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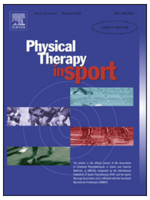

Original research

The within-day and between-day reliability of using sacral accelerations to quantify balance performance

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ABSTRACT

Objectives: To investigate the between-day and within-day reliability of a sacral mounted accelerometer to quantify balance performance and different balance metrics.
Design: Experimental, cross-sectional.
Setting: Laboratorial experiment.
Participants: Thirty healthy volunteers.
Main outcome measures: Balance tasks were double leg stance, tandem stance and single leg stance with eyes open and closed. Performance was measured by converting accelerations into path length (PL, length of the sway trace), jerk (jerkiness of sway trace) and root mean square (RMS) of the accelerations.
Results: Within-day ICC for PL were excellent (mean 0.78 95%CI 0.68–0.89), with Jerk and RMS demonstrating means of 0.60 and 0.47, respectively. The mean percentage minimal detectable change (MDC) within-day were small for PL (mean 6.7%, 95%CI 5.3–8.1).
Between-day ICC were good for PL (mean 0.61, 95%CI 0.50–0.71), but more varied for Jerk and RMS. The mean percentage MDC was small for PL (mean 6.1%, 95%CI 5.0–7.2). No significant differences were determined for measurements between-days for any metric or task. PL had the highest discriminatory value between the 8 tasks.
Conclusions: The sacral mounted accelerometer reliably measured balance performance within- and between-days. The PL is the recommended metric as it was the most reliable, most discriminatory and most sensitive to change.

1. Introduction

Balance measurement has traditionally focused on the determination of postural sway quantified by tracking the trajectory of the centre of pressure (COP). This commonly requires the use of expensive laboratory mounted force plates (Mancini, Salarian, Carlson-Kuhta, Zampieri, King, & Chiari, 2012). Clinicians often measure balance using crude measures such as time spent on one leg or star excursion balance test (Coughlan et al., 2014; O'Sullivan, Blake, Cunningham, Boyle, & Finucane, 2009). These measures provide limited detail about the quality of performance. Clinicians are therefore faced with a challenge of obtaining detailed objective information regarding balance performance without being constrained to a laboratory environment.

Body mounted sensors, such as accelerometers, have been suggested as an alternative balance measurement method (Moe-Nilssen, 1998a, 1998b; Moe-Nilssen & Helbostad, 2002). These sensors are capable of measuring linear acceleration along each sensing axis and when attached close to the body's centre of mass (COM) have the ability to measure acceleration of the body's COM. This has been suggested as a viable method to quantify balance (Moe-Nilssen 1998). Studies comparing the traditional force plate measures with the accelerometer method have shown promising results. However the two methods measure balance in unique ways. Force plates are usually employed to measure the behaviour of the COP, which represents the point location of the vertical ground reaction force vector (Winter, 1995). However changes in COP do not always correspond to change in the position of the body's COM (Winter, 1995). Accelerometers, on the other hand, measure acceleration of the COM and therefore describe the body's attempt to control movement of the COM (Adlerton, Moritz, & Moe-Nilssen, 2003). As the two devices measure different metrics

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they are not necessarily interchangeable, however the correlation of the attempts to maintain balance are good (Mancini et al., 2012; Mayagoitia, Lotters, Veltink, & Hermens, 2002; Whitney, Roche, Marchetti, Lin, Steed, & Furman, 2011). Therefore it may be possible to obtain sway signatures using the accelerometer method which has distinct advantages over the force plate method for the clinician being smaller, cheaper and not constrained to a specific environment.

There are a few technical issues around the use of accelerometers for measuring postural sway. Body-worn sensors are unlikely to be mounted perfectly to the horizontal and vertical resulting in an element of sensor tilt. This tilt affects the output of the accelerometer as acceleration due to gravity is an intrinsic component of the sensor output. This aspect needs addressing in order to resolve the true accelerations. This can be overcome by registering the degree of tilt of the sensor and using this to remove the gravity component of the sensor output. This method has been successfully applied in previous research involving accelerometers (Moe-Nilssen, 1998a; Morgado-Ramirez, Strike, & Lee, 2013; Williams & Cuesta-Vargas, 2014) and accelerometers have successfully been used to quantify balance in older persons who fall (Doheny et al., 2012), children with dyslexia (Moe-Nilssen, Helbostad, Talcott, & Toennessen, 2003) and those with Huntington's disease (Dalton, Khalil, Busse, Rosser, van Deursen, & Olaighin, 2013), Parkinson's disease (Mancini, Horak, Zampieri, Carlson-Kuhta, Nutt, & Chiari, 2011) and Vestibular disorders (Marchetti, Bellanca, Whitney, Lin, Musolino, & Furman, 2013).

More recently these devices have been designed so that data is presented in a usable format for clinicians and as such could be used in every day practice. However, there is still a requirement to explore the reliability of these devices. Test-retest reliability for various stance tasks, including double leg stance (ICC 95% confidence interval (CI) = 0.35–0.89; Mancini et al., 2012), single leg stance (ICC 95%CI = 0.62–1; Moe-Nilssen, 1998b) and tandem stance tasks (ICC 95% CI = 0.75–0.89) have been reported. These values represent the combination of biological (human) and equipment (sensor) variability and the spread of the confidence intervals demonstrate the inherently variability in human movement. Furthermore different specific metrics have been used to quantify performance from the acceleration data. Whitney et al. (2011) demonstrated that the path length (PL), a measure of the length of the mediolateral acceleration data plotted against the anteroposterior acceleration data, was the most reliable measure across a range of balance tasks (ICC range 0.63–0.80). Mancini et al., (2012) also reported that PL was the most reliable balance performance metric however also suggested Jerk, the time derivative of acceleration, was reliable, a finding supported by Marchetti et al., (2013). In addition to PL and jerk, previous authors have also reported the root mean square value (RMS) as a method of quantifying postural sway. Reliability estimates of 0.51–0.81 have been reported (Mancini et al., 2012; Moe-Nilssen, 1998b) for double leg stance and single leg stance. It would appear that PL, Jerk and RMS are the most commonly reported metrics to quantify balance measured using an accelerometer, with previous studies demonstrating their reliability. Previous studies have not investigated these metrics across a wide range of balance tasks or investigated the between-day reliability of such a method. It is suggested that before such a method can be accepted in clinical practice a better understanding of the variability of repeated testing, within and between-day, is required along with the computation of the minimal detectable change (MDC). These values will then enable clinicians to interpret changes in balance performance to go beyond that expected from normal human variability.

The aim of this study was to determine the within-day and between-day repeated measures reliability of a novel device for measuring balance within a clinical setting, along with the determination of minimal detectable change values across a series of balance tasks.

2. Methods

This study employed an experimental cross-sectional test retest study design.

2.1. Participants

Thirty participants were recruited from the student population within Bournemouth University. All participants were free from any musculoskeletal or neurological disorders or any other conditions which may affect their balance. Bournemouth University ethics committee granted the study ethical approval and all participants provided informed written consent to participate in the study. Mean (sd) age was 28.8 (8.7) years, height 1.71 (0.1) m, weight 73.4 (15.3) kg and 18 were female. A smaller sample of seven was asked to return the following day to repeat the tasks and explore the between-day reliability (mean (sd) age 24.9 (4.8) years, height 1.75 (11.5) m, weight 75.0 (15.3) kg). This value was calculated by declaring an acceptable correlation coefficient of 0.75, with alpha as 0.05 resulting in the required sample size, to achieve a power of 0.8, of 7 as calculated by Gpower (3.0).

2.2. Instrumentation

A commercially available balance sensor (THETAmetrix, Waterlooville, Hampshire, UK) was used to quantify balance. The sensor's dimensions were 73 mm × 45 mm × 19 mm and weight 58 g. The sensor houses a triaxial accelerometer and triaxial rate gyroscope which communicate wireless to a PC. The accelerometer measures linear acceleration along its sensing axes while the rate gyroscope quantifies rate of turn about its sensing axes. The company supplied software uses both sensing elements to overcome the limitations of using an accelerometer in isolation (outlined in the introduction), namely the dynamic correction for sensor tilt and removal of the gravity component of the signal. Therefore the software calculates orientation independent linear acceleration at 16 Hz. With the sensor attached to the skin over the sacrum this acceleration data represents the small adjustments used to maintain balance i.e. the postural sway of the sacrum.

2.3. Procedure

Participants' height (Seca 274 Stadiometer, Seca, UK) and weight (Seca 761 Mechanical Scales, Seca, UK) were measured and the balance sensor was attached to the skin over the spinous process of S2 using double sided tape. This location was chosen as it is close to the centre of mass of the human body (Kim, Kim, Kim, Hwang, & Han, 2013; Mancini et al., 2011; Whitney et al., 2011). All participants wore self-selected training shoes throughout as this reflects function and clinical practice. Eight balance tasks were completed, namely double leg stance, feet naturally apart with eyes open (DLSFNEO); double leg stance feet naturally apart with eyes closed (DLSFNEC); double leg stance, feet together with eyes open (DLSFTEO); double leg stance, feet together with eyes closed (DLSFTEC); tandem stance (right foot in front of the left) eyes open (TandEO); tandem stance eyes closed (TandEC); single leg stance with eyes open (SLSEO) and single leg stance with eyes closed (SLSEC). Participants were instructed to stand and maintain balance as best they can. Participants stood on a line positioned 2 m from the wall and were asked to look at a wall marker 1.7 m high