to balance and (iii) to characterise acceleration patterns between fallers and non-fallers.

Study design and setting: torso accelerations were measured at the level of L3 using a tri-axial accelerometer under four conditions; standing unsupported with eyes open (EO), eyes closed (EC) and on a mat with eyes open (MAT EO) and closed (MAT EC). Older patients (n = 21, 8 males, 13 females) with a mean age of 78 (SD ± 7.6) years who attended a day hospital were recruited for this study. Patients were identified as fallers or non-fallers based on a comprehensive falls history.

Measurements: Spearman’s rank correlation analysis examined the relationship between acceleration root mean square (RMS) data and the BBS while Pearson’s correlation was used with TUG scores. Differences in accelerometer RMS between fallers and non-fallers and between test conditions were examined using t-test and non-parametric alternatives where appropriate.

Results: there was a stepwise increase in accelerometer RMS with increasing task complexity, and the accelerometer was able to distinguish significantly between sway responses to all test conditions except between EO and EC (P < 0.05). Acceleration data for MAT EO were significantly and inversely correlated with BBS scores (r = −0.829, P < 0.001) and positively correlated with TUG values (r = 0.621, P < 0.01). There was a significant difference in acceleration RMS for MAT EO between fallers and non-fallers (P < 0.011).

Conclusions: this is the first study of its kind to show a high correlation between accelerometry, the BBS and TUG. Accelerometry could also distinguish between sway responses to differing balancing conditions and between fallers and non-fallers. Accelerometry was shown to be an efficient, quantitative alternative in the measurement of balance in older people.

Keywords: older people, falls, accelerometers, Berg Balance Scale, Timed Up and Go, elderly

Background

Falls present a substantial health problem among the older population. Approximately one-third of community-dwelling people over 65 years of age will experience one or more falls each year [1]. Clearly this problem deserves clinical attention, especially owing to recent global demographic trends towards increased life expectancy. In Ireland alone, there are approximately 650,000 people over 60 years of age and this number is estimated to increase to 892,000 by 2020 [2].

Fall prevention strategies are most effective if the person at risk can be identified before injury occurs [3]. Risk
identification tools that accurately measure physical performance and postural control are thus essential [4]. Current clinical assessment of balance is complicated by the lack of reliable, objective, inexpensive, simple and time-efficient tests. Clinical testing can in parts be subjective, but there are benefits to be gained from examination of postural control and balance in a more quantitative manner. Many of these tests described in the literature are impractical for a clinic, as they may require sophisticated equipment or are time-consuming and expensive to administer [5]. Most researchers using quantitative measurements to assess static postural sway have used force platforms [6].

It has been noted while using force platforms that older people have increased postural sway regardless of falls history [6]. Postural sway is believed to have an important role in the control of standing balance and many indicators of it have been proposed; most notably, these are the excursions of the body centre of mass (COM) or the centre of pressure (COP). However, the implication that the body sways as a single link with all its mass concentrated at the force platform may not always be valid. The resultant COP measurements may not be reliable and the equipment can be both cumbersome and non-portable [7]. Panzer et al. [8] demonstrated in their study of quiet standing that changes in COP movements were not always associated with corresponding changes in the COM, suggesting a change in postural control strategy rather than balance impairment. There has been some confusion in the literature regarding the interpretation of movements of COP relative to movements of the COM in standing [9]. Horizontal acceleration of body COM should be proportioned to the difference between COP and COM which has been suggested to be an error signal that the body’s balance control system is sensing [10]. Acceleration of COM may therefore be a more adequate measure of balance than parameters derived from the displacement of COP alone as measured by a force platform [9]. In this investigation a reference point over the lumbar spine was chosen, as this was believed to be a good estimation of the COM. It is assumed that this point can be used in place of COM, as a point moving parallel to the COM produces the same results for velocity, displacement and acceleration [9].

Accelerometers have been proposed as a quantitative measure of balance and offer a practical and low-cost alternative to force plates [11]. They have been tested for both precision and accuracy [12]. Accelerometers have been shown to have the ability to significantly detect the differences between test conditions, young and older subjects and between fallers and non-fallers [7, 13–16]. They have also been found to be a reliable method for the measurement of balance during standing and walking, with high absolute test–retest reliability [17]. Accelerometry has been demonstrated to be more sensitive in the ability to detect the difference between more balance challenging conditions than a force plate [16]. There has been some research comparing accelerometry to clinical balance tests including Romberg’s test and functional reach, and it has been found to be far superior to these tests in the ability of distinguishing fallers from non-fallers [13]. The Berg Balance Scale (BBS) and the Timed Up and Go (TUG) are two of the more validated tests in use clinically. However, to the author’s knowledge there has been no study to examine if there are any correlations between accelerometry and these tests in an older population.

The aim of this study was (i) to examine if a correlation exists between accelerometry-derived variables and the BBS and TUG in older adults, (ii) to characterise accelerometer responses to increasingly difficult challenges to balance and (iii) to explore accelerometer patterns in fallers and non-fallers.

**Methods**

**Subjects**

Older patients ($n=21$, 8 males, 13 females) with a mean age of 78 (SD ± 7.6) years who presented to physiotherapy in a geriatric day hospital, St James Hospital, Dublin, were recruited prospectively for this study. Details of the study were explained to the patients and consent forms were signed as approved by St. James Hospital/Adelaide Meath incorporating the National Children’s Hospital ethics committee. The sequence of testing was randomly allocated in order to minimize any learning effects and subjects were either assessed by BBS and TUG or accelerometry before crossing over to the other test. Past medical history and falls history over the previous year were also obtained. Patients who needed assistance to mobilise or could not follow simple commands and those with recent neurological impairment were excluded from the study.

**Accelerometer**

A 1.5 g tri-axial accelerometer (ActivPal Trio™) sampling at a frequency of 100 Hz with a sensitivity of 0.004 g and embedded flash storage of 8 MB was used. Prior to mounting the accelerometer, a calibration protocol was performed according to the technique used by Ferraris et al. [18]. These data were later used to calibrate accelerometer data. The accelerometer was then affixed to the lumbar spine at the approximate level of L3 with hypoallergenic reusable adhesives (PalStickies™). The accelerometer was aligned in the medio-lateral plane using a small spirit level to minimize alignment errors.

**Testing protocol**

A pilot study was carried out on six patients using different test conditions to assess suitability of test battery. These data were not included in the final results. Based on these initial data it was decided to measure torso accelerations using four paradigms:

- Standing with eyes open on firm ground (EO).
- Standing with eyes closed on firm ground (EC).

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"Correlation of accelerometry with clinical balance tests in older fallers and non-fallers"
Standing on a compliant foam mat (Airex®) with eyes open (MAT EO).

Standing on a compliant foam mat with eyes closed (MAT EC).

These tasks provided a range of postural stability challenges suitable for the clinical population of interest and were safe and efficient to administer in a clinical environment. Each task was performed once in normal footwear, during which feet were positioned 10 cm apart and positions held for 30 s.

Clinical balance tests
Each patient was assessed using the BBS and the TUG. Accelerometers were not used during these tests. Order of testing was randomized. The BBS is a 14-item scale with proven reliability to measure balance in the older adult. It involves 14 different tasks that challenge balance both statically and dynamically and each task is scored out of 4, giving a maximum score of 56 [19]. The TUG also assesses physical mobility in older populations. It measures the time taken to stand up, walk 3 m, turn and return to sitting. It has good inter-rater and intra-rater reliability, respectively, and is a valid and sensitive (87% sensitivity and specificity) measure of functional mobility [20].

Accelerometer data analysis
Accelerometer data collected during testing were analysed using in-house custom written software using Matlab®. Accelerometer voltages were calibrated and transformed to acceleration values using the method described by Ferraris et al. [18]. This enabled us to compare torso accelerations measured between individuals and validate our measurements against previously published data [12]. Since RMS values are dependent on the magnitude of measured accelerations, a further correction algorithm was then employed to correct static accelerations due to misalignment of the accelerometer axes and average tilt of the spine using the method of Moen-Nillson [12], although it was noted that the use of the spirit level removed a large proportion of static tilt errors. These data were further detrended using a second-order polynomial fit to remove very low frequency drift artefact. Five seconds of data at the beginning and end of each record were discarded to remove transient setup noise and bias resulting in 20 s of data for each task. The instantaneous resultant acceleration vector \( \mathbf{A}_r \) was derived by combining accelerations measured in the medio-lateral \( (a_x) \), vertical \( (a_y) \) and anterior–posterior \( (a_z) \) planes by standard vector addition given by

\[
\mathbf{A}_r = \sqrt{a_x^2 + a_y^2 + a_z^2}. \tag{1}
\]

The 20 s root mean square (RMS) value was found for each task according to equation (2):

\[
RMS = \sqrt{\frac{\sum_{i=1}^{n} A_i^2}{n}}. \tag{2}
\]

The differences in RMS values (measured in g, where 1 g = 9.8 m/s\(^2\)) between tasks were also found to examine whether the accelerometer could distinguish between patient responses to various tasks.

Statistical analysis
Preliminary analyses were performed to ensure that subject data did not violate the assumptions of normality and linearity, which included histogram visualisation and calculation of one-sample Kolmogorov–Smirnov and Shapiro–Wilks tests for normality. Spearman’s rank correlation coefficient \( \rho \) was used to investigate the relationship between accelerometer-derived measures of balance and the ordinal BBS using SPSS®, while Pearson’s product-moment correlation analysis \( \rho \) was performed to examine the relationship to ratio level TUG scores. Differences between fallers and non-fallers and differences between RMS values derived from different tasks were examined using \( t \)-tests, and non-parametric alternatives (Mann-Whitney \( U \)-test, Wilcoxon rank-sum test) where appropriate. Statistical results were assumed to be significant at a level of \( P < 0.05 \).

Results
Four subjects were excluded from analysis as complete accelerometer data were unavailable for one subject and data for three other subjects were disregarded, as they had to be steadied during testing on the mat. Of the 17 remaining subjects, the mean age was 77 ± 7.5 years (8 males; 9 females). The mean BBS score was 46 ± 6 and the mean TUG was 21 ± 8 s. Preliminary analyses indicate data sets obtained when dichotomised into fallers and non-fallers to be normally distributed during EO \( (P = 0.2) \), EC \( (P = 0.2) \), MAT EO \( (P = 0.106) \) and BBS tasks \( (P = 0.2) \) and to be non-normally distributed for MAT EC \( (P < 0.0001) \) and TUG tasks \( (P = 0.028) \). When comparing data between tasks and thus considering data as a whole, the distributions were normal for EO \( (P = 0.2) \) and EC \( (P = 0.052) \) tasks but non-normally distributed for MAT EO \( (P = 0.007) \) and MAT EC \( (P < 0.0001) \) tasks.

Comparing RMS values between tasks
The mean RMS values for the tasks demonstrated a concomitant increase with increasing complexity and were as follows: EO = 0.025 g ± 0.0050; EC = 0.026 g ± 0.0006;
Correlation of accelerometry with clinical balance tests in older fallers and non-fallers

**Table 1. Wilcoxon signed-rank sum test results comparing RMS values between tasks (N = 17).**

<table>
<thead>
<tr>
<th>Test 1 vs. test 2</th>
<th>Acceleration differences</th>
<th>% Change from test 1</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>EO vs. EC</td>
<td>0.001 g</td>
<td>4</td>
<td>0.463</td>
</tr>
<tr>
<td>EO vs. MATEO</td>
<td>0.006 g</td>
<td>24</td>
<td>0.019*</td>
</tr>
<tr>
<td>EO vs. MATEC</td>
<td>0.017 g</td>
<td>68</td>
<td>0.001*</td>
</tr>
<tr>
<td>EC vs. MATEO</td>
<td>0.005 g</td>
<td>19</td>
<td>0.025*</td>
</tr>
<tr>
<td>EC vs. MATEC</td>
<td>0.016 g</td>
<td>61.5</td>
<td>0.001*</td>
</tr>
<tr>
<td>MATEO vs. MATEC</td>
<td>0.011 g</td>
<td>35.5</td>
<td>0.019*</td>
</tr>
</tbody>
</table>

*P < 0.05.

MAT EO = 0.031 g ± 0.0090 and MAT EC = 0.042 g ± 0.020. Table 1 demonstrates this and the ability of the accelerometer to distinguish between tasks.

**Fallers versus non-fallers**

Accelerometer RMS values for MAT EO were significantly greater in those who had a history of falls (N = 12) versus those without falls (N = 5) (0.0339 g ± 0.009 vs. 0.0262 g ± 0.004; *P = 0.029*), while RMS values for EO (0.025 g ± 0.006 vs. 0.025 g ± 0.002; *P = 0.87*), EC (0.027 g ± 0.007 vs. 0.023 g ± 0.008; *P = 0.29*) and MAT EC (0.046 g ± 0.022 vs. 0.033 g ± 0.007; *P = 0.195*) did not show significant differences between groups. No significant differences were detected for BBS (49.8 ± 5.01 vs. 44.2 ± 6.2; *P = 0.9*) and TUG (16.8 ± 4.86 s vs. 23.25 s ± 8.54; *P = 0.13*) scores between groups. However, MAT EO RMS values alone identified fallers with sensitivity of 58.3% and specificity of 80% in comparison to the BBS, which demonstrated a sensitivity of 83% with a similar specificity of 80%.

**Correlation with clinical balance scales**

MAT EO RMS scores were strongly correlated with the TUG (*r* = 0.621) and inversely correlated with the BBS (*ρ* = −0.8290). Both were statistically significant at *P < 0.01* and *P < 0.001*, respectively (see Figure 1). The other test conditions of EO, EC and MAT EC did not correlate significantly with BBS and TUG. A significant relationship was observed between BBS and TUG values (*ρ = −0.767, *P = 0.0001*).

**Discussion**

To our knowledge there have been no previous studies examining a relationship between accelerometry and clinical balance tests in the older population. As the BBS can be time consuming to administer, requires specialist training and is open to subjective error, accelerometry could be a viable alternative in the measurement of balance especially when measured on the mat with eyes open (MAT EO). In this study it was observed that BBS and TUG scores correlated significantly with each other at *ρ = −0.767*; this is similar to the correlation of *ρ = −0.76* reported by Berg et al. [21]. RMS acceleration values when measured on the mat with eyes open were negatively correlated with BBS scores, thus demonstrating convergent validity between these two stability measures. There was also convergent validity shown between MAT EO RMS and TUG, i.e. the better the balance, the faster the TUG speed (lower score) and the smaller the RMS value.

The other test conditions were not significantly correlated with these clinical tests. Standing on compliant foam produces greater sway responses than standing on firm ground [7, 13]. However, some studies report more limited movements of COP under more challenging conditions [22], which possibly explain the poor correlation of MAT EC RMS with BBS and TUG scores. In a study examining the correlation of the BBS to various force plate measures, the only one to correlate significantly was the vertical force measure (*r = −0.76*); they infer that this could be due to the BBS and the different force plate measures quantifying different aspects of human standing [23], possibly explaining the poor correlation between EO, EC and MAT EC with BBS and TUG values in our study.

Accelerometry RMS values increased as the complexity of the predetermined tasks increased. RMS values also significantly differentiated between all conditions except between EO and EC. This is in agreement with other studies that have determined the ability of accelerometry to distinguish between tasks of increasing complexity [7, 13, 14, 16]. Cho and Kamen [13] also found that standing on compliant foam produced the greatest sway responses and that the accelerometer variables of both amplitude and frequency identified differences between eyes open and eyes closed and between standing on a firm surface and mat. Mayagotita et al. [16] found that accelerometry was able to distinguish between conditions of eyes open and closed while standing on a firm surface and a mat in 19 out of 20 test conditions as compared to 16 with a force plate. Kamen et al. [7] also found that their accelerometer was able to distinguish between these various test conditions. However, results of their study have to be analysed with caution, as they did not account for tilt of the accelerometer as described in other studies [8, 12, 14]. Moe-Nilsen and Helbostad [14] in their study found that accelerometry was able to significantly discriminate between various test conditions except between that of eyes open and eyes closed. This was a similar result to our study. They infer that these two balance tasks only represent a marginally different challenge to balance control and that this difference is difficult to detect. In our study subjects stood with their feet apart which increased medio-lateral stability. The mean BBS score of 46 of this study population also represents a relatively high functioning group and the ability to maintain balance between eyes open and eyes closed should be well within their control. These arguments seem to agree with those of Geurts et al. [24], who examined the movement of COP under a variety of conditions and only found the antero-posterior direction to be sensitive to visual obstruction when standing with feet well apart. This would imply that accelerometry is able to distinguish between various test conditions and thus establishes criterion validity.
To identify those at risk of falls, tools that correctly measure physical performance are essential [4]. In this study, accelerometry RMS values of MAT EO were significantly different between fallers and non-fallers. This further establishes criterion validity. This concurs with other studies of which accelerometers were also able to discriminate between both young and older groups [7, 14] and between fallers and non-fallers [8, 13–15]. However, the inability of BBS to also detect this difference despite its higher sensitivity and specificity requires investigation. One possible explanation is that the BBS displays less variance but smaller difference in means between groups than the MAT EO RMS values. This could explain the higher sensitivity and specificity but non-significant difference between means recorded. An overlap between groups using RMS values alone results in relatively poor sensitivity of 58.3% compared to BBS of 83%. Future work should be aimed at improving the sensitivity of this approach by incorporating more advanced signal analysis techniques [13] and modifying the protocol to include alternative dynamic balance tasks such as step standing and walking.

This is the first study of its kind to show a high correlation between accelerometry, the BBS and TUG in older adults. On the basis of these results, we conclude that accelerometer-based measures hold potential as the basis of an efficient, quantitative alternative in the measurement of balance in older people. We would suggest that this technique with refinement could be used clinically to complement the more detailed BBS. RMS values initially could be used to track balance training progression following an initial BBS measurement. The technique could be used as a quick BBS estimate for clinicians where time is critical and thus be of particular benefit in GP clinics, busy out-patient departments and day hospitals. Future work would thus be aimed at further establishing the clinical significance of these exploratory results.

Key points
- Clinical assessment of balance is complicated by the lack of reliable, objective, inexpensive, simple and time-efficient tests. Accelerometers have been proposed as a quantitative measure of balance and offer a practical and low cost alternative to force plates.
- Our findings support this theory as accelerometer data when standing on a compliant foam mat with eyes open correlated significantly with both the Berg Balance Scale and the Timed Up and Go.
- In agreement with other studies, accelerometry data in this study were able to distinguish between responses to different test conditions and between fallers and non-fallers.

Conflicts of interest
There were no conflicts of interest.

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