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Leveling the playing field: Evaluation of a portable instrument for quantifying balance performance

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ABSTRACT

Balance is a complex, sensorimotor task requiring an individual to maintain the center of gravity within the base of support. Quantifying balance in a reliable and valid manner is essential to evaluating disease progression, aging complications, and injuries in clinical and research settings. Typically, researchers use force plates to track motion of the center of gravity during a variety of tasks. However, limiting factors such as cost, portability, and availability have hindered postural stability evaluation in these settings. This study compared the "gold standard" for assessing postural stability (i.e., the laboratory-grade force plate) to a more affordable and portable assessment tool (i.e., BTrackS balance plate) in healthy young adults. Correlations and Bland-Altman plots between the center of pressure outcome measures derived from these two instruments were produced. Based on the results of this study, the measures attained from the portable balance plate objectively quantified postural stability with high validity on both rigid and compliant surfaces, demonstrated by thirty-five out of thirty-eight observed postural stability metrics in both surface conditions with a correlation of 0.98 or greater. The low cost, portable system performed similarly to the lab-grade force plate indicating the potential for practitioners and researchers to use the BTrackS balance plate as an alternative to the more expensive force plate option for assessing postural stability, whether in the lab setting or in the field.

1. Introduction

Postural steadiness, or postural stability, is defined as the ability of an individual to maintain their balance during quiet standing. More specifically, maintaining balance means keeping the center of gravity within the base of support (Bronstein and Pavlou, 2013; Horak, 2009; Marcolin et al., 2016; Prieto et al., 1996). Postural stability can be quantified with measures of vertical and horizontal reaction forces, center-of-pressure (CoP) displacement, or lumbar horizontal displacement (Prieto et al., 1996). Measures of force and displacement are typically calculated via instruments such as force plates, balance platforms, or accelerometers.

For decades, laboratory-grade force plates have set the standard by which measures of postural stability are quantified. However, the large expense of these devices, costing upwards of ~$5000–$75,000 or more, lack of portability, and requirement for external power sources, often preclude this option for individuals conducting assessments in the clinical or field settings (Goble et al., 2016; Whitney and Wrisley, 2004). In addition to an AC power requirement, the laboratory-grade force plate (FP) is also required to be fixed (bolted) to a surrounding structure. To address this problem, a more cost effective ($~795, plus software) and lighter (<7 kg) option has been developed by Balance Tracking Systems Inc., identified here as the BTrackS Balance Plate (BBP). This device has shown to have high accuracy and precision, as well as near perfect inter-device reliability for both X and Y CoP directions when compare to a laboratory-grade force plate (Goble et al., 2018).

In their initial evaluation of the BBP, O'Connor and colleagues (O'Connor et al., 2016) utilized an inverted pendulum model to provide a proof of concept that the BBP is a valid device for measuring CoP (Goble et al., 2016; O'Connor et al., 2016). These researchers demonstrated this validity through the comparison of the signals from the BBP and a FP. However, prior validation studies did not break the CoP signal into separate dependent variables for discrete evaluation of medio-lateral and antero-posterior motion. Further, previous work has only reported linear regression associations between output variables, only reflecting a snapshot

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of the validity of the BBP, particularly because correlations only show an association between variables, and not that the values are equal (O'Connor et al., 2016). Further, output of the BBP has yet to be directly compared against a laboratory-grade force plate for multiple postural stability metrics during actual balance tasks in healthy adults, rather than using a more abstract inverted pendulum model.

The aim of this study was to compare the "gold standard" for assessing postural stability to a more affordable and portable assessment tool in healthy young adults. Using derived postural metrics from the CoP time series, calculations were performed according to the methods of Prieto and colleagues (Prieto et al., 1996). This included both time dependent variables and combined distance and time-dependent variables. We hypothesized that CoP-based metrics of postural stability as measured by the BBP and FP would be similar. Furthermore, we hypothesized that by utilizing Bland-Altman plots, an interpretation of the results could be made beyond simple correlations between the two devices and validation provided that there is true agreement in the output(s) signals.

2. Methods

2.1. Participants

Twenty healthy college adults (10 males and 10 females; 26 ± 4 years, 1.7 ± 0.1 m, 66.68 ± 9.35 kg, body mass index 22.86 ± 1.58 kg m^{-2}) were recruited to participate in this study. Eligible participants were young adults between 18 and 30 years who were (1) able to stand on two feet for at least an hour, (2) free from neurological disorders or recent musculoskeletal injuries that would impact balance, and (3) not taking medications known to impact balance. Approval for this study was given by the local Institutional Review Board at Colorado State University and all participants provided written informed consent before participation.

2.2. Experimental procedure

All assessments occurred within a single testing session. Each participant's postural stability was simultaneously measured using an embedded force plate (Bertec Corporation, Columbus, OH) with Vicon Nexus (VICON, Englewood, CO) and via the BBP (Balance Tracking Systems, Inc., San Diego, CA). The BBP was placed on top of the FP with the long axis of the BBP in line with the long axis of the FP (see Fig. 1). For reference the alignment of the device axes were aligned via the outer edge (posterior (heel) side) of the BBP parallel with the edge of the FP.

Each system was zeroed in this configuration prior to each trial. Participants performed two 30-s trials of standing quietly. Prior to any participation all participants were given verbal and visual instructions by the lead researcher. Once the participant acknowledged understanding of these instructions, the researcher began collecting FP and BBP data. First, participants stood on a rigid surface (i.e., directly on the BBP) with eyes open and looking at a fixed target 4.37 m away. Second, a compliant, 7 cm thick Elite Balance pad (Airex, Sins, Switzerland) was placed on top of the BBP and participants again attempted to stand quietly while focusing on the same fixed target. In each condition, participants were instructed to stand in the base position as quietly/still as possible with their hands on their hips and their feet together (see Fig. 2). Participants were given a "step up" cue and then stepped on to the BBP, assuming the base position. Participants remained as still as possible until the researcher indicated the trial was over (~35 s after the participant first stepped onto the BBP). The participant was then asked to step back off the plate. Then, this procedure was repeated for the second condition of the protocol. The FP and BBP instruments continuously collected data prior to and after each quiet standing trial. This was necessary for time synchronizing the two separate recordings during post-processing. Since the aim of this study was not to compare differences between the testing surfaces, the order of the testing was kept consistent throughout the entirety of the protocol.

2.3. Data analysis

During all trials, ground reaction forces were collected at 25 Hz by the BBP and 100 Hz by the force plate. Text data files from both systems were exported to MATLAB (MathWorks, Natick, MA, version R2017a) for processing. BTS, Inc.'s proprietary software filters the CoP data prior to export using a second order, low-pass Butterworth filter with a cutoff frequency of 4 Hz. All force plate data

Fig. 1. Orientation of the BTrackS Balance Plate (atop the force plate) to the Bertec force plate. The directional difference was accounted for in the devised MATLAB script when calculating postural stability metrics.

Fig. 2. Postural stability assessments occurred on both rigid (A) and compliant (B) surface conditions.