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published in
Journal of Biomechanics
2013

DOI (link to publisher)
10.1016/j.jbiomech.2013.02.018

Link to publication in VU Research Portal

citation for published version (APA)

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Download date: 02. Aug. 2024
Short communication

Comparison of a laboratory grade force platform with a Nintendo Wii Balance Board on measurement of postural control in single-leg stance balance tasks

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1. Introduction

Training and testing of balance have potential applications in sports and medicine. Laboratory grade force plates (FP) are considered the gold standard for the measurement of balance performance. Measurements in these systems are based on the parameterization of center of pressure (CoP) trajectories. Previous research validated the inexpensive, widely available and portable Nintendo Wii Balance Board (WBB). The novelty of the present study is that FP and WBB are compared on CoP data that was collected simultaneously, by placing the WBB on the FP. Fourteen healthy participants performed ten sequences of single-leg stance tasks with eyes open (EO), eyes closed (EC) and after a sideways hop (HOP). Within trial comparison of the two systems showed small root-mean-square differences for the CoP trajectories in the x and y direction during the three tasks (mean ± SD; EO: 0.33 ± 0.10 and 0.31 ± 0.16 mm; EC: 0.58 ± 0.17 and 0.63 ± 0.19 mm; HOP: 0.74 ± 0.34 and 0.74 ± 0.27 mm, respectively). Additionally, during all 420 trials, comparison of FP and WBB revealed very high Pearson's correlation coefficients ($r$) of the CoP trajectories ($x$: 0.999 ± 0.002; $y$: 0.998 ± 0.003). A general overestimation was found on the WBB compared to the FP for 'CoP path velocity' (EO: 5.3 ± 1.9%; EC: 4.0 ± 1.4%; HOP: 4.6 ± 1.6%) and 'mean absolute CoP sway' (EO: 3.5 ± 0.7%; EC: 3.7 ± 0.5%; HOP: 3.6 ± 1.0%). This overestimation was highly consistent over the 140 trials per task ($r$ > 0.996). The present findings demonstrate that WBB is sufficiently accurate in quantifying CoP trajectory, and overall amplitude and velocity during single-leg stance balance tasks.

2. Methods

2.1. Participants

Fourteen healthy volunteers were recruited from the members of staff at the Faculty of Human Movement Sciences (6 males, 8 females; mean (range); age 28.0 (24-34) years; height 175.3 (165-197) cm; body weight 67.2 (55-85) kg). The local Ethics Committee approved the study and all participants provided informed consent.

2.2. Measurement setup

A WBB (45 × 26.5 cm in the x and y direction, respectively) was placed upon a FP (Kistler model 9218B), which measured 60 × 40 cm and was mounted flush with the laboratory floor. The WBB has four strain gauge load sensors and is only...
able to measure vertical forces. The WBB was connected wirelessly to a laptop computer via Bluetooth. The WBB data were sampled at 35 sample s⁻¹ (Pagnacco et al., 2011) and retrieved with custom-written software (Labview 8.5 National Instruments, Austin, TX, U.S.A.). The FP data were sampled at 1000 sample s⁻¹.

2.3. Procedures

Prior to our measurements, dead weight noise tests of 55 to 80 kg were performed to estimate the amount of noise disturbance of the FP and WBB (Pagnacco et al., 2011). Participants performed ten series of three balance tasks of 10 s in a single session: single-leg stance with eyes open (EO) and closed (EC), and single-leg stance after a short sideways hop (HOP). The hop was performed in lateral direction and was commenced while standing with both legs next to the WBB. Participants were instructed to perform all tasks on their preferred leg and barefoot. Participants were asked to stand as still as possible, to keep their hands on their hips and to focus on a point 2 m ahead. A trial was considered invalid if participants displaced their standing leg or touched the floor with the contralateral leg.

2.4. Data processing

A custom MATLAB (The Mathworks, Natick, RI, USA) program was designed for data reduction. Our data showed that the time interval between samples of WBB data was inconsistent (SD: 0.42 ms), therefore linear interpolation of the raw signals for the four WBB load sensors was applied to obtain a regular sample rate of 1000 sample s⁻¹ (Pua et al., 2012). The data were filtered with a second order Butterworth low-pass filter. Close examination of the WBB CoP signal frequency distribution and the WBB noise effects have led to an estimated optimal cutoff frequency of 12 Hz, which was similar to Clark et al. (2010). FP signals processed with a low-pass filter up to a cutoff frequency of 12 Hz, faithfully represented single-leg stance balance assessments (Ross et al., 2009). However, we decided to be consistent across both systems with regards to the low-pass filter cutoff frequency. To synchronize the onset of measurements, the time lags between FP and WBB were corrected with a time series covariance function of the vertical force data. CoP calculations for the WBB were performed with vertical forces of the four load sensors, and the distance between a load sensor and the middle of the WBB (21.6 × 11.8 cm, in the x (anteroposterior) and y (mediolateral) direction, respectively). CoP calculations for the FP were based on vertical and horizontal forces in accordance with the manufacturer’s manual. However, the moment arm of the horizontal forces was adapted to take the height of the WBB into account. Within each trial, for both FP and WBB, the mean CoP was considered as the origin.

2.5. Data analysis

The total trial length was analyzed for the EO and EC tasks, while for the HOP task only the data from 0.5 to 3.5 s after initial contact (vertical force > 10 N) were taken into account. To quantify the horizontal ground reaction force (GRF), both mean and maximum value of the total vector horizontal GRF were calculated per trial.

The RMS error and Pearson’s correlation coefficient (r) between FP and WBB were calculated for CoP trajectories in x and y direction during each trial (Derrick et al., 1994). Additionally, two common CoP parameters (i.e., ‘CoP path velocity’ and ‘mean CoP sway’), which are axis independent, were calculated for the FP and WBB (Clark et al., 2010; Melzer et al., 2010). The ‘mean CoP sway’ is considerable, which is in accordance with Pagnacco et al. (2011). The higher noise levels compared to FP (0.6–1.0 mm s⁻¹) are most likely due to hardware configuration (Pagnacco et al., 2011). Furthermore, the low sample rate might have further increased the noise as a consequence of aliasing the high frequency noise (Pagnacco et al., 1997). Estimations can be made from the result of the FP (RFP) and dead weight noise measurements (NFP and NWBB) on how noise could have affected the WBB result (RWBB). According to the equation RWBB = √(RFP² + NWBB² – NFP²) (Pagnacco et al., 2011) and the outcomes presented in Tables 1 and 2, it can be calculated that the present noise levels did cause an overestimation of the three balance tasks were similar for FP and WBB systems (mean RMS: 0.31–0.74 mm; mean 0.997–0.999; see Table 2).

The WBB measurements overestimated the ‘CoP path velocity’ and ‘mean CoP sway’ averaged outcomes of FP by 3.5 to 5.3% (SD < 2%). For both balance measures, outcomes were highly correlated between FP and WBB over 140 trials per task (r > 0.996). Fig. 2 presents scatter plots of the two balance measures for all 420 trials (14 subjects × 10 trials × 3 tasks).

4. Discussion

In line with results of Clark et al. (2010), we found good correspondence between balance measures obtained with FP and WBB. In addition, we showed that instantaneous estimates of CoP location obtained with a WBB are very similar to those obtained with a FP. The latter adds significantly to the literature, since comparable outcomes between FP and WBB on averaged measures, such as ‘CoP path velocity’, do not necessarily generalize to other balance measures. Within the range of tasks evaluated, the good correspondence between CoP trajectories suggests that any balance measure based on a WBB CoP trajectory can be considered sufficiently accurate.

The present findings seem a thorough validation for further exploitation of the WBB in the design and control of tasks that train or test balance. An elegant approach was investigated by Young et al. (2011), who incorporated real-time visual feedback of CoP into virtual environments (i.e., serious gaming) in order to create custom diagnostic or training programs. By, for instance, implementing such systems in (home-based) training regimes, compliance and effectiveness of balance training might be improved. Various disciplines (e.g., sports, sports medicine and rehabilitation medicine) might benefit from large-scale implementation of the low-cost WBB.

As the WBB might be employed in the field of sports, sports medicine or rehabilitation medicine, it is of necessity to thoroughly consider the limitations of the WBB. The results of the present dead weight noise testing indicate that the ‘CoP path velocity’ noise of the WBB (4.1–5.3 mm s⁻¹) is considerable, which is in accordance with Pagnacco et al. (2011). The higher noise levels compared to FP (0.6–1.0 mm s⁻¹) are most likely due to hardware configuration (Pagnacco et al., 2011). Furthermore, the low sample rate might have further increased the noise as a consequence of aliasing the high frequency noise (Pagnacco et al., 1997). Estimations can be made from the result of the FP (RFP) and dead weight noise measurements (NFP and NWBB) on how noise could have affected the WBB result (RWBB). According to the equation RWBB = √(RFP² + NWBB² – NFP²) (Pagnacco et al., 2011) and the outcomes presented in Tables 1 and 2, it can be calculated that the present noise levels did cause an overestimation of the
Fig. 1. Typical example of center of pressure trajectories for WBB and FP data on EO (1A), EC (1B), and HOP (1C). Presented trials were comparable with the mean outcome and mean differences of the present sample.

Table 2

<table>
<thead>
<tr>
<th></th>
<th>EO</th>
<th>EC</th>
<th>HOP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Horizontal GRF (FP)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absolute mean (N)</td>
<td>3.2 (0.9; 0.9)</td>
<td>6.9 (2.7; 1.6)</td>
<td>8.9 (3.3; 0.7)</td>
</tr>
<tr>
<td>Absolute max (N)</td>
<td>9.3 (3.7; 3.0)</td>
<td>25.1 (14.5; 8.3)</td>
<td>39.2 (16.5; 11.8)</td>
</tr>
<tr>
<td><strong>CoP trajectory</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RMS–x (mm)</td>
<td>0.33 (0.10; 0.05)</td>
<td>0.58 (0.17; 0.11)</td>
<td>0.74 (0.34; 0.14)</td>
</tr>
<tr>
<td>RMS–y (mm)</td>
<td>0.31 (0.16; 0.06)</td>
<td>0.63 (0.19; 0.12)</td>
<td>0.74 (0.27; 0.09)</td>
</tr>
<tr>
<td>r–x</td>
<td>0.999 (0.001; 0.000)</td>
<td>0.999 (0.000; 0.000)</td>
<td>0.999 (0.000; 0.000)</td>
</tr>
<tr>
<td>r–y</td>
<td>0.999 (0.001; 0.000)</td>
<td>0.999 (0.000; 0.000)</td>
<td>0.997 (0.005; 0.002)</td>
</tr>
<tr>
<td><strong>‘CoP path velocity’</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outcome (mm s⁻¹)</td>
<td>32.3 (6.5; 5.1)</td>
<td>34.0 (6.5; 5.1)</td>
<td>75.5 (21.3; 14.7)</td>
</tr>
<tr>
<td>Difference (%)</td>
<td>5.3 (1.9; 1.4)</td>
<td>4.0 (1.4; 1.1)</td>
<td>78.4 (22.2; 15.0)</td>
</tr>
<tr>
<td>r</td>
<td>0.997</td>
<td>0.999</td>
<td>0.998</td>
</tr>
<tr>
<td><strong>‘mean CoP sway’</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Outcome (mm)</td>
<td>7.1 (1.7; 1.1)</td>
<td>7.3 (1.8; 1.1)</td>
<td>13.6 (3.9; 2.2)</td>
</tr>
<tr>
<td>Difference (%)</td>
<td>3.5 (0.7; 0.3)</td>
<td>3.7 (0.5; 0.3)</td>
<td>14.1 (4.0; 2.3)</td>
</tr>
<tr>
<td>r</td>
<td>1.000</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

RMS, root-mean-square error between WBB and FP data.

r, Pearson’s correlation coefficient between WBB and FP data.

Diff, difference as percentage relative to FP value.

a Presented as mean (SD over all trials; SD over subjects after averaging over 10 trials).

b Within trial analysis for x and y directions.

c Analysis over 140 data points (14 subjects × 10 trials) per task.
In addition to noise effects, the overestimation of WBB ‘CoP path velocity’ (4.0–5.3%) is likely to be caused by a negligence of horizontal forces. The latter accounts for the overestimation of WBB ‘mean CoP sway’ values (~ 3.5%). Finally, the low sample rate restricts the applicability of the WBB to measurements in the relatively low frequency domain. However, this seems not to be of importance concerning standing balance assessments (Ross et al., 2009; Schmid et al., 2002).

Despite the limitations of the WBB, we found that the present balance measures showed very high Pearson’s correlations and small differences in error between FP and WBB. This indicates linearity and consistency of measurement outcomes. In addition, Fig. 2 reveals that the WBB measurement error is consistent over the present ranges of ‘CoP path velocity’ and ‘mean CoP sway’. Therefore, it is unlikely that errors of WBB estimates in single-leg balance tests will lead to false conclusions. However, this should be verified for populations and tests that differ from the ranges of the present study, especially concerning body weight and ‘CoP path velocity’ values.

In conclusion, the WBB is sufficiently accurate for quantifying CoP trajectory, and overall amplitude and velocity during single-leg stance balance tasks.

Conflict of interest statement

There is no conflict of interest.

Acknowledgements

We would like to thank Dr. Max Feltham for his useful comments while drafting the manuscript.

References


