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Original Research

The Agreement Between a Portable Contact-Mat and Force-Plates During Bilateral Vertical Jumps

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ABSTRACT

International Journal of Exercise Science 15(1): 632-644, 2022. Force plates are commonly used when assessing vertical jumping performance but are not always affordable or practical tools for all testing situations. Twenty-four participants volunteered to take part in a study investigating the agreement between bilateral force plates and a new commercially available contact mat that records jump height, flight-time (FT), and FT of individual limbs during both countermovement (CMJ) and squat (SJ) jumps. Each participant performed six jumps of each type while standing on a contact mat placed upon a pair of in-ground force plates. When compared to the force plate via ordinary least products regression, the contact mat agreed with force plate CMJ and SJ jump height, individual limb FT during CMJs, and left-leg FT during SJs. The bilateral contact mat provided valid assessment of individual limb FT during CMJs, but not SJs. Practitioners can therefore use a bilateral contact mat interchangeably with bilateral force plates to measure SJ and CMJ performance.

KEY WORDS: Performance testing, athlete monitoring, athlete testing

INTRODUCTION

Vertical jump tasks are frequently used by strength and conditioning professionals to monitor an athlete's ability to rapidly generate force, adaptions to training interventions, or the fatigue accumulated in response to both competition and training (18, 21, 30). Traditionally, these measurements have been performed in laboratory or institutional settings using force plates (24), which enable the direct measurement of the force applied during the jump. The vertical force-time record enables variables like jump height and flight-time (FT) to be calculated along with force or impulse during specific subphases of the movement (21).

Despite their frequent use, force plates and their associated software systems have historically been relatively expensive which has precluded their use in some situations.

As such, contact mat devices that record the time the athlete spends in the air during a jump (i.e., FT) using switch triggered timers are commonly used in their place (14, 19, 21, 23, 26, 33). The recorded flight-time is then entered into a conversion equation and used to estimate jump height without direct measurement of the force applied during the concentric phase of the jump task (11, 15, 21). These devices can also have the added benefit of providing immediate results that are displayed on a computer or, more recently, a smartphone or tablet application (19, 21). This removes the need to perform potentially time-consuming post-collection analysis associated with many typical force-plate systems.

Recently, a bilateral contact mat (EzeJump; Swift Performance, QLD, Australia) was designed to assess the flight-time of individual limbs during vertical jumping tasks such as the countermovement (CMJ) and squat (SJ) jump. To our knowledge, it is not known whether a device of this nature provides a valid assessment of vertical jump performance. If shown to be valid, this device may offer a more logistically feasible alternative to traditional force-plate methods of assessing bilateral vertical jump performance. As such, the aim of this study was to investigate the concurrent validity and reliability of a portable bilateral jump mat device during both CMJs and SJs. We hypothesized that all jump mat derived jump characteristics would agree with those calculated from flight-time data recorded using bilateral force plates.

METHODS

Participants

Based on the effect size of 1.49 reported by McMahon, Jones and Comfort (19) when comparing jump height between a contact mat and force plate and an expected power of 0.95, a minimum sample size of 9 participants was estimated using the jpower module in jamovi (version 2.0.0, the jamovi project, NSW, Australia) (28, 31). Based on the recommendation of Bablok and Passing (2) that a minimum of 20 participants be recruited when comparing methods of measurement, five female and nineteen male participants (age = 28.5 ± 4.0 years, height = 170.5 ± 17.2 cm, body mass = 83.5 ± 26.8 kg) were recruited for this study. All participants were healthy and reported no lower-body musculoskeletal injury within the previous six months that would affect their jumping performance. Before undertaking the testing protocol, participants read and returned signed informed consent forms, as approved by the Edith Cowan University Human Research Ethics Committee (Project 2019-00364).

Protocol

A within-participant, repeated measures design was used to assess the agreement between a portable bilateral contact-mat and two force-plates during multiple CMJ and SJ performance. Participants performed two testing sessions separated by a minimum of 48 hours, with a total of twelve jumps performed in each session. Participants were asked to refrain from lower-body exercise for the 48 hours before each testing session, which were performed at the same time of day (± one hour) to account for any potential effects of circadian rhythm. This research was carried out fully in accordance with the ethical standard of the International Journal of Exercise Science (25).

Before vertical jump testing, participants performed a five-minute warm-up that included dynamic stretching, bodyweight squats and lunges, and sub-maximal vertical jumps. Following this, participants completed a total of twelve vertical jumps: six CMJs and six SJs. Test order was block-randomized to reduce the potentially detrimental effects of fatigue. Briefly, during CMJs and after a countdown of "3, 2, 1, Jump!", participants lowered themselves to a self-selected depth and rapidly reversed their movement to propel themselves upwards in one motion (11). During SJs, participants were asked to squat to an ~90° knee angle (11). Once a stable bottom position had been established, a countdown of "3, 2, 1, Jump!" was provided and the participant rapidly propelled themselves upwards. Before the jump trials, participants were instructed to jump "as high and as fast as possible" while keeping their hands on their hips (21). Each jump trial and jump type were separated by one and three minutes of passive rest, respectively. SJ trials were repeated if there was a visually obvious countermovement during real-time inspection of the force-time curve. All trials were performed standing on a contact-mat (EzeJump; Swift Performance, QLD, Australia) that was positioned over a pair of in-ground force plates (Type 9287CA/9287BA, Kistler Instruments, Winterthur, Switzerland). Vertical ground reaction force data was sampled at 1000 Hz using BioWare software (version 5.1; Kistler Group, Winterthur, Switzerland) and exported to text files for offline analysis. The contact-mat was interfaced with a tablet via Bluetooth (iPad 6th Gen; Apple Inc, CA, USA) and calculated both jump height and flight-time for each limb individually in real-time using the EzeJump application (version 2.5.10).

Unfiltered right- and left-leg vertical forces recorded during each jump trial were analyzed as separate and summated force-time curves using custom Excel spreadsheets (Microsoft Corp, WA, USA). Bodyweight (BW) was calculated as the average force during a one second pre-jump 'quiet standing' period (29). The start of the CMJ was identified by finding the first instance where force exceeded BW ± 5 SDs (27). To satisfy the assumption of zero velocity, a backwards search of the force-time data was then performed to find the last sample equal to BW (29). The start of each SJ trial was identified as the first instance of BW + 5 SDs. Take-off and landing were identified according to the methods of Lake et al. (13). Right-leg (FTR), left-leg (FTL), and combined flight-time (FT) were calculated as the time between these two points. Jump height (JH) was calculated from the collected force-time data via FT (21), using the equation:

$$\text{JH} = \frac{FT^2 \times 9.81}{8}$$

The contact-mat software also calculated JH according to the FT method (combined), as well as recording FT from each limb individually. The trial with the highest JH calculated from the force-plate data during each jump type in session one was carried forward for the assessment of agreement between devices, while the two trials with the highest JH were used to determine within-session reliability. The trial with the highest JH during each session was used determine between-session reliability.

Statistical Analysis
Descriptive statistics were calculated as means and standard deviations (SD). Normality of distribution was assessed using the Shapiro-Wilk test, with an alpha level of 0.05, and visual inspection of Q-Q plots. The agreement between the contact-mat and bilateral force-plates was assessed using ordinary least products regression (16). Fixed bias (a significant systematic difference) was deemed present if the 95% confidence interval (CI) of the intercept did not include zero, while proportional bias (a significant proportional difference) was deemed present if the 95% CI of the slope did not include one (16). Hedges g effect sizes with 95% CIs were calculated to estimate the magnitude of differences between devices (6) and interpreted as trivial (<0.2), small (0.2-0.5), moderate (>0.5-0.8), or large (>0.8) (3). Statistical analyses were performed in the R language and environment for statistical computing (version 4.0.0) (28). Ordinary least products regression analyses were performed according to the procedures of Ludbrook (17), with 95% CIs calculated in a custom script via bootstrap resampling (5, 7, 32, 34). Effect sizes were calculated using the MBESS package (version 4.8.0) (9). Within- and between-session reliability of each variable during both CMJs and SJs was determined using the intra-class correlation coefficient (ICC, type 3,1), coefficient of variation (CV), and 95% CIs calculated in an Excel spreadsheet (8). The magnitude of the ICCs were interpreted according to the scale outlined by Koo and Li (12), with ICCs of <0.5, 0.5-0.75, >0.75-0.9, and >0.9 representative of poor, moderate, good, and excellent relative reliability, respectively. CV values of <5%, 5-10%, and >10% were indicative of good, moderate, and poor absolute reliability (4).

RESULTS

All data are presented as means ± SD (Table 1; Table 2). No fixed or proportional bias was present for JH, FTR or FTL during CMJs (Figure 1), however, both proportional (slope 95% CIs: 1.011, 1.032) and fixed (intercept 95% CIs: -0.012, -0.001) bias was present between devices for FT. During SJs, no fixed or proportional bias was present for JH, FT, or FTL (Figure 2). Both fixed (intercept 95% CIs: 0.019, 0.073) and proportional (slope 95% CIs: 0.871, 0.979) bias was present for FTR. Trivial differences were found for all variables (Table 1 and 2), regardless of jump type. All variables exhibited excellent within-session relative reliability (ICCs >0.9) and good absolute reliability (CV <5%) in both CMJs (Figure 3) and SJs regardless of measurement device. JH exhibited good to excellent between-session relative reliability and moderate to poor absolute reliability during both jump types, regardless of jump type (Figure 4).

Table 1. Descriptive statistics and Hedges *g* effect sizes for variables calculated using each device during countermovement jumps

Variable	Force Plate	Jump Mat	Hedges g (95% CI)
JH (cm)	36.452 ± 8.887	35.867 ± 8.703	0.066 (-0.501, 0.631)
FT (s)	0.541 ± 0.067	0.537 ± 0.065	0.071 (-0.496, 0.636)
FTR (s)	0.546 ± 0.066	0.542 ± 0.066	0.063 (-0.503, 0.628)
FTL (s)	0.541 ± 0.067	0.540 ± 0.064	0.006 (-0.560, 0.571)

Note: JH = jump height; FT = flight-time; FTR = Right-leg flight-time; FTL = Left-leg flight-time; CI = confidence interval

Table 2. Descriptive statistics and Hedges g effect sizes for variables calculated using each device during squat jumps.

Variable	Force Plate	Jump Mat	Hedges g (95% CI)
JH (cm)	33.370 ± 8.141	32.833 ± 8.159	0.058 (-0.508, 0.624)
FT (s)	0.518 ± 0.064	0.514 ± 0.065	0.058 (-0.508, 0.624)
FTR (s)	0.524 ± 0.061	0.516 ± 0.067	0.107 (-0.459, 0.673)
FTL (s)	0.517 ± 0.065	0.519 ± 0.062	-0.025 (-0.590, 0.542)

Note: JH = jump height; FT = flight-time; FTR = Right-leg flight-time; FTL = Left-leg flight-time; CI = confidence interval

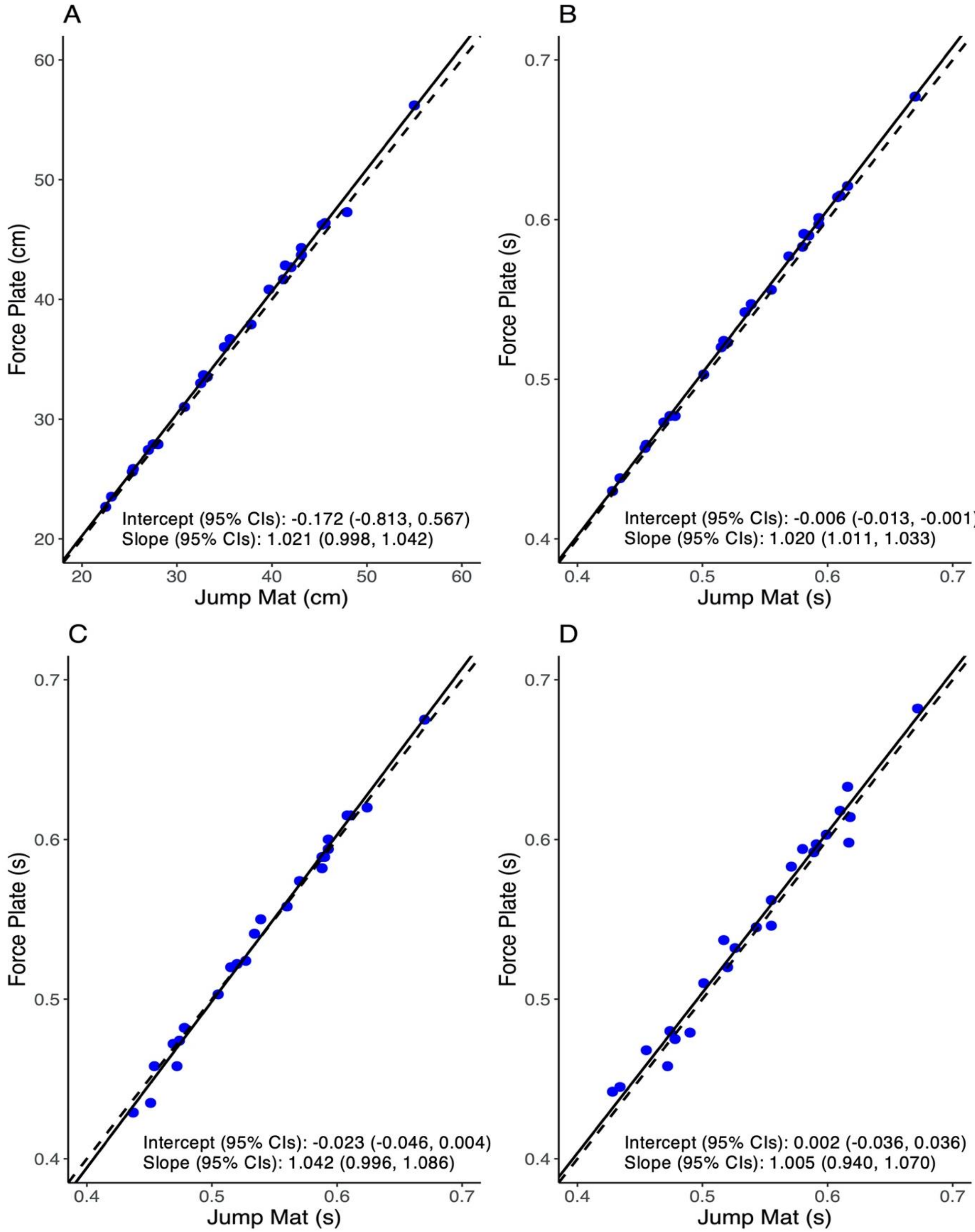

Figure 1. Countermovement jump (CMJ) ordinary least products comparisons between force plate and EzeJump. The solid line represents the ordinary least products regression line, while the dashed line represents identity. A) Jump height (JH); B) Flight-time (FT); C) Left-leg flight-time (FTL); D) Right-leg flight-time FTR).

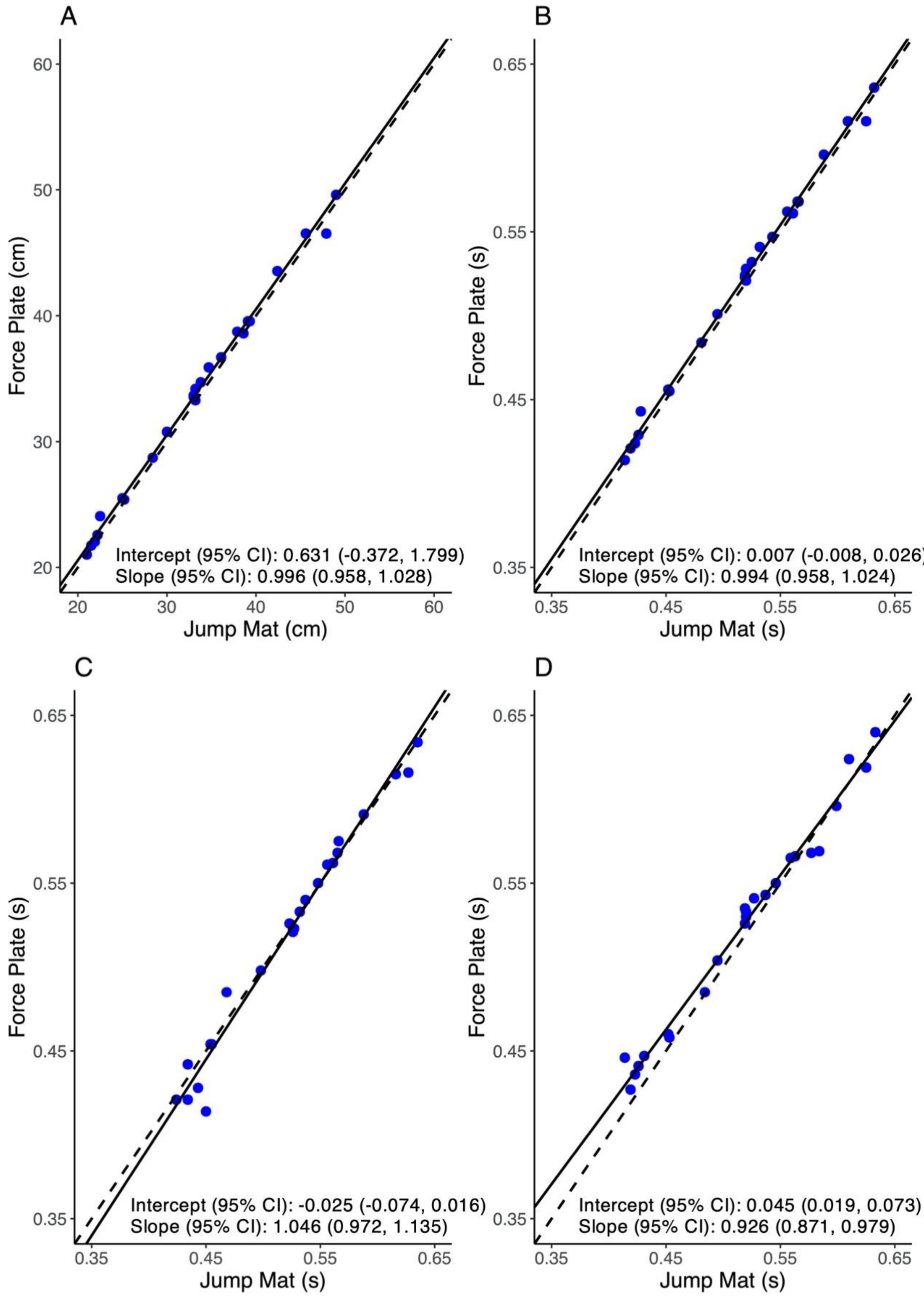

Figure 2. Squat jump (SJ) ordinary least products regression comparisons between force plate and EzeJump. Solid line represents the ordinary least products regression line. Dashed line represents identity. A) Jump height (JH); B) Flight-time (FT); C) Left-leg flight-time (FTL); D) Right-leg flight-time (FTR).

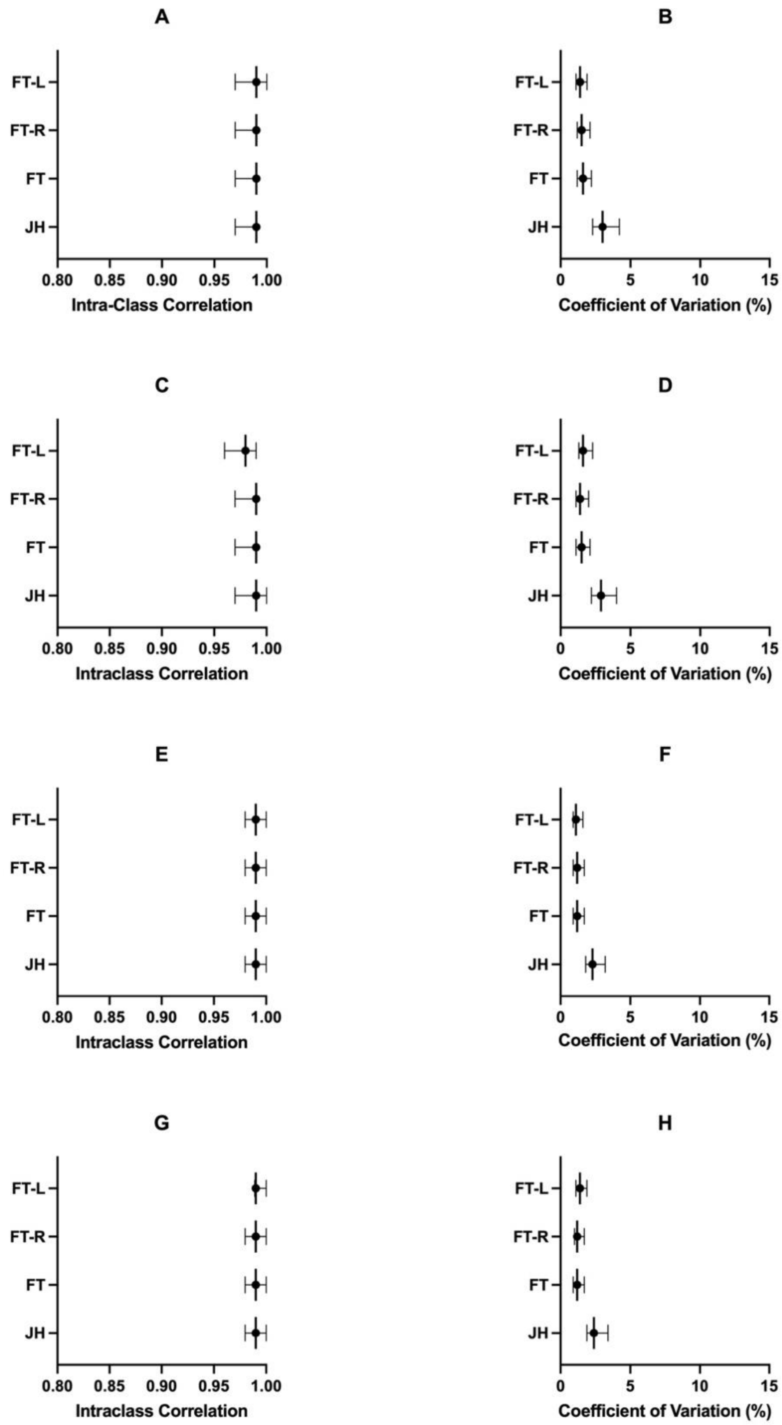

Figure 3. Within-session reliability statistics for countermovement jump (CMJ) and squat jump variables from both the force plates and EzeJump. Error bars represent 95% confidence intervals. A) CMJ force plate intraclass correlation (ICC); B) CMJ force plate coefficient of variation (CV); C) CMJ EzeJump ICC; D) CMJ EzeJump CV; E) SJ force plate ICC; F) SJ force plate CV; G) SJ EzeJump ICC; H) SJ EzeJump CV. JH = jump height; FT = flight-time; FT-L = Left-leg flight-time; FT-R = Right-leg flight-time.

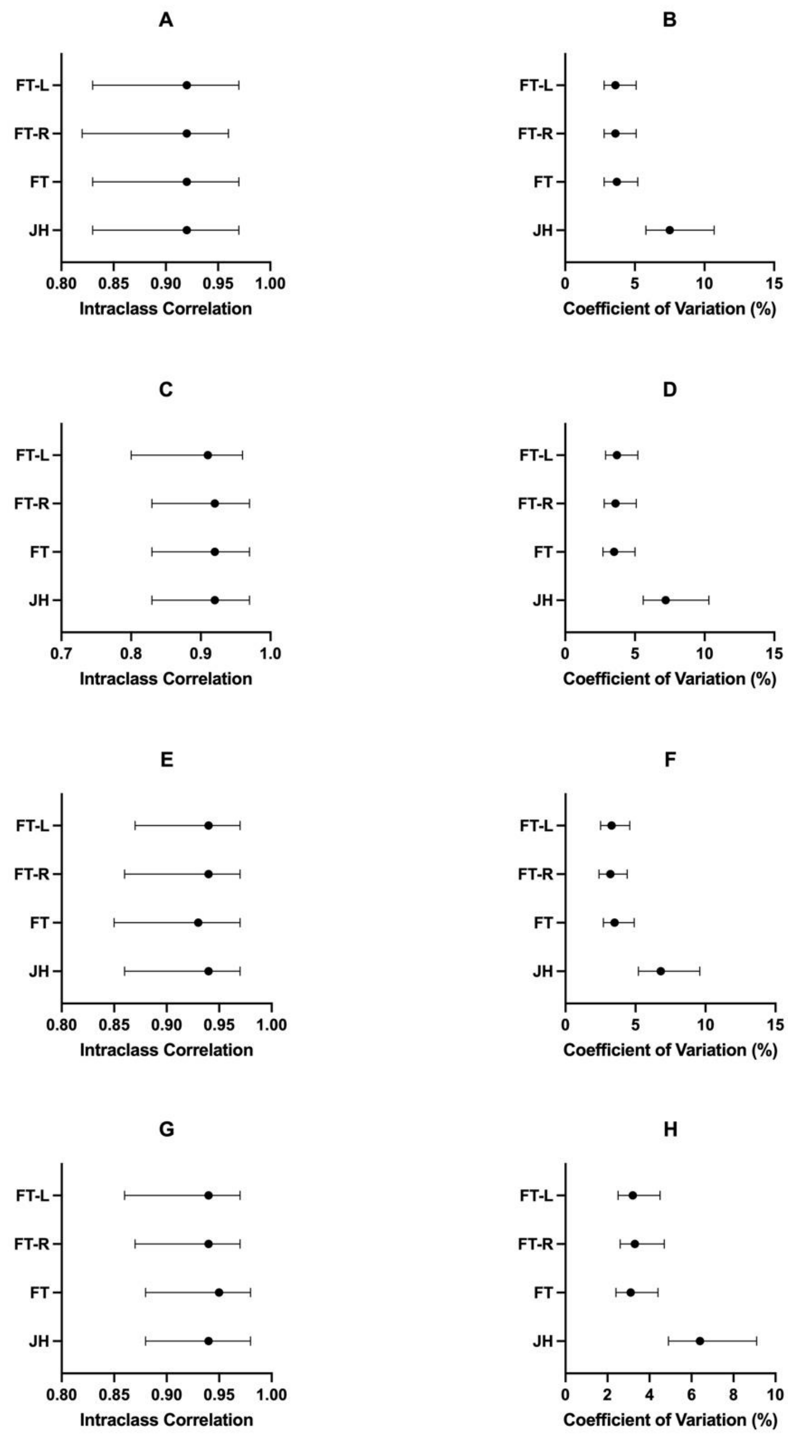

Figure 4. Between-session reliability statistics for countermovement (CMJ) and squat jump (SJ) variables from both the force plates and contact mat. Error bars represent 95% confidence intervals. A) CMJ force plate intraclass correlation (ICC); B) CMJ Force plate coefficient of variation (CV); C) CMJ contact mat ICC; D) CMJ contact mat CV; E) SJ force plate ICC; F) SJ force plate CV; G) SJ contact mat ICC; H) SJ contact mat CV. JH = jump height; FT = flight-time; FT-L = Left-leg flight-time; FT-R = Right-leg flight-time.

DISCUSSION

This study aimed to determine the concurrent validity and reliability of a novel contact-mat system that enabled the calculation of individual limb FT during both CMJs and SJs. The primary finding was that individual limb flight-time, as estimated by the contact-mat, agreed with force plate measures during CMJs, with only practically trivial differences between each of the devices. Similarly, CMJ jump height estimated by the contact-mat agreed with the force-plate. SJ FTR estimated by the contact-mat, however, did not agree with the force plate as both fixed and proportional bias were present. This therefore suggests that the contact-mat cannot be used interchangeably with a force-plate for FTR measures. No fixed or proportional bias was present for all other SJ metrics, indicating that the contact-mat and force-plate could be used interchangeably to assess JH and combined FT.

Importantly, along with being valid for the estimation of both JH and individual-limb flight-time during the CMJ, the contact-mat demonstrated excellent within-session reliability for each of these measures (Figure 3). These results were consistent with those reported for the force-plates and are consistent with the results of McMahon et al. (19), who also reported excellent relative reliability (ICC = 0.96) and low CVs for CMJ jump height estimated using the Just Jump system. When the between-session 95% CIs were examined, relative reliability during CMJs was considered 'good-to-excellent' for both the contact-mat and force-plates (Figure 4), while combined and individual limb flight-time absolute reliability was 'moderate-to-good' (Figure 4). CMJ jump height was more variable between-sessions for both the force-plates and contact-mat, with moderate to poor CVs based on the 95% CIs found. Given these results were also consistent between devices, this suggests that the greater variability observed during CMJs was a function of biological factors rather than variability of the measurement device. These findings also align with those of Moir et al. (23) and Moir et al. (22) who reported 'good-to-excellent' between- session ICCs and 'moderate-to-good' CVs for CMJ JH estimated via a different model of contact-mat.

Although the contact-mat investigated in the present study is largely valid when compared to force plate measures for JH during both CMJs and SJs, strength and conditioning professionals should remain cognizant of the assumptions and limitations of assessing vertical jump performance through the calculation of flight-time (20). JH calculated via this method assumes that the height of the athlete's center of mass is the same at the instant of landing as the instant of take-off (11, 15). Given the flight-time method typically results in overestimations of JH when compared to the take-off velocity method, even when position is maintained (1, 10, 24), violation of this assumption will likely exacerbate the error. Furthermore, although the contact-mat investigated in this study enables the estimation of individual-limb flight-time during bilateral countermovement jumps, the information it provides is limited in comparison to force plates. Therefore, practitioners should consider whether they would like to be able to assess more than jump height and flight-time as part of their equipment procurement process.

The EzeJump contact-mat investigated in this study may be used interchangeably with a force plate for the measurement of individual limb flight-time during CMJs, provided the assumptions of the flight-time method are met. Similarly, JH calculated from flight-time during both squat and countermovement jumps are valid when compared to the force plate. When FTR is measured during squat jumps however, the presence of both fixed and proportional bias suggests that it cannot validly be used in place of a force plate to assess individual-limb flight-time during that jump task.

CONFLICT OF INTEREST DISCLOSURE

Swift Performance provided access to both the EzeJump contact-mat and associated proprietary iPad application used in this study. They played no part in the study's design, analysis of the data, or preparation and decision to publish this manuscript. Jason Lake provides consultancy services and is Director of Education for Hawkin Dynamics, a portable force plate manufacturer and analysis software company. Hawkin Dynamics' products were not used in this study, nor did they play any role in its design, analysis of the data, or preparation and decision to publish this manuscript. The authors have no further interests to declare.

REFERENCES

1. Aragón LF. Evaluation of four vertical jump tests: Methodology, reliability, validity, and accuracy. Meas Phys Edu Exerc Sci 4(4):215-228, 2000.

2. Bablok W, Passing H. Application of statistical procedures in analytical instrument testing. J Automat Chem 7(2):74-79, 1985.

3. Cohen J. The t test for means. In. *Statistical power analysis for the behavioral sciences*. Hilldale, NJ: Lawrence Earlbaum Associates; 1988, pp. 19-74.

4. Duthie G, Pyne D, Hooper S. The reliability of video based time motion analysis. Journal of Human Movement Studies 44:259-272, 2003.

5. Efron B, Hastie T. Bootstrap confidence intervals. In. *Computer age statistical inference: Algorithms, evidence, and data science*. Cambridge, UK: Cambridge University Press; 2016, pp. 181-207.

6. Hedges LV, Olkin I. Estimation of a single effect size: Parametric and nonparametric methods. In. *Statistical methods for meta-analysis*. San Deigo, CA: Academic Press; 1985, pp. 75-106.

7. Henry L, Wickham H. Purrr: Functional programming tools. In: 2020.

8. Hopkins WG. Spreadsheets for analysis of validity and reliability. Sportscience 19:36-42, 2015.

9. Kelley K. Mbess: The mbess r package. In: 2020.

10. Kibele A. Possibilities and limitations in the biomechanical analysis of countermovement jumps: A methodological study. J Appl Biomech 14(1):105-117, 1998.

11. Komi PV, Bosco C. Utilization of stored elastic energy in leg extensor muscles by men and women. Med Sci Sports 10(4):261-265, 1978.

12. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficents for reliability research. J Chiropr Med 15:155-163, 2016.

13. Lake JP, Mundy PD, Comfort P, Suchomel TJ. Do the peak and mean force methods of assessing vertical jump force asymmetry agree? Sports Biomech 19(2):227-234, 2020.

14. Leard JS, Cirillo MA, Katsnelson E, Kimiatek DA, Miller TW, Trebincevic K, Garbalosa JC. Validity of two alternative systems for measuring vertical jump height. J Strength Cond Res 21(4):1296-1299, 2007.

15. Linthorne NP. Analysis of standing vertical jumps using a force platform. Am J Phys 69(11):1198-1204, 2001.

16. Ludbrook J. Statistical techniques for comparing measurers and methods of measurement: A critical review. Clin Exp Pharmacol Physiol 29(7):527-536, 2002.

17. Ludbrook J. A primer for biomedical scientists on how to execute model ii linear regression analysis. Clin Exp Pharmacol Physiol 39(4):329-335, 2012.

18. McLellan CP, Lovell DI, Gass GC. Markers of postmatch fatigue in professional rugby league players. J Strength Cond Res 25(4):1030-1039, 2011.

19. McMahon JJ, Jones PA, Comfort P. A correction equation for jump height measured using the just jump system. Int J Sports Physiol Perform 11(4):555-557, 2016.

20. McMahon JJ, Jones PA, Comfort P. Comment on: "Anthropometric and physical qualities of elite male youth rugby league players". Sports Med 47(12):2667-2668, 2017.

21. McMahon JJ, Lake JP, Suchomel TJ. Vertical jump testing. In: P Comfort, P A Jones and J J McMahon editors. *Performance assessment in strength and conditioning*. Oxon, UK: Routledge; 2019, pp. 96-118.

22. Moir G, Button C, Glaister M, Stone MH. Influence of familiarization on the reliability of vertical jump and accleration sprinting performance in physically active men. J Strength Cond Res 18(2):276-280, 2004.

23. Moir G, Shastri P, Connaboy C. Intersession relability of vertical jump height in women and men. J Strength Cond Res 22(6):1778-1784, 2008.

24. Moir GL. Three different methods of calculating vertical jump height from force platform data in men and women. Meas Phys Edu Exerc Sci 12(4):207-218, 2008.

25. Navalta JW, Stone WJ, Lyons TS. Ethical issues relating to scientific discovery in exercise science. Int J Exerc Sci 12(1):1-8, 2019.

26. Nuzzo JL, Anning JH, Scharfenberg JM. The reliability of three devices used for measuring vertical jump height. J Strength Cond Res 25(9):2580-2590, 2011.

27. Owen NJ, Watkins J, Kilduff LP, Bevan HR, Bennett MA. Development of a criterion method to determine peak mechanical power output in a countermovement jump. J Strength Cond Res 28(6):1552-1558, 2014.

28. R Core Team. R: A language and environment for statistical computing. In. Vienna, Austria: R Foundation for Statistical Computing; 2020.

29. Street G, McMillan S, Board W, Rasmussen M. Sources of error in determining countermovement jump height with the impulse method. J Appl Biomech 17(1):43-54, 2001.

30. Taylor K-L, Chapman DW, Cronin JB, Newton MJ, Gill N. Fatigue monitoring in high performance sport: A survey of trends. J Austral Strength Cond 20(1):12-23, 2012.

31. The jamovi project. Jamovi. In. Sydney, Australia2021.

32. Warton DI, Duursma RA, Falster DS, Taskinen S. Smatr 3 – an r package for estimation and inference about allometric lines. Methods Ecol Evol 3(2):257-259, 2012.

33. Whitmer TD, Fry AC, Forsythe CM, Andre MJ, Lane MT, Hudy A, Honnold DE. Accuracy of a vertical jump contact mat for determining jump height and flight time. J Strength Cond Res 29(4):877-881, 2015.

34. Wickham H. Modelr: Modelling functions that work with the pipe. In: 2020.