



Short communication

Validating the BTrackS Balance Plate as a low cost alternative for the measurement of sway-induced center of pressure



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ABSTRACT

The BTrackS Balance Plate (BBP) is a low-cost force plate that provides objective balance assessment and true portability for the user. Given that this technology is relatively new, the purpose of the present study was to provide the first center of pressure (COP) validation of the BBP. Two BBP devices (one new and one used) were compared with a laboratory-grade force plate (LFP) during simultaneous collection of COP that was induced by an inverted pendulum device with human-like sway characteristics. The results of this study showed almost perfect agreement between the BBP devices and the LFP (ICC > 0.999), as well as a high degree of BBP accuracy (< 1% error magnitude) and precision (< 0.2 mm regression residuals). These results suggest the BBP can serve as an effective, low-cost solution for objective balance testing in the laboratory or clinic.

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1. Introduction

Balance can be defined as the ability to maintain upright stance despite the presence of small kinematic disturbances or control errors. Biomechanically, this innate skill requires control of the body's center of mass to ensure it remains over the body's base of support (i.e. the area within and below the feet) when standing. The importance of balance in daily living cannot be understated, as there is a positive relationship between balance, functional ability and neuromuscular status (Lord and Sturnieks, 2005). Balance is also monitored in many clinical settings as a biomarker of health and well-being (Horak et al., 1997).

Force plates are often cited as the “gold standard” for balance assessment, offering an objective and sensitive means of measuring body sway control (Chang et al., 2014; Clark et al., 2010; Huurnink et al., 2013). Specifically, force plates measure balance by calculating an individual's center of pressure (COP) from foot contact forces generated when standing on the plate. Metrics based on the COP signal (e.g. velocity) are a proxy for the amount of body sway control necessary to maintain balance, whereby an increase in COP metric magnitude is thought to represent poorer regulated center of mass and higher likelihood of falling (Piirtola and Era, 2006; Swanenburg et al., 2010). Unfortunately, force plate balance testing is not widespread due to high cost (~\$5000–\$100,000) and a lack of portability for feasibly testing balance at multiple sites.

The BTrackS Balance Plate (BBP) is a recently developed force plate for balance testing that is portable, relatively inexpensive (~\$800 US), and, thus, has potential for widespread clinical use. The purpose of the present study was to provide the first set of COP validation data for the BBP. This was accomplished using an inverted pendulum mechanical system with human-like body sway characteristics to simultaneously produce controlled COP displacements on a laboratory-grade force plate (LFP) and a new versus used BBP respectively.

2. Methods

2.1. BTrackS Balance Plate (BBP)

One new (out of the box), and one used (~six months old, 500+ tests conducted) BBP (Balance Tracking Systems Inc., CA, USA) were tested in this study. The BBP is a FDA registered force plate comprised of a rectangular platform (0.4 m × 0.6 m), with four enclosed strain gauge sensors located on the underside of each corner (Fig. 1). Adjustable feet below each sensor allow levelling of the device. Each sensor is wired to a bridge-type circuit board that provides vertical force-related voltage signals. A standard USB connection powers the circuit board (5 V) and allows exchange of the force-related sensor data with an attached computer. Custom software determines ML and AP COP location as the spatially weighted averages of the four forces.

2.2. Laboratory-grade force plate (LFP)

A LFP (AMTI OPT464508, Advanced Medical Technology, Inc., MA, USA) served as the gold standard for COP measurement in this study, with a manufacturer specified accuracy of ± 0.2 mm. This LFP determined COP location using vertical force and horizontal (ML and AP) moment of force readings. These data were

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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 a computer.

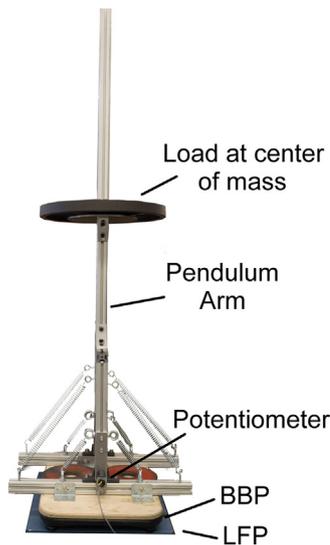


Fig. 2. Inverted pendulum used in this study mounted on a BBP and LFP for testing.

obtained from bridge-type strain gauge load cells within the plate that interfaced with the force plate's electronics, which were connected to a computer via USB.

2.3. Inverted pendulum

An inverted pendulum mechanical system was constructed to provide controlled COP perturbations emulating the characteristics of human postural sway (Fig. 2). The design of this device was based on a similar pendulum model (Leach et al., 2014) and consisted of an 80/20[®] aluminum arm attached to a base plate by two pillow bearings. Four sets of extension spring pairs (spring constants of ≈ 6500 and 775 N/m) were attached to the arm and baseplate at 45° angles to create a vertical arm equilibrium position and increase the natural frequency of sway. A potentiometer attached at the point of rotation outputted angular displacement of the arm from vertical.

The pendulum structure weighed 15.8 kg and a 29.5 kg weight set was placed at the height (1.06 m) of an average human center of mass during bipedal stance (McDowell et al., 2008). Additionally, a 22.7 kg load was added to the base of the pendulum to stabilize the structure and achieve a total mass of 68.0 kg. This is the approximate weight of an average adult woman (Prieto et al., 1996). The pendulum's natural frequency was 0.3 Hz, which is within the range of dominant frequencies exhibited by young and older adults during typical bipedal standing (Chaudhry et al., 2004).

2.4. Experimental procedure

All force plate devices (LFP, new BBP and used BBP) were calibrated and verified prior to testing. The LFP was calibrated and verified by the device manufacturer during a recent laboratory installation, and each BBP was calibrated and verified using custom software provided by the manufacturer at the time of testing. Following this, the devices were prepared for data acquisition, as shown in Fig. 2. First, the LFP data collection software was launched and LFP amplifiers were zeroed. Next, the BBP of interest (new versus used) was mounted and centered on the LFP, and its data collection software was subsequently used to zero the four sensors. Lastly, the inverted pendulum mechanical device was mounted and centered on top of the BBP and attached with C-clamps, ensuring broad surface contact.

Each trial conducted consisted of free pendulum oscillations, while both LFP and BBP COP signals were recorded at 25 Hz. BBP data recording was manually triggered prior to the inverted pendulum being displaced to a specified

displacement angle and released. LFP software was automatically triggered after the pendulum passed through the vertical position. The full testing protocol consisted of five trials each at six displacement angles ($\theta = 1.5^\circ, 2^\circ, 3^\circ, 4^\circ, 5^\circ, 6^\circ$) implemented in both the ML and AP directions. The selected angles were chosen as they represent a range of healthy and unhealthy (i.e. clinical) sway amplitudes (Chaudhry et al., 2004).

2.5. Data analysis

Individual COP time series were initially filtered using a fourth-order low-pass Butterworth filter (5 Hz cut-off) to reduce signal noise, and interpolated at 50 Hz to improve timing resolution when the LFP and BBP signals were later synced. LFP COP data were then corrected to account for the fact that the LFP and BBP systems recorded COP in different coordinate space, separated by the height of the BTrackS device. Corrected COP values projected the resultant LFP force vector from the LFP COP location to the surface of the BBP, while accounting for the BBP mass (Leach et al., 2014). Following this procedure, temporal alignment of the data was performed using custom software that automatically determined the period of free oscillations for the BBP time series. An autocorrelation between this subset of data and the LFP time series determined the time delay between the time series producing the greatest correlation. The BBP time series was then shifted by this time delay and cropped to 20 s in length to match the length of the LFP time series. Each trial of LFP and BBP COP data was then compared for 20 s of simultaneous data collection.

To measure the degree of agreement between the LFP and BBP signals, an intraclass correlation coefficient (ICC) and its 95% confidence interval lower limit were determined for each trial. In addition, two technical performance metrics were quantified in each trial based on linear regressions between the LFP and BBP COP signals. First, the percent error magnitude was calculated as an indicator of device accuracy according to the following formula:

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

where β was equal to the regression slope. Second, the BBP precision was quantified as the standard deviation of the regression residuals. Lastly, COP velocity error was computed between the LFP and BTrackS as an example of a common COP outcome measure. COP velocity was calculated from the sum of the magnitudes of the vectors connecting sequential COP locations (i.e. path length), which were then normalized by dividing by the 20 s collection period.

Summary values from all three performance metrics (i.e. ICC, percent error magnitude, and standard deviation of the residuals) and the COP outcome measure (i.e. velocity) were subjected to three-way Analysis of Variance (ANOVA) with repeated measures where appropriate to determine any main effects related to the factors Board Age (i.e. new versus used), COP Direction (i.e. ML versus AP) or Displacement Angle (i.e. $1.5^\circ, 2^\circ, 3^\circ, 4^\circ, 5^\circ, 6^\circ$). Statistical significance was considered at the $p < 0.05$ level. Values presented are mean \pm standard deviation unless otherwise stated.

3. Results

Representative data comparing the LFP and BBP signals is shown in Figs. 3 (new BBP) and 4 (used BBP) for each COP Direction and Displacement Angle condition. Based on the ICC statistical analysis, almost perfect agreement was found between the LFP and BBP devices, as evidenced by an average ICC of $0.999 \pm < 0.001$ across all trials. The average lower limit of the 95% confidence interval for each ICC value was $0.999 \pm < 0.003$. There were no significant differences in ICC based on Board Age, COP Direction or Displacement Angle ($p = 0.12\text{--}0.61$).

With respect to technical performance, both BBP devices had a high degree of COP measurement accuracy with an average percent error magnitude of less than 1% ($0.646 \pm 0.399\%$). There were no significant differences in percent error magnitude based on Board Age, COP Direction or Displacement Angle ($p = 0.13\text{--}0.74$). The BBP devices were also found to have a high degree of COP measurement precision, with an average standard deviation of regression residuals of 0.152 ± 0.122 mm. There were no significant differences in the standard deviation of regression residuals due to Board Age, COP Direction or Displacement Angle ($p = 0.07\text{--}0.73$). Overall, COP velocity error (0.02 ± 0.27 mm/s across all trials) was practically small as a percentage of the average COP velocity between LFP and BBP ($0.23 \pm 0.83\%$ across all trials), with no significant differences found due to Board Age, COP Direction or Displacement Angle ($p = 0.12\text{--}0.54$).

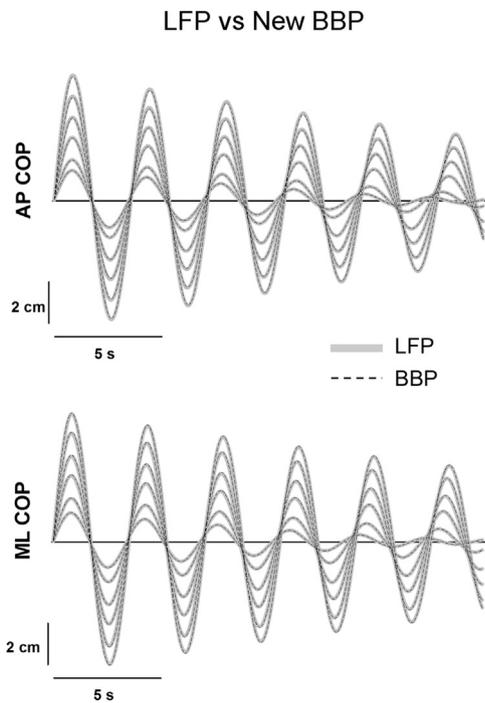


Fig. 3. Representative COP time series data for the LFP and new BBP in each COP Direction (ML, AP) and Displacement Angle (1.5°, 2°, 3°, 4°, 5°, 6°) condition.

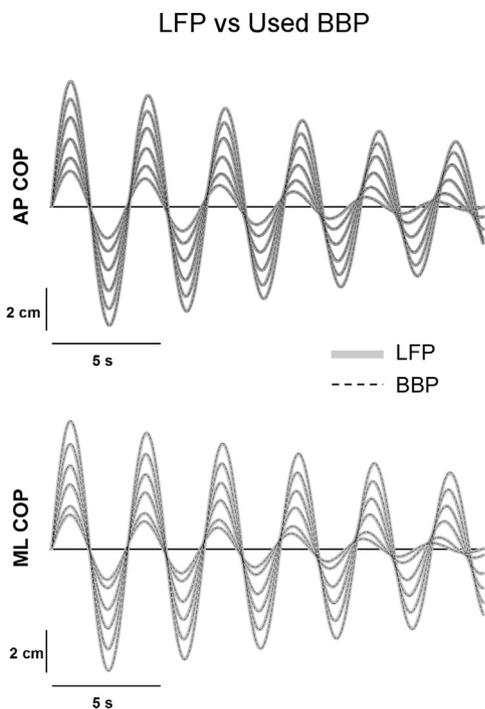


Fig. 4. Representative COP time series data for the LFP and used BBP in each COP Direction (ML, AP) and Displacement Angle (1.5°, 2°, 3°, 4°, 5°, 6°) condition.

4. Discussion

The present study sought to validate the BBP, a new low-cost force plate for the objective measurement of COP signals, which might serve as an ideal alternative to expensive LFP devices and/or subjective clinical rating scales. This was accomplished by comparing the agreement between a new and used BBP versus a LFP during multiple trials where an inverted pendulum device created sway with human-like characteristics. The results of the study

showed that both BBP devices had near perfect agreement with the LFP for measurement of COP signals, regardless of COP Direction and Displacement Angle condition, indicating that the devices are practically interchangeable (Lee et al., 1989). Relative to the LFP, the BBP devices were highly accurate, with an average absolute measurement error of < 1%, and highly precise, with a standard deviation of residuals that averaged < 0.2 mm.

While the present results are highly encouraging, several caveats should be acknowledged. First, the relevance of using quiet standing measures of COP signals as an indicator of balance has been questioned in the literature. Since COP variation during quiet standing lies well within the base of support, falls (i.e. losses of balance) may be better associated with difficulty transferring weight prior to and during action (Robinovitch et al., 2013). In this case, measuring COP patterns in response to daily living stimuli may have the greatest potential for predicting balance capability and fall risk.

Secondly, while no differences were found between the new and used BBP, the number BBP devices tested ($n=2$) renders this finding preliminary. Additionally, this study focused only a single sway frequency (0.3 Hz) within the dominant range for bipedal stance conditions (Prieto et al., 1996) at a fixed load. Future investigations are, therefore, necessary to definitively determine the durability of BTrackS, as well as the effects of sway frequency and force magnitude on COP error. It should also be noted that BTrackS remains limited in terms of the ability to account for the generally negligible horizontal (i.e. shear) forces associated with standing balance. However, we found excellent agreement between the BBP and LFP even under conditions or relatively large shear forces associated with the pendulum.

Lastly, the controlled pendulum data generated in this study differ from the time-varying persistent and anti-persistent structure of human-generated COP data (Ihlen et al., 2013). As such, complementary data from human subjects comparing BTrackS and LFP performance are planned.

Conflict of interest statement

D. Goble holds an equity stake (i.e. stock options) in the parent company for the BTrackS Balance Plate. Authors O'Connor and Baweja have no conflicts of interest to declare.

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