AGREEMENT AMONG COUNTERMOVEMENT JUMP FORCE-TIME VARIABLES OBTAINED FROM A WIRELESS DUAL FORCE PLATE SYSTEM AND AN INDUSTRY GOLD STANDARD SYSTEM

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The purpose of this study was to explore the agreement between a wireless and portable dual force plate system, and an in-ground force plate system, which is an industry gold standard. The countermovement jump (CMJ) was compared across the two systems because it is the most popular force plate test in sports settings. Recreationally active adults (*n*=20) performed three maximal-effort CMJs on the portable force plates which were placed atop two adjacent in-ground force plates to enable simultaneous collection of raw force-time data (1000 Hz) over five seconds. Popular CMJ force-time variables were analysed for each system using a custom Microsoft Excel spreadsheet using criterion methods. Ordinary least products regression (OLPR) showed no fixed or proportional bias between the force plate systems for all variables. Thus, the portable force plate system may be considered a valid alternative to an industry gold standard for the assessment of CMJ force-time variables.

KEYWORDS: Neuromuscular function, physical performance testing, concurrent validity.

INTRODUCTION: Neuromuscular function (NMF) is commonly evaluated utilising biomechanical apparatus such as force plates, which enable the collection of force-time data. Appropriate software (e.g., proprietary software or Microsoft Excel) can then be used to produce force-time curves and, in vertical jump tasks, forward dynamics can be applied to calculate a multitude of performance variables relating to acceleration, velocity, and displacement (McMahon et al., 2018). Practitioners utilise force-time data to objectify physical capacities, evaluate athlete's neuromuscular response to training and match play stimuli, and ultimately highlight individual and team physical preparedness.

The advent of commercially available, portable, and affordable hardware and software, which produces immediately available reports, means there is a new opportunity to gain more informative data on NMF, more easily, and in situations where this was not previously possible. These data can be used immediately to inform players, coaches, and medical staff on individual preparedness to train and compete, and recommended prescription (McMahon et al., 2018). However, with the increased practicality of systems, accuracy must be maintained, as this is the main factor in determining an appropriate evaluation device (Lake et al., 2019). To establish system accuracy, uncovering any systematic disagreement between said apparatus and a widely used and thoroughly investigated "gold standard" system using appropriate agreement statistics is critical (Ludbrook, 1997, 2012). A recently emerging system, which is gaining popularity within high performance, occupational, and medical contexts is a portable, wireless, dual force plate system by Hawkin Dynamics (HD). A single study has looked to establish the concurrent validity of the HD force plate system, however, with limited statistical analyses (e.g., Pearson correlation coefficients and limits of agreement), and CMJ (a common test of NMF) outcome variables alone (Crowder et al., 2020).

In this study, we aimed to determine the concurrent validity of the HD force plate system by assessing agreement between select variables derived from the force-time data (herein defined as "force-time variables") during the CMJ task to those derived from a laboratory grade, in-ground force plate system (i.e., a "gold standard"). The results of this study will inform the efficacy of using the HD force plate system in future research projects, and in applied sports settings.

METHODS: Twenty recreationally active adults (age = 27 ± 6 years, body mass = 85 ± 14 kg) with a varied sports background and who were injury free volunteered to participate. Current training status and previous resistance and CMJ training experience were not a limiting factor in this study, due to its focus on agreement between the two force plate systems alone. Informed consent was provided, and the study was pre-approved by the Institutional Ethics Committee before recruitment and testing commenced.

A cross-sectional design was employed, whereby testing was conducted during a single session within a human performance laboratory. A standardised warm-up (~ 10 mins) consisting of dynamic stretching and submaximal CMJs was performed by each participant prior to testing to reduce the risk of injury. The HD force plate system (Hawkin Dynamics Inc., Maine, USA) consisting of 2 force plates was placed directly on top of two adjacent in-ground force plates (Advanced Medical Technology Inc., [AMTI], Massachusetts, USA) to collect forces produced through each leg independently and simultaneously. The vertical component of the raw ground reaction force (vGRF) data was collected at 1000 Hz over five seconds via HD proprietary software and Qualisys Track Manager software (Qualisys Ltd., Gothenburg, Sweden) for the HD and AMTI systems, respectively. Both systems were zeroed before each CMJ trial. Participants then stepped onto the force plates, stood completely upright (extended hips and knees) and motionless for at least one second before completing a maximal effort CMJ following a “3, 2, 1, jump” command. Participants were cued to jump “as fast and high as possible” for three recorded CMJ trials with arms akimbo.

The raw vGRF data was exported from each system’s software to Microsoft Excel, which was used to analyse the bilateral forces (summed left and right leg forces) using a custom spreadsheet. The average across three CMJ trials (for each variable) was taken forward for statistical analyses. The participants’ body weight was calculated by averaging the vertical force trace over the first one second of data collection when the subject was stationary on the force plate (Moir, 2008). Onset of movement was identified as 30 ms prior to the instant when vertical force is reduced by a threshold equal to 5 times the standard deviation (SD) of BW (calculated in the weighing phase) (Owen et al., 2014). To identify take-off and touchdown, a threshold of force equal to 5 times the SD of flight force (when the force platform is unloaded), taken over a 300-ms portion of the flight phase, was used (McMahon et al., 2018). Time to take-off was calculated as the time between the onset of movement and take-off. Due to the AMTI system having greater flight phase force (~16 N vs ~ 8 N), we used the AMTI take-off threshold for both systems. The CMJ phases were identified using the terminology explained recently (McMahon et al., 2018). Braking and propulsion peak force, mean force, and net impulse, were defined as explained in previous research (McMahon et al., 2022). Countermovement depth was taken from the onset of movement to the end of the braking phase. Peak propulsive velocity and take-off velocity (TOV) were determined based on impulse-momentum theorem. Jump height (JH) was derived from the TOV method (Moir, 2008). The modified reactive strength index (mRSI) was calculated as JH divided by time to take-off (McMahon et al., 2022).

Statistical analyses were performed using SPSS software (version 25; SPSS Inc., Chicago, IL, USA). The potential sources of systematic disagreement between force plate systems were determined via OLPR, which was conducted following the recommendations of Ludbrook (1997, 2012). If the bootstrapped 95% confidence interval (CI) for the intercept did not include 0, then fixed bias was inferred to be present. If the bootstrapped 95% CI for the slope did not include 1, then proportional bias was inferred to be present.

RESULTS: The OLPR coefficients and corresponding bootstrapped 95% CIs are reported in Table 1. For all variables investigated, one can infer there was no fixed or proportional bias between the two force plate systems. Therefore, it may be suggested that the wireless dual force plate system may be considered a valid alternative to the industry gold standard with respect to measuring common CMJ force-time variables.

Table 1. Descriptive and agreement statistics for the selected variables.

	AMTI (Mean ± SD)	Hawkin Dynamics (Mean ± SD)	Slope	Slope *95% CI*	Intercept	Intercept *95% CI*
mRSI (ratio)	0.43 ± 0.10	0.43 ± 0.10	1.013	*0.991 to 1.036*	-0.004	*-0.012 to 0.004*
Jump Height (m)	0.31 ± 0.07	0.31 ± 0.06	1.030	*0.978 to 1.082*	-0.005	*-0.020 to 0.010*
Time to Takeoff (s)	0.763 ± 0.089	0.768 ± 0.088	1.006	*0.956 to 1.036*	-0.013	*-0.057 to 0.004*
Peak Velocity (m/s)	2.6 ± 0.3	2.6 ± 0.2	1.033	*0.989 to 1.077*	-0.074	*-0.186 to 0.038*
Propulsive Net Impulse (Ns)	210 ± 42	209 ± 42	0.992	*0.974 to 1.010*	2.789	*-1.043 to 6.622*
Avg. Propulsive Force (N)	1668 ± 292	1664 ± 291	1.003	*0.997 to 1.010*	-2.258	*-12.429 to 7.912*
Peak Propulsive Force (N)	2043 ± 344	2041 ± 344	0.999	*0.995 to 1.003*	3.921	*-5.245 to 13.088*
Countermovement depth (m)	-0.30 ± 0.06	-0.30 ± 0.06	1.014	*0.971 to 1.058*	0.007	*-0.006 to 0.020*
Braking Net Impulse (Ns)	107 ± 25	107 ± 25	1.004	*0.991 to 1.016*	-0.907	*-2.073 to 0.259*
Avg. Braking Force (N)	1496 ± 251	1498 ± 251	0.999	*0.993 to 1.005*	-1.584	*-10.655 to 7.487*
Peak Braking Force (N)	1952 ± 320	1953 ± 320	0.998	*0.991 to 1.005*	2.526	*-11.804 to 16.856*
Body Weight (N)	833 ± 142	834 ± 142	1.002	*0.995 to 1.009*	-1.881	*-7.795 to 4.032*

Key: SD, standard deviation; CI, confidence interval; m, metres; s, seconds; N, Newtons; Avg, Average.

DISCUSSION: The purpose of this study was to determine the concurrent validity of a wireless and fully portable dual force plate system by HD, by assessing agreement between select force-time variables during the CMJ task to those derived from an AMTI system, considered a "gold standard". The wireless dual force plate system can be considered a valid alternative to the criterion, industry gold standard with respect to collecting CMJ force-time data, because the OLPR analysis showed no fixed or proportional bias between the two force plate systems for any of the variables (Table 1).

Although the present findings support the conclusions of the sole previous study with a similar approach (Crowder et al., 2020), the results here indicate a better agreement between the two force plate systems. This is due to this study performing what may be considered a philosophically more robust methodological and statistical approach design. For example, in the study by Crowder et al. (2020), it is unclear whether their participants performed three maximal effort CMJs on the HD and AMTI systems, separately. This is an initial concern, as it is rare that participants will perform separate CMJ trials with identical force-time variables. This introduces random error due to inherent biological variation, which confounds the mechanical variation we are investigating. Additionally, the previous study only assessed the mean bias between systems for the outcome JH alone without assessing agreement between the strategy metrics underpinning JH. In contrast, the present study performed a more thorough analysis by including CMJ strategy variables. From a statistical perspective, the more philosophically robust OLPR analysis was chosen in this study, according to recommendations from Ludbrook (1997, 2012), as opposed to the lesser regarded Pearson's Correlation Coefficients, and Bland-Altman plots with 95% limits of agreement (LOA) used by Crowder et al. (2020). Differences in data collection frequencies were also evident, with the AMTI system collecting at 1200Hz, whereas the HD system collected at 1000 Hz (Crowder et al., 2020). This discrepancy can affect key events of the CMJ, such as onset of movement and take-off thresholds. Additionally, they allowed participants to use arm swing (AS) during trials, which adds another factor which can affect the variability of trials. The researchers highlighted that the inclusion of AS could have increased the variability of trials, as has been seen in previous research, and thus the pattern of mean difference seen between systems (Crowder et al., 2020). Taken together, the methodological shortcomings of the Crowder et al. (2020) study may explain why their LOA analysis showed that JH collected with the HD system could be expected to range anywhere from 7.10 cm lower to 7.63 cm higher than that measured by the AMTI system, which we deem unacceptable.

Based on the present study, practitioners can consider the HD system as an accurate system to use as an alternative to the traditional, non-portable and more expensive in-ground AMTI system. This is useful information for practitioners seeking a system to evaluate NMF using CMJs in sports, but are restricted by system complexity, location, and price. Due to the increased practicality of the HD system, this can now be done easily in competition and training environments previously unavailable to practitioners. For example, the system can be used at any training facility to monitor NMF capacity, as a training tool in the gym to increase within-session intent and monitor between-session progress, and pitch- or trackside after sessions to determine the neuromuscular response to training or competition. These factors also apply to researchers who can now ask and answer more authentic research questions relating to neuromuscular fitness and fatigue in sports settings.

As this study has found agreement in the commonly used CMJ assessment, further research should consider identifying these patterns with different vertical jump tasks. Exploring agreement between these systems for jumps that involve different magnitudes, rates, and frequencies of loading (e.g., repeated peak landing forces in rebound jumps) would be worthwhile. Additionally, the strain gauge-based HD force plate system may also be compared to other portable force plate systems, including those that use piezoelectric sensors. Finally, replicating this study with athletes who can obtain extreme jump heights would be efficacious.

CONCLUSION: The results of this study demonstrate that there is no fixed or proportional bias between the HD and AMTI (gold standard) force plate systems for measuring common CMJ strategy and outcome variables. Therefore, this wireless and fully portable dual force plate system may be considered a valid alternative to the industry gold standard for the assessment of CMJ force-time variables and thus may be confidently used for this purpose by researchers and practitioners alike who currently (or plan to) use the HD force plate system.

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ACKNOWLEDGEMENTS: This study was conducted as part of the lead author's PhD research which is jointly funded by Hawkin Dynamics Inc. and the University of Salford.