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Concurrent validity of a portable force plate using vertical jump force-time characteristics

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Running Title: Portable force plate validity

Abstract

This study examined concurrent validity of countermovement vertical jump (CMJ) reactive strength index modified and force-time characteristics recorded using a one dimensional portable and laboratory force plate system. Twenty-eight men performed bilateral CMJs on two portable force plates placed on top of two in-ground force plates, both recording vertical ground reaction force at 1000 Hz. Time to take-off, jump height, reactive strength index modified, braking and propulsion impulse, mean net force, and duration were calculated from the vertical force from both force plate systems. Results from both systems were highly correlated ($r \geq .99$). There were small ($d < .12$) but significant differences between their respective braking impulse, braking mean net force, propulsion impulse, and propulsion mean net force ($p < .001$). However, limits of agreement yielded a mean value of 1.7% relative to the laboratory force plate system (95% CL: .9% to 2.5%), indicating very good agreement across all of the dependent variables. The largest limits of agreement belonged to jump height (2.1%), time to take-off (3.4%), and reactive strength index modified (3.8%). The portable force plate system provides a valid method of obtaining reactive strength measures, and several underpinning force-time variables, from unloaded CMJ and practitioners can use both force plates interchangeably.

Keywords: Countermovement jump, force plates, method comparison

Word Count: 1914

Introduction

Force plates are often used to measure countermovement vertical jump (CMJ) ability. This provides practitioners with information about the athlete's capacity to accelerate their body mass using variables like impulse, mean force, phase duration [1-4] and the reactive strength index modified (the ratio between jump height and time to take-off [jump initiation to take-off]).[2,5-11] Practitioners are then able to understand the underlying force and time components to establish whether an athlete is able to produce sufficient force in the time available during sports actions. If not, shortcomings in the relevant aspect can be addressed before being subsequently reassessed.

Although force plates can provide practitioners with a lot of potentially useful data, typically laboratory-based, in-ground ('gold standard', £30 k - £70 k) and portable force plates (~£10 k – 15 k) are expensive. A more affordable force plate system recently became available as a portable, dual-plate system that retails at around £600 (approximately $800 USD at the time of writing). It uses strain gauge technology, with each plate providing a measurement range of -1.1 kN to 4.4 kN, with overload protection up to 6.6 kN. Therefore, using the dual-plate system yields a typical measurement range upper limit of 8.8 kN with protection up to 13.2 kN.

While it appears that this portable force plate system may provide a realistic alternative to established systems, nothing is known about its reliability and concurrent validity. This company currently manufacturers a 1D (vertical only) and 2D (horizontal and vertical) model. Research has established acceptable concurrent validity of the 2D (horizontal and vertical) model [12]; however, the 2D system has a separate metal sheet that is attached to a separate force measuring sensor, and many of the variables mentioned above were not considered. Before the 1D system can be used with confidence, it is necessary to quantify its concurrent validity.

The aims of this study were to assess the concurrent validity of this portable force plate system by comparing it with a laboratory force plate system via simultaneously recording key CMJ performance characteristics. These results will inform practitioners about the relative merits and limitations of the portable force plate system.

Method

Twenty-eight men (age: 20.0 ± 0.8 years, body mass: 83.2 ± 7.9 kg, height: 1.80 ± 0.56 m) who regularly participated in university level sports (soccer, rugby (league and union), basketball and volleyball), volunteered and provided written informed consent to participate in this study, which was approved by the institutional ethics committee.

Participants performed four bilateral CMJ, interspersed with 30 s of rest. They were instructed to stand still until given the word of command to ‘jump’ where they performed a rapid countermovement to a comfortable depth that enabled them to perform the transition from braking to propulsion as quickly and safely as possible; this tended to be approximately quarter squat depth. They followed this with a rapid propulsion to jump as high as possible while keeping their hands on their hips throughout. Each CMJ was performed with each foot on a portable force plate (35 cm by 35 cm each, PASPORT force plate, PS-2141, PASCO Scientific, California, USA) that was placed directly on top of two in-ground force plates (40 cm by 60 cm each, Kistler Type 92538, Kistler Instruments, Hampshire, UK) (Figure 1). These force plates simultaneously recorded vertical force at 1000 Hz, using Pasco Capstone software (PASCO Scientific, California, USA) for the portable force plates and Kistler Bioware software (Kistler

Instruments, Hampshire, UK) for the laboratory force plates, and left and right side vertical forces were summed for analysis.

Insert Figure 1 about here please

Force-time data were not filtered [13] and were processed in a customised spreadsheet. Countermovement start was identified using the methods described in the literature (Figure 2). [14] Body weight equalled the averaged first 1 s of ‘quiet standing’ force (portable force plate weight was negated by zeroing the laboratory force plate system before each trial). Quiet standing force standard deviation (SD) was calculated and the start threshold of body weight ±5 SD set; subsequent data processing began 30 ms before this point because research shows that the subject is still motionless here and the assumption of zero velocity is not compromised.[14] Take-off was identified in three stages (see Figure 2): first, the first force value less than 10 N and the next force value greater than 10 N were identified; second, points 30 ms after and before these points were determined to identify the centre ‘flight phase’; third, mean and SD ‘flight phase’ force was calculated, and mean ‘flight phase’ force +5 SD was used to determine take-off.

Braking began one sample after the lowest countermovement phase centre of mass velocity and ended at the lowest displacement; this (plus one sample) marked the beginning of propulsion, which ended at take-off (Figure 2). Braking and propulsion duration were recorded and time to take-off was calculated by subtracting the start time from take-off time. Net force was calculated by subtracting body weight from force, which was then averaged over braking and propulsion. Impulse was calculated by integrating net force over braking and propulsion using the trapezoid method.[13-15] Centre of mass velocity was calculated by dividing successive samples of impulse by body mass (body weight ÷ g [9.81 m.s^{-2}]). Jump height was calculated using the following equation [16]:

$$\text{Take-off velocity}^2 \div 2g$$

Reactive strength index modified was then calculated by dividing jump height by time to take-off.[2,7,10,11]

Insert Figure 2 about here please

Before statistical analyses, the assumption of normal distribution was confirmed. The intra-class correlation coefficient (ICC) assessed relative within-session reliability, while the coefficient of variation assessed absolute within-session reliability.[17] The concurrent validity of the dependent variables recorded from both force plate systems, association was assessed using the Pearson product moment coefficient, bias was assessed using paired *t* tests, standardised effect sizes (*d*), and limits of agreement. The latter were calculated using methods described by Bland and Altman.[18] Effect sizes (*d*) were quantified using a published scale, where ES of 0.20, 0.60, 1.20, 2.0, and 4.0 represented small, moderate, large, very large and extremely large, effects respectively.[19] An alpha value of $p \leq 0.05$ was used to indicate statistical significance.

Insert Table 1 and 2 about here

Results

The reliability of the dependent variables was high (Table 1). However, readers should note that while the relative reliability exceeded ICC *R* values of .94 throughout, relatively high coefficients of variation indicated that the absolute reliability of braking mean net force (coefficient of variation, laboratory: 9.8%, portable: 9.7%) and braking duration (coefficient of variation, laboratory and portable: 7.1%) was not as good as the other dependent variables. However, they were consistent across both force plate systems (Table 1).

Results obtained from the laboratory and portable force plate systems were highly correlated with r values ≥ .99 (Table 2). There were significant ($p < .001$) but small ($d < .12$) differences between laboratory and portable force plate braking impulse, braking mean net force, propulsion impulse, and propulsion mean net force ($p < .001$) (Table 2). Limits of agreement showed a mean value of 1.7% relative to the laboratory force plate system (95% CL: 0.9% to 2.5%), indicating very good concurrent validity across all of the dependent variables (Table 2). The largest limits of agreement were found for jump height (2.1%), time to take-off (3.4%), and reactive strength index modified (3.8%) (Table 2).

Discussion

The aim of this study was to assess the concurrent validity of a portable force plate system by comparing it with a laboratory force plate system that simultaneously recorded vertical force to provide both reactive strength and force-time variables that underpin CMJ performance. The results showed that the concurrent validity of the portable force plate system was acceptable.

Beginning with the reactive strength index modified and its constituent parts, jump height and time to take-off and jump height, the results of the within-session reliability demonstrated high levels of relative and absolute and relative reliability for time to take-off, jump height and reactive strength index modified derived from both systems, with ICC *R* values of > .94 and CV values of <5.7%. The result of the concurrent validity analysis demonstrated nearly perfect correlations, and trivial biases limits of agreement and effect sizes. These data demonstrate that the portable force plate system can be used interchangeably with the laboratory force plate system to obtain time to take-off, jump height, and reactive strength index modified.

To describe the mechanisms that underpin time to take-off and jump height we studied braking and propulsion impulse, mean net force and their durations. The results of the within-session reliability analysis demonstrated high levels of absolute and relative reliability. However, while propulsion variables yielded ICC *R* values of > .96 and CV values of <3.7%, braking absolute reliability was not as high. The ICC *R* values were > .96, while CV values were 5 to 9.8%. That said, these high CV values were comparable across both force plate systems indicating that they were the product of biological variability rather than device variability. The results of the concurrent validity analyses demonstrated perfect correlations, and trivial biases. Recent research has shown that a portable force plate system made by the same company that make the system analysed in the present study demonstrated similarly very high concurrent validity for CMJ propulsion impulse.[12] However, this is the first study to analyse the concurrent validity of braking impulse and braking and propulsion mean net force and duration from a similar system. This is important because it provides insight into jump strategy and coupled with study of reactive strength index modified, and its constituent parts, helps provide a detailed athlete force-time profile. This enables practitioners to identify areas that their athletes need to work on to maximize their ability to rapidly flex then extend their hips, knees and ankles to accelerate their body mass.

Although measures of reactive strength and force-time characteristics that underpin CMJ performance recorded from the portable force plate system are both reliable and valid, this system is not without its limitations. The first limitation is its size. Each plate is 0.35 m by 0.35 m, which is relatively small compared to most laboratory-based force plate systems. Although this increases to a 0.35 m by 0.70 m surface area when placed side-by-side, this still may not be large enough for some athletes or for some movements. With care and habituation, the participants in this study were able to perform the CMJ safely. We also know of some practitioners who have constructed platforms to surround this system to reduce the likelihood of an athlete falling off the edge of one and injuring themselves. Therefore, practitioners should employ discretion when deciding whether to use this system or not. The potential limitation of the measurement range of this system should also be considered. Each plate has a measurement range of -1.1 kN to 4.4 kN and overload protection to 6.6 kN. Using two plates together provides a more than adequate measurement range for unloaded CMJ, but the validity of this system with loaded CMJ or resistance exercises has yet to be established. To summarize, the portable force plate system provides a reliable and valid method of obtaining CMJ reactive strength and force-time variables.

In conclusion, the portable force plate system provides valid and reliable measures of CMJ reactive strength and underpinning force-time variables. These results clearly show that practitioners can use this relatively inexpensive portable force plate system in place of the laboratory-based force plate system to record accurate measures of CMJ reactive strength and force-time variables.

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Table and figure legends

Table 1. Results of the within-session reliability analysis.

Table 2. Results of the comparison between CMJ force-time characteristics obtained from the laboratory and portable force plate.

Figure 1. The portable force plate system positioned on top of the laboratory force plate system.

Figure 2. Identification of the time to take-off and the braking and propulsion sub-phases from the laboratory and portable force plate systems.