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Original Research

Validation of a Portable Wireless Force Platform System To Measure Ground Reaction Forces During Various Tasks

Vasileios Mylonas[1a], Christos Chalitsios[1], Thomas Nikodelis[1]

[1] Physical Education and Sport Science, Aristotle University of Thessaloniki

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Background

Force platforms are widely used in biomechanics to measure ground reaction forces (GRF) during various human movements. However, traditional force plates are not easily used outside a research lab. To overcome this issue, researchers and manufacturers are developing low-cost portable force platforms that can be used in a variety of settings, including outdoors.

Purpose

To validate the kinetic data obtained from a pair of portable K-Deltas force platforms compared to gold standard platforms fixed in the lab and to examine the measurement reliability between this pair of portable force platforms.

Methods

Force-time curves from known masses, countermovement vertical jumps, and balance tests were used to assess validity of K-Deltas using a pair of Bertec force plates as a gold standard and between the K-Deltas pair of plates. Bland-Altman plots were used to evaluate the differences between K-Deltas and Bertec force plates. For the assessment of countermovement vertical jumps, impulse, peak rate of force development and peak force were calculated for both instruments and checked for agreement between instruments. Three young adults (2 male, 1 female, 25.4±0.83 years) participated in the study.

Results

The percentage of Bland-Altman plot point within the limits of agreement was 94.59 % for the comparison between K-Deltas and Bertec and 94.83% between the pair of K-Deltas.

Conclusion

The results show that the portable force platforms could be utilized successfully for assessing pertinent parameters in clinical and sports biomechanics. The findings suggest that portable force platforms can be used as an alternative to traditional laboratory equipment for field assessment, providing significant improvements compared to the past.

Level of Evidence

Level 3

a Corresponding Author:
Vasileios Mylonas, Biomechanics Laboratory, School of Physical Education and Sport Science, Aristotle University of Thessaloniki, Thessaloniki, 54124, Greece.
vmylonas@phed.auth.gr

INTRODUCTION

Force platforms are devices that are widely used in biomechanics and sports science to measure vertical or three-dimensional (3D) ground reaction forces during various human movements like gait,[1-3] running,[4,5] vertical jumps[6,7] and balance.[8] In special cases they are used to detect asymmetries by comparing the ground reaction forces exerted by the left and right lower[9] or upper limbs.[10] Nevertheless, such instruments are usually expensive, mounted on the ground of a laboratory, not easily portable, and in most cases only used by scientists/researchers.

Although force plates and other force transducers are commercially available, the aforementioned features are negatively associated with their use during sports and in clinical practice. Researchers and manufacturers are looking into more useful alternatives, based on cost and portability, in an effort to broaden the application of kinetic instrumentation during on-field assessment and daily practice. Portable force plates can make it easier for practitioners, athletes, and researchers to record vertical force data. Currently, the availability of low-cost portable force platforms with weight and dimensions that make it possible to use it in a variety of different settings, allowing for a quick installation and removal while traveling for competitions or training sessions is improving. Much of the focus is due to the mobile technology advances, i.e., modern instruments that can record and store the measured data wirelessly in the cloud through a mobile device and a dedicated application.

Although the above-mentioned features provide significant improvements compared to the past, the quality of every measuring instrument is largely dependent on its accuracy and precision. As an alternative to the typical laboratory equipment, new pieces of equipment that can be used outdoors for 'ecological' measurements during a variety of sports would be of great assistance to applied research in the field of sports science.

The purpose of this study was to validate the kinetic data obtained from a pair of portable K-Deltas force platforms compared to gold standard platforms fixed in the lab and to examine the measurement reliability within this pair of portable force platforms. Force-time curves from known masses (dead weights), counter movement jumps (CMJ), and balance tests were chosen as representative tasks to be used for validity comparisons. The balance task was also used for testing the reliability between the two portable platforms.

The working hypothesis was that the portable force plates could be utilized successfully for the purpose of assessing pertinent parameters in clinical and sports biomechanics.

METHODS

PARTICIPANTS

Three participants (2 male, 1 female, 25.4±0.83 years., 85.4±18.5 kg, 181.6±9.4 cm) conducted the trials. Participants were physical education students and had no recent injury or medical issue of any kind, who were postgraduate students in sport biomechanics, had graduated from a sport science department, so they were all to some extent familiar with the tasks. They all signed a participation consent form. The study was approved by the ethics committee of the university (133750/2019).

INSTRUMENTS

The portable force plate system (K-Deltas, Kinvent Inc, Montpellier, France) was tested for validity to a force plate system commonly used in research laboratories around the globe, a pair of Bertec force plates (FP4060-08, 40 cm x 60 cm) as a gold standard. (Bertec Inc., Ohio, USA). The K-Deltas plates were used with the K-invent physio dedicated application (Kinvent Inc, Montpellier, France). The Android application was used to record the data via Bluetooth (BLE 5.1) with a sampling frequency of 1000Hz. The Bertec plates were recorded through Vicon Nexus software (Nexus 2.15.0) via a cable connection. The forces from the Bertec platforms were recorded at 960Hz. Since the K-Deltas are 1-D force plates only vertical ground reaction force data were used from the Bertec devices.

EXPERIMENTAL PROCEDURE

Prior to the comparison with the gold standard, the K-Deltas were validated using standard weights. Four distinct weight plates ranging from 20.04 kg to 82.18 kg were utilized. The weight was recorded for two seconds. Both plates underwent the same procedure. The sampling frequency for these tests was set at 75 Hz.

After the weight validation each participant performed a total of two postural stability trials. The first was a bipedal stance held for 60 seconds while standing on the two K-Deltas plates that were placed on top of the Bertec force plates. The Bertec plates were calibrated so that the weight of the Deltas would be zeroed out (Setup A, Figure 1A). Ground reaction force (GRF) was measured, and the center of pressure (CoP) was calculated for each lower limb separately. The second test was another 60-second bipedal stance using only one Bertec plate, and the two K-Deltas plates were stacked on top of it, one above the other. A baseline process ensured the zeroing of the instruments (Setup B, Figure 1B). GRF and CoP were extracted and calculated as a total, representing the whole body. For Setup B, comparisons were made between the top K-Deltas plate and the Bertec (D1-B) and the bottom K-Deltas plate and the Bertec (D2-B) to test validity, as well as between the two Deltas (D1-D2) to test reliability in between the pair. In both setups double-sided tape was utilized to fixate the plates to ensure that they would be tightly fixed on one another.

Finally, each subject performed 10 consecutive countermovement vertical jumps. After each landing, the participant returned to the upright stance to start the next jump. A metronome was used that instructed the subject to jump every two seconds. The setup used for the multiple jumps was identical to Setup A of postural trials (Figure 1A). No jumps were performed on Setup B.

Table 1. Bland Altman plot results for experimental Setup A

Subject	Lower Limb	Axis	Out Perc (%)	Mean Difference
Male 1	Left	X	4.68	0.14 (cm)
	Left	Y	4.93	0.43 (cm)
	Right	X	5.12	0.21 (cm)
	Right	Y	5.2	0.38 (cm)
	Left	Force	5.22	0.49 (N)
	Right	Force	5.17	0.55 (N)
Male 2	Left	X	5.03	0.69 (cm)
	Left	Y	6.07	0.66 (cm)
	Right	X	6.65	0.4 (cm)
	Right	Y	5.07	0.11 (cm)
	Left	Force	5.43	0.06 (N)
	Right	Force	5.52	0.93 (N)
Female	Left	X	5.73	0.09 (cm)
	Left	Y	5.13	0.2 (cm)
	Right	X	4.75	0.24 (cm)
	Right	Y	4.63	0.68 (cm)
	Left	Force	4.97	0.5 (N)
	Right	Force	5.2	0.27 (N)

Figure 1. Experimental setups. Figure 1A depicts experimental Setup A and Figure 1B depicts experimental Setup B

Participants were verbally instructed to perform a heel strike at the start and at the end of the trial. The two pairs of devices were externally synchronized using the spike in vertical force signal from the heel strike.

DATA ANALYSIS

A dual pass second-order low-pass Butterworth filter was used with cutoff frequencies of 40 Hz for the K-Deltas plates (1000 Hz sampling frequency) and 38 Hz for the Bertec plates (960 Hz sampling frequency). The cutoff frequencies were selected using residual analysis and the method proposed by Winter[11] for choosing the appropriate cut-off frequency with respect to the sampling frequency.

For the analyses of the posture trials, the GRF and the CoP outputs of both instruments were tested for agreement. Bland-Altman plots[12] were used to present the level of agreement between the two-time series. Limits of agreement were set as ±2 times the standard deviation of the difference. To quantify the agreement, the percentage of data points outside the limits of agreement relative to the total points was determined. Each participant was subjected to individual analyses. The total GRF time-series of each instrument and jump were used to calculate the impulse, maximum force (maxF), and maximum rate of force development (maxRFD). These variables served as the key variables for each of the ten jumps and were used to achieve agreement between the instruments for the jump measurements. Both the stacked plates protocol and the Bland Alman plot approach to validate the results have been used in previous literature.[13]

RESULTS

Measurements with weights were performed for both force plates of the K-Deltas pair. Deviations from the known masses were 0.03 ± 0.06 kg at 0 kg, 0.01 ± 0.04 kg for 20.04 kg, 0.01 ± 0.05kg for 40.06 kg and 0.02 ± 0.05kg at 58.2 and 0.04 ± 0.03kg for 82.18 kg. This error was comparable with the data sheet provided by Bertec which reports less than 0.2% error for the vertical component.[14]

Regarding the postural stability tests, the comparison of the two instruments was quantified by the number of points outside the limits of agreement of the Bland Altman plots. These numbers are presented as percentages of the total data points for Setup A (Table 1) and Setup B (Table 2).

Table 2. Bland Altman plot results for experimental Setup B

Subject	Comparison	Axis	Out Perc (%)	Mean Difference
Male 1	D1-D2	X	5.07	0.09 (cm)
	D1-D2	Y	5.18	0.06 (cm)
	D1-D2	Force	5.02	0.82 (N)
	D1-B	X	6.17	0.05 (cm)
	D1-B	Y	7.7	0.27 (cm)
	D1-B	Force	5.35	0.24 (N)
	D2-B	X	6.03	0.14 (cm)
	D2-B	Y	7.35	0.21 (cm)
	D2-B	Force	4.93	0.58 (N)
Male 2	D1-D2	X	5.13	0.03 (cm)
	D1-D2	Y	5.38	0.01 (cm)
	D1-D2	Force	5.02	0.82 (N)
	D1-B	X	4.97	0.01 (cm)
	D1-B	Y	4.9	0.02 (cm)
	D1-B	Force	5.35	0.24 (N)
	D2-B	X	5	0.04 (cm)
	D2-B	Y	5.37	0.03 (cm)
	D2-B	Force	4.93	0.58 (N)
Female	D1-D2	X	5.25	0.14 (cm)
	D1-D2	Y	5.48	0.09 (cm)
	D1-D2	Force	5.02	0.82 (N)
	D1-B	X	5.57	0.04 (cm)
	D1-B	Y	5.7	0.24 (cm)
	D1-B	Force	5.35	0.24 (N)
	D2-B	X	5.7	0.1 (cm)
	D2-B	Y	5.22	0.15 (cm)
	D2-B	Force	4.93	0.58 (N)

Regarding the analysis of the jumps, impulse, maximum RFD and maximum force were computed separately for the two instruments and tested for agreement for all jumps. Bland Altman plots are presented in Figure 2.

DISCUSSION

These findings indicate a high degree of agreement in measurements between the two instruments. This supports the hypothesis that the K-Deltas force plates are valid in comparison to the Bertec force plates, which are considered the gold standard instrument. The validity of the K-Delta plates is also supported by the results of the weight testing. In all cases, the measured values varied by less than 100 grams from the true (known weight), and the CoP mean difference was less than 1 cm, values that were similar to or less than previous results in other validation studies.[13] The high levels of agreement in the GRF measurements during the quiet standing trials suggest that K-Deltas portable force plates are as capable as embedded lab force plates to measure postural stability. The comparisons of the CoP time series also indicate that K-Deltas can be used to accurately evaluate the postural stability of human subjects.

The Bland-Altman analysis revealed on average satisfactory levels of agreement between the K-Deltas and Bertec force plates. Specifically, for the variable "Impulse," the limits of agreement ranged from approximately -0.52 to 5.54 N·s. For "MaxF," the limits were between -1.93 and 4.15 N, and for "MaxRFD," they ranged from -0.0096 to 0.0296 N/s. The limits of agreement indicate a strong concordance between the two instruments. In comparison to previous validation studies, the mean limits of agreement from this study align well and are narrower,[15] further reinforcing the validity of K-Deltas force plates.

In comparison to previous validation studies,[16,17] the limits of agreement in the current study are narrower. It is worth noting that previous studies employed different postural trials, which may introduce trial-to-trial variability affecting the limits of agreement. The current study's methodology, involving simultaneous recording, addresses this limitation and possibly results in a more reliable estimate of agreement. Moreover, the high sampling rate of 1000Hz and strong agreement in jump parameters further validate the efficacy of K-Deltas in capturing vertical GRF, even when mathematical processes like integration are involved.

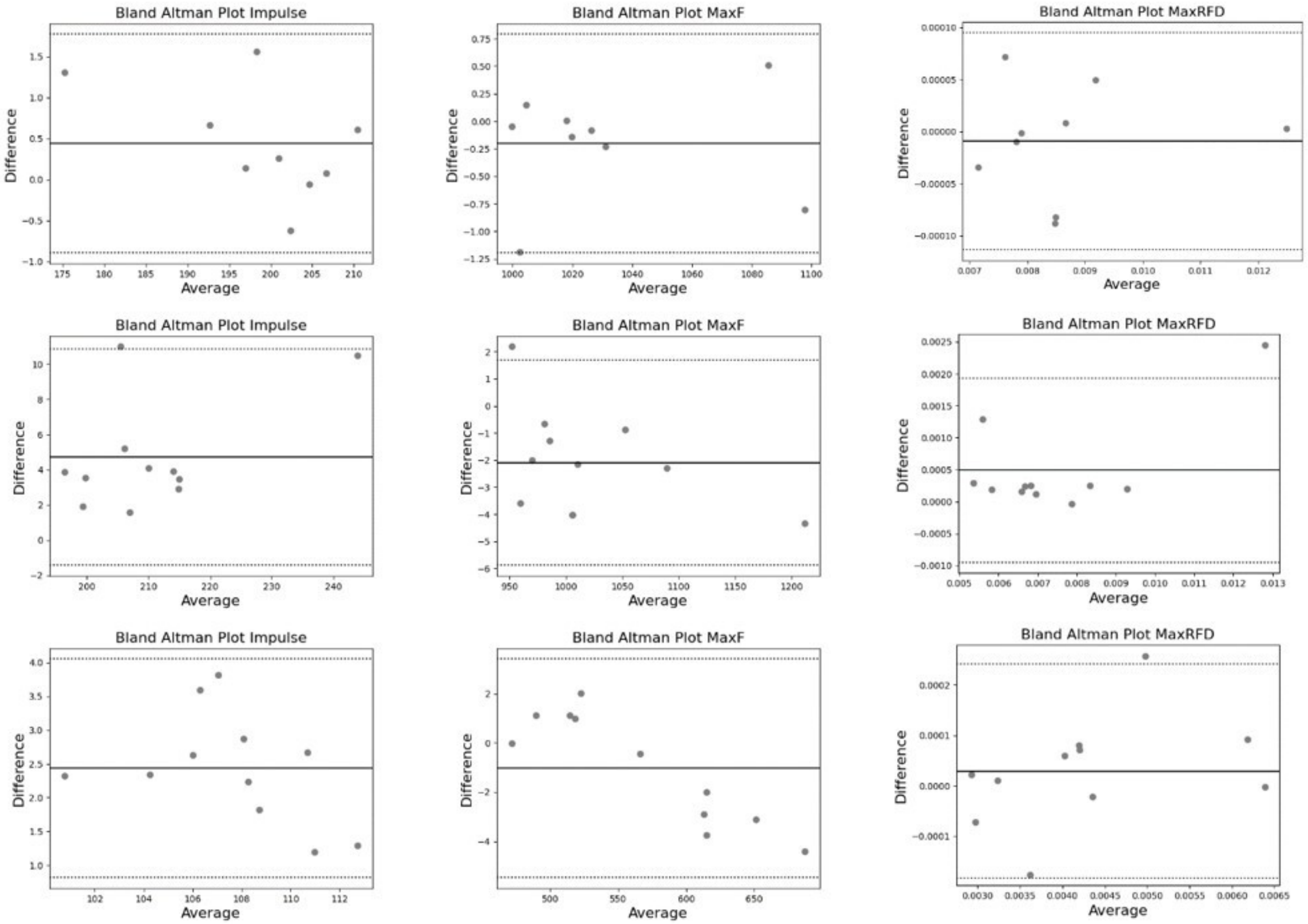

Figure 2. Bland Altman plots present the average plotted against the difference of the two measurements. Each column presents the results of the different variables (Column 1: Impulse (Newton seconds [N·s]), Column 2: Max force {Newtons], Column 3: Max rate of force development [N/s]). Each row is a different participant (Row 1: Male 1, Row 2: Male 2, Row 3: Female 1).

Therefore, these findings not only validate the use of K-Deltas force plates but also contribute to the existing literature by providing an alternate methodological approach to assessing instrument agreement.

Previous studies that have attempted to validate force plates have used different setups. Different postural trials were used,[16,17] with participants being measured separately using each of the two instruments and then measuring the Intraclass Correlation between the two trials. Postural control, however, is a skill composed of many factors interacting with each other and it is expected that postural metrics present variability from trial to trial. Thus, the authors of the current study used a protocol that simultaneously recorded data from the two pairs of plates to overcome this limitation which has been reported in literature.[13]

The computation of jump parameters requires high frequency rates and accurate GRF measurements. For this test, the K-Deltas measured GRF with 1000Hz sampling rate wirelessly. High accuracy is also necessary when using mathematical processes such as integration (present in the computation of impulse) because a small measurement error would cumulate and lead to large error. Results of the comparison between parameters computed from the two instruments indicate strong agreement. Therefore, the K-Deltas plates are capable of measuring vertical GRF accurately in multiple jumps and report valid results with respect to the floor-embedded gold standard plates.

However, limitations include the possibility of slippage of the portable force plates relative to the mounted surface as they are not permanently fixed, especially in dynamic conditions like jump tests. Also, the fact that the specific plates are 1-D limits their use when comprehensive, multidimensional analysis is needed like including joint moments and torques during gait, as an example. Another possible limitation could be the low number of participants, as a larger sample could account for the greater general variance in the population. Finally, it must be acknowledged that in the setup of the present study the force dispersion may not be the same across force plates as the contact surface of the upper one is the "foot" while for those below (each is not directly on the solid floor surface), and force is being measured as it is transmitted through the four contact points of each plate. Although this is not expected to affect the vertical force component, it is still a limitation since the setup is not identical to prior studies.

CONCLUSIONS

The reliability and validity of a portable, wireless pair of force plates, the K-Deltas, were examined relative to a floor-embedded system that has been repeatedly demonstrated to be valid. The results indicate that the K-Deltas plates are a valid alternative to the gold standard for vertical GRF measurements. The portable and wireless design of this product makes it more versatile than a conventional force plate for many types of users. Both standing and jumping can be measured accurately outside of the laboratory. Although the current analyses were performed using raw time series, the end user is not required to go through this process and can select the automated filtering techniques that are available in the app based on the type of test that is being conducted. The dedicated app builds a PDF report right after the measurement with all key variables according to the selected test. Nevertheless, extracting the raw signal is important as a function as users can perform their own more detailed analyses.

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