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Short communication

A point of application study to determine the accuracy, precision and reliability of a low-cost balance plate for center of pressure measurement

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ABSTRACT

Changes in postural sway measured via force plate center of pressure have been associated with many aspects of human motor ability. A previous study validated the accuracy and precision of a relatively new, low-cost and portable force plate called the Balance Tracking System (BTrackS). This work compared a laboratory-grade force plate versus BTrackS during human-like dynamic sway conditions generated by an inverted pendulum device. The present study sought to extend previous validation attempts for BTrackS using a more traditional point of application (POA) approach. Computer numerical control (CNC) guided application of ~155 N of force was applied five times to each of 21 points on five different BTrackS Balance Plate (BBP) devices with a hex-nose plunger. Results showed excellent agreement (ICC > 0.999) between the POAs and measured COP by the BBP devices, as well as high accuracy (<1% average percent error) and precision (<0.1 cm average standard deviation of residuals). The ICC between BBP devices was exceptionally high (ICC > 0.999) providing evidence of almost perfect inter-device reliability. Taken together, these results provide an important, static corollary to the previously obtained dynamic COP results from inverted pendulum testing of the BBP.

1. Introduction

The innate ability of humans to stand upright without falling (i.e. balance) relies on the control of "postural sway". Postural sway is biomechanically defined as sustained oscillatory motion about a fixed postural position in the presence of gravity (Hellebrandt and Braun, 1939). The importance of postural sway was first underscored in the mid-1880s by famed neurologist Moritz Romberg (see Pearce, 2005 for review). Today, postural sway is routinely-assessed as an indicator of poor performance on activities of daily living (Era et al., 1997), high fall risk (Pajala et al., 2008; Thapa et al., 1996) and elevated potential for sport injury (McGuine and Greene, 2000).

For decades, force plates have been a well-recognized means of assessing postural sway. Force plates determine a metric called center of pressure (COP), representing the weighted average location of the ground reaction forces. During quiet standing, COP is correlated with changes in a person's center of gravity and, thus, their postural sway (Browne and O'Hare, 2000). While COP is a sensitive and objective measure of postural sway, the use of force plate-guided balance testing is not currently widespread. This is likely due to the lack of portability, and high cost (~$5000–$100,000 US), of typical force plate systems.

The BTrackS Balance Plate (BBP) is a relatively new force plate that is portable (<7 Kg, no AC power required) and affordable (~$795 US). Using an inverted pendulum device to mimic human postural sway, the BBP was recently shown to have a high degree of COP accuracy (<1% error) and precision (<0.02 cm) relative to a laboratory-grade force plate (O'Connor et al., 2016). There was also no difference found between a single new (out of the box) and used BBP.

The present study sought to extend existing validation work on the BBP by using a point of application (POA) approach to test BBP accuracy and precision. Specifically, POA testing involved application of perpendicular forces to known locations on the surface of a BBP, and comparing their position with concurrently-measured COP. POA is a common approach for determining force plate performance metrics (Bartlett et al., 2014; Bobbert and Schamhardt, 1990; Browne and O'Hare, 2000; Hall et al., 1996), and provides

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an important, static corollary to the previously obtained dynamic COP results from inverted pendulum testing (O'Connor et al., 2016). The present study also aimed to provide more extensive inter-device reliability assessment for the BBP, comparing the results from five different devices.

2. Methods

2.1. Experimental setup

Five lightly used (<1000 tests) BBP devices (Balance Tracking Systems Inc., CA, USA) were tested in this study. The BBP (Fig. 1) is a FDA registered class 1 medical device with a 40 cm × 60 cm rectangular platform surface and enclosed strain gauge sensors on the underside of each platform corner. Adjustable feet below the sensors allow levelling of the BBP and ensure firm contact of the legs with the surface below. BBP sensors input to a bridge-type circuit board on the BBP, which, in this study, provided vertical force-related voltage signals to a laptop (Dell, TX, USA) via a standard USB cord. Custom data collection software developed in the LabVIew environment (National Instruments, TX, USA), was used to calculate medial lateral (X) and anterior-posterior (Y) COP according to the following formulas:

$$\text{COP X} = 24.25((\text{TR} + \text{BR}) - (\text{TL} + \text{BL}))/(\text{TL} + \text{TR} + \text{BL} + \text{BR})$$

$$\text{COP Y} = 15.50((\text{TL} + \text{TR}) - (\text{BL} + \text{BR}))/(\text{TL} + \text{TR} + \text{BL} + \text{BR})$$

where TR, TL, BR and BL are the force sensor values from the top right, top left, bottom right and bottom left corners of the BBP respectively.

A Shopbot Buddy Computer Numerical Control (CNC) router (ShopBot Tools, Inc., NC, USA) served as the method of POA delivery, with a manufacturer specified positional accuracy of <0.01 cm. The CNC delivered POA forces using a standard hex-nose spring plunger (McMaster-Carr Supply Co., IL, USA) installed onto the head of the CNC. The spring plunger allowed a relatively constant force to be delivered at a single point on each BBP being tested. Both CNC and BBP devices were calibrated and verified prior to data collection.

2.2. Experimental procedure

At the time of data acquisition, a given BBP was mounted and aligned on the CNC table with its feet stabilized by a custom jig. The jig was aligned such that the X and Y axes of the CNC internal stepper motor controller corresponded with the X (mediolateral) and Y (anterior-posterior) axes of the BBP. The feet of the BBP were adjusted such that the BBP surface was level, and the BBP collection software was used to "zero" the BBP sensors.

Following BBP preparation on the CNC table, POA testing began. POA trials consisted of depressing the spring plunger onto the BBP for several seconds, while the instantaneous X and Y COP locations were manually triggered and recorded from the data collection laptop. For each trial, the spring-loaded plunger was raised, moved to the appropriate X-Y location, and then lowered until ~155 N of force was applied to the BBP surface. This level of force was chosen based on the capacity for force generation of the CNC machine and available plunger characteristics. The full testing protocol consisted of five consecutive trials at each of 21 POAs (Fig. 2), for total of 105 trials. POAs included three locations at the plate midline (X = 0 cm, Y = −5 cm, 0 cm, 5 cm), where COP is commonly seen during standing, and two nine-point grids (X = −25 cm, −20 cm, −15 cm, 15 cm, 20 cm, 25 cm; Y = −5 cm, 0 cm, 5 cm), where the feet are typically placed on the BBP when standing with a natural stance width (Middleton et al., 1999).

2.3. Data analysis

For each BBP, the five COP recordings from a given POA location were first averaged to reduce signal noise. COP data were then corrected for translational and rotational offsets of the BBP COP and CNC X-Y coordinate systems. To accomplish this, linear regressions were performed on the X-Y COP data from each BBP for each of the Y coordinate rows (Y = −5 cm, 0 cm, 5 cm). The three calculated slopes were averaged and converted into a rotational offset θ_{avg} in degrees, and the X-Y COP data were then multiplied by a rotation matrix (rotation by -θ_{avg}) to correct for any rotational offset. Subtracting the averaged COP X and Y values respectively, subsequently corrected any translational offsets.

The agreement between the standard, CNC POA X-Y locations and the measured, BBP X-Y COP was subsequently determined using an absolute (A,1 model) intraclass correlation coefficient (ICC) and its 95% confidence interval lower limit. In addition, two technical performance metrics were quantified from linear regressions between the CNC POAs and BBP COP data. First, the percent error was calculated as an indicator of absolute BBP accuracy according to the following formula:

$$\text{Accuracy} = \text{Percent Error} = |(\beta - 1)| * 100$$

where β was equal to the regression slope. Second, BBP precision was quantified as the standard deviation of the regression residuals.

Summary values from the above metrics (i.e. ICC, accuracy and precision) were further subjected to paired *t*-test analyses to determine the effect of direction (X vs. Y). Statistical significance was considered at the $p < 0.05$ level. As a final step, inter-device

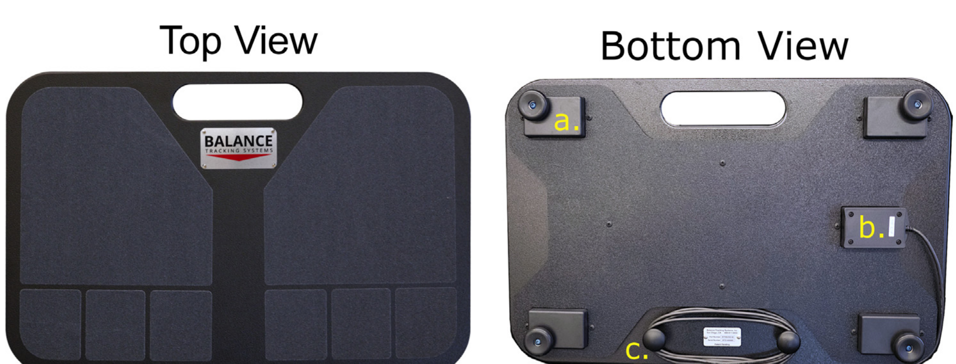

Fig. 1. Top (left) and Bottom (right) views of the BBP. Labelled are (a) one of the four enclosed sensors in the plate corners, (b) the enclosed bridge-type circuit board, and (c) the USB connector for interfacing with the laptop.