

Original Article

Validity, reliability, and usefulness of jump performance from a low-cost contact mat

HARIS POJSKIC^{1,2}, EMMANUEL VER PAPA³, SAM SHI XUAN WU⁴, JEFFREY CAYABAN PAGADUAN⁵ 

¹Department of Sports Sciences, Linnaeus University, Kalmar, Sweden

²The Swedish Winter Sports Research Centre, Mid Sweden University, Östersund, Sweden

³College of Human Kinetics, University of the Philippines – Diliman, Quezon City, Philippines

⁴School of Health Sciences, Faculty of Health, Arts and Design, Swinburne University, Melbourne, Australia

⁵College of Medicine, School of Health Sciences, University of Tasmania, Tasmania, Australia

ABSTRACT

The purpose of this study was to establish the validity, reliability, and usefulness of a low-cost contact mat equipment (CM) with a force plate (FP) as the reference. Eleven female (18.6 ± 3.67 yrs.) and male (18.2 ± 2.71 yrs.) basketball athletes performed hands-on-waist countermovement jump (CMJ) and squat jump (SJ) trials. Flight time (FT) and jump height (JH) in CMJ and SJ were subjected for analysis. Relative error expressed as percentage (%RE) was utilized to examine criterion validity between CM and FP. Concurrent validity was also established using Pearson moment correlation (r). Absolute reliability was determined using coefficient of variation (%CV). Relative reliability was identified using intra-class correlation coefficient (ICC). Usefulness was established by comparing typical error (TE) vs. smallest worthwhile change (SWC). Results revealed that CMJ and SJ from a low-cost CM can be used as an alternative tool in assessment of jump performance.

Keywords: Vertical jump; Contact mat; Countermovement jump; Squat jump.

Cite this article as:

Pojskic, H., Papa, E.V., Wu, S.S.X., & Pagaduan, J.C. (2020). Validity, reliability, and usefulness of jump performance from a low-cost contact mat. *Journal of Human Sport and Exercise*, in press. doi:<https://doi.org/10.14198/jhse.2022.172.03>

 **Corresponding author.** College of Medicine, School of Health Sciences, University of Tasmania, Tasmania, Australia.

E-mail: jcpagaduan@gmail.com

Submitted for publication June 23, 2020

Accepted for publication September 02, 2020

Published in press September 28, 2020

JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202

© Faculty of Education. University of Alicante

doi:10.14198/jhse.2022.172.03

INTRODUCTION

Jumping ability plays an integral part in the successful execution of sport skills and performance (Pojskić, Šeparović, Užičanin, Muratović, & Mačković, 2015; Ziv & Lidor, 2010). There is also evidence that jumping performance is a key indicator and useful discriminator of sporting level and player position (Abdelkrim, Chaouachi, Chamari, Chtara, & Castagna, 2010; Delextrat, & Cohen, 2008; Ostojic, Mazic, & Dikic, 2006; Ostijic, Mazic, & Dikic, 2006; Pojskic, Sisic, Separovic, & Sekulic, 2018; Sallet, Perrier, Ferret, Vitelli, & Baverel, 2005). Moreover, regular monitoring of athletes' jumping ability can assist in monitoring training load and fatigue (Malone et al., 2015; McLean, Coutts, Kelly, McGuigan, & Cormack, 2010; Thorpe et al., 2015).

Jump performance can be assessed using different methods. The 'gold standard' for jumping ability is measured using a force platform (FP) that derives kinetic data and jump height (JH), wherein JH is estimated from the impulse-momentum approach or flight time (FT) method (Attia et al., 2017; Buckthorpe, Morris, & Folland, 2012; Cordova & Armstrong, 1996; Cronin, Hing, & McNair, 2004; Dias et al., 2011; Ferreira, Schilling, Weiss, Fry, & Chiu, 2010; García-López et al., 2005; Moir, Shastri, & Connaboy, 2008; Walsh, Ford, Bangen, Myer, & Hewett, 2006). Although utilization of FP in jump measurement presents high validity and consistency, FP entails issues on affordability, portability, and technical expertise for set-up and data management. To address the challenges demonstrated by FP, several low-cost jump measurement systems were developed (Attia et al. 2017; Balsalobre-Fernandez, Glaister, & Lockey, 2015; García-López, Morante, Ogueta-Alday, & Rodríguez-Marroyo, 2013; Kenny, Cairealláin, & Comyns, 2012). Among these, the most frequently used system is through a contact mat (CM). Studies comparing CM with FP as criterion showed equivocal results (Borges Júnior et al. 2011; Kenny et al., 2012; McMahan, Jones, & Comfort, 2016; Rogan, Radlinger, Imhasly, Kneubuehler, & Hilfiker, 2015) which suggest the need for further research and development of CM equipment.

The utilization of jump measurement tools among practitioners depend on equipment reliability and functionality (Pyne, Hopkins, Batterham, Gleeson, & Fricker, 2005). In addition, jump equipment that are easy to operate and portable also provide merit for use. Therefore, the aim of this study was to evaluate the validity, reliability, and functionality of the low-cost CM in estimating JH.

MATERIAL AND METHODS

Participants

Eleven female (age: 18.6 ± 3.67 yrs.; weight: 67.2 ± 9.52 kg) and 11 males (age: 18.2 ± 2.71 yrs.; weight: 74.9 ± 6.34 kg) basketball athletes in the competitive phase volunteered in the study. All the players have reported no history of any neuromuscular disease or injury in the previous 6 months. At the time of the study, they had a mean of 4.7 ± 1.8 years of competitive experience. Athletes trained 8 hours a week (4 sessions of 2 hours each) on the court to improve technical and tactical skills and 3 hours a week (2 sessions of 1.5 hours each) off the court in the gym to improve their strength and power. Athletes also participated in a basketball game every Saturday or Sunday. Participants were asked to refrain from heavy training and tobacco, alcohol and caffeine use, and to avoid sleep deprivation for at least 2 days before the testing sessions. To stay properly hydrated, players were asked not to drink a large amount at once but to drink water frequently in small amounts during the testing sessions. All participants were informed of the purpose, benefits, and risks of the investigation, and all participants voluntarily participated in the testing. Written informed consent for the participation in the study was received from all participants older than 18 years of age. Parents or responsible adults (guardians) signed informed consent for those participants under the age of 18 years. This study was approved by the Mid-Sweden University Ethical Board (Approval No: 2018/714).

Procedures

Experimentation occurred for two sessions separated by 48 h at a basketball facility located at Östersund, Sweden. To avoid diurnal variation, the sessions were performed in the same time between 6 and 8 pm. Anthropometric measurements and familiarization were administered in the first session. To avoid a systematic change in JH, athletes were provided with verbal encouragement to execute jump tests with maximal effort. In the second session, a standardized warm-up of approximately 15 min in duration was performed at the beginning of testing session. It included 10 minutes of a basketball-specific warm-up including the full court drills with dribbling and lay-ups and dynamic stretching. The dynamic stretching included front and lateral lunges, squats with dynamic exercise for the leg adductors, and exercises for the gluteus and gastrocnemius muscles. This was followed by a specific warm-up with high-intensity exercises: six vertical jumps (performed from $\approx 90^\circ$ of the knee flexion angle) and two sub-maximal (70%) and maximal (95–100%) sprints. After the warm-up, there was an active rest of 3–5 min prior to the testing. Then, vertical jump testing occurred.

Anthropometrics

Body height and mass were measured to the nearest 0.01 m and 0.1 kg respectively, using a portable stadiometer and scale (Seca, Birmingham, UK) at the beginning of the familiarization session. Body mass index (BMI) = body mass (kg) / body height (m²) was also calculated for each player.

Vertical jump

This study involved athletes performing CMJ and SJ jump trials at an indoor basketball gymnasium during training time. For CMJ, athletes stood on a shoulder-width apart stance, and hands kept on the waist (Figure 1a-e). Then, a quick countermovement was executed followed by a vertical jump whilst keeping hands on the waist. After CMJ testing, a 2-minute active rest followed. This was succeeded by performance of SJ trials. In SJ, athletes used the same stance and hand position of CMJ. Afterwards, the athletes were asked to bend their knees at approximately 90-120 degrees. This position was kept for 3 seconds. Then, the athletes proceeded with vertical jump without any countermovement. Three trials were administered for both CMJ and SJ with rest intervals of 30 seconds in between the trials. However, additional trial or trials were given if any faulty CMJ or SJ pattern execution was detected by the equipment or tester. Average FT and JH values in CMJ and SJ from CM and FP were kept for analysis.

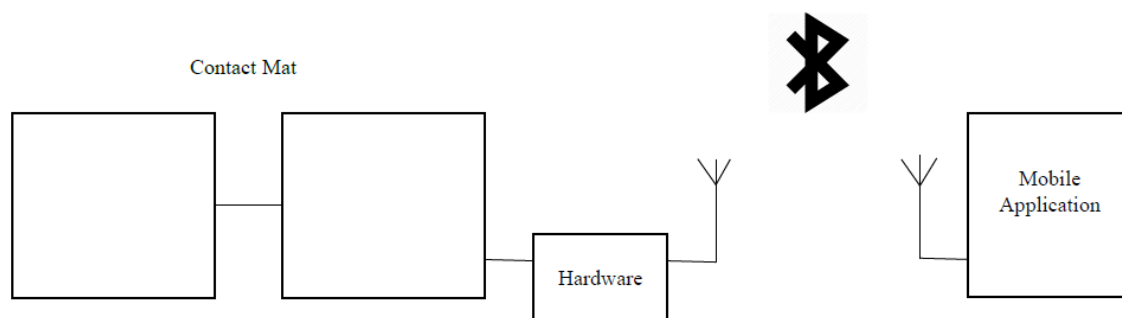


Figure 1. Low-cost CM system block scheme.

Equipment

Two-parallel copper-plated CM (28.54 x 28.54 cm) separated by 12 cm were placed over the FP. CM is connected to a hardware via a mobile application to arrive jump parameters. The hardware consists of a

development board (Adafruit Feather MO Basic Proto, Adafruit, USA), a Bluetooth module (BLE Micro, DF Robot, USA), and two 3 mm LED lights. The block scheme of the CM equipment is presented in Fig 2. FT was detected when the foot immediately leaves the contact mat and stops once the foot landed an area of the mat. JH was measured from FT applying the method described by Markovic, Dizdar, Jukic, & Cardinale (2004), JH values is displayed a developed android mobile application.

A portable FP (80x60x6cm) (Ergotest innovation AS, Muscle Lab V10, Norway) with a sampling rate of 1000 hz was used as criterion reference. For the purposes of our study, FP was connected to a laptop PC operated on Windows 7 with installed appropriate MUSCLELAB software for the data analysis. FP records vertical ground reaction force and automatically calculates JH from take-off velocity (Street, McMillan, Board, Rasmussen, & Heneghan, 2001) and FT from time in air method (Moir et al., 2008). To get unnecessary data for the ground force reaction and later take-off velocity calculation each subject's body weight was measured by FP as subjects were required to stand still at the plate approximately 5 seconds prior every jump. Figure 2 displays the equipment set-up.

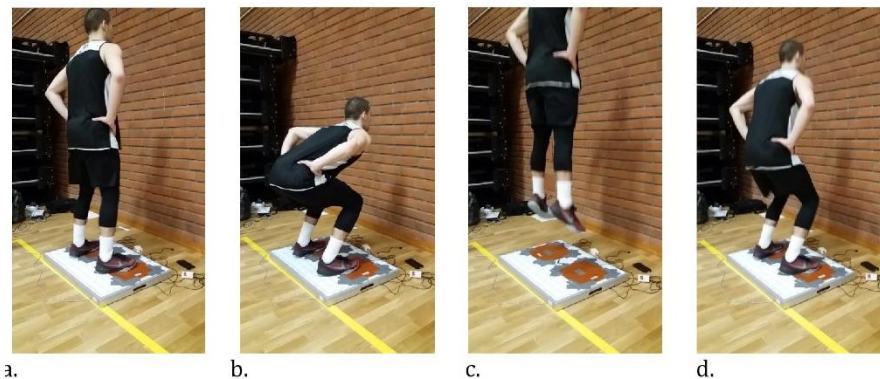


Figure 2. Measurement and set-up of the vertical jump performance using simultaneously a low-cost contact mat and a force plate (a. Starting position for CMJ; b. Starting position for SJ; c. Maximal jump height; d. Landing).

Data analysis

Descriptive statistics (mean, standard deviation and range) were calculated for each outcome variables. Data sets were checked for normality using the Shapiro Wilk test and by visual observation of the normality QQ plots. Criterion validity was established using relative error (RE) in measurement in terms of percentage (%RE). Interpretation of %RE was based on the following criteria: 1.5%, accurate; 1.5 – 2.5%, moderately accurate; > 2.5%, inaccurate (Abbiss, Quod, Levin, Martin, & Laursen, 2009). Concurrent validity was calculated using Pearson product moment correlation coefficient (r). The strength of the correlations was interpreted using the following qualitative descriptors: < .20, “very weak”; .20 – .40, “weak”; .40 – .70, “moderate”; .70 – .90, “strong” and > .90, “very strong” correlation (Learner & Goodman, 1996). Absolute reliability (within-subject variation) was established using coefficient of variation (%CV) expressed in percentage. It was calculated as outlined by Hopkins (2000). Intra-class correlation coefficient (ICC) was used to determine reliability (Bruton, Conway, & Holgate, 2000; Hopkins, Marshall, Batterham, & Hanin, 2009; Weir, 2005). A high test-retest reproducibility was considered to be for ICC > 0.70 (DeVellis, 2016). Lastly, usefulness was computed by comparing the smallest worthwhile change (SWC) derived from between-subject SD multiplied by 0.3 and typical error (TE) (Hopkins, 2004; Pyne et al. 2005). In addition, Hopkins' validity tool was applied derive regression equation for JH in CMJ and SJ (Hopkins, 2004). The statistical

Table 1. Validity, reliability, and usefulness indices in CM and FP.

	Force Platform					Contact Mat					%RE	r (CI)
	Mean ± SD	%CV	ICC	TE	SWC	Mean ± SD	%CV	ICC	TE	SWC		
<i>CMJ</i>												
JH (cm)	29.8 ± 6.29	4.82	0.89	1.63	2.00	33.5 ± 6.51	4.77	0.87	1.72	2.00	12.3	.91 (.83, .96)
FT (ms)	0.50 ± 0.05	2.37	0.89	0.01	0.02	0.52 ± 0.05	2.93	0.77	0.02	0.02	5.08	.92 (.83, .96)
<i>SJ</i>												
JH (cm)	26.9 ± 6.06	3.94	0.92	1.22	1.84	29.3 ± 5.86	4.59	0.88	1.50	1.80	9.48	.93 (.83, .97)
FT (ms)	0.47 ± 0.05	1.97	0.93	0.01	0.02	0.52 ± 0.05	2.56	0.84	0.02	0.02	4.78	.93 (.85, .96)

**CMJ* = Countermovement jump; *SJ* = Squat jump; *FT* = Flight time; *JH* = Jump height; *%RE* = Relative error in percentage; *r* = Correlation coefficient; *CI* = Confidence interval.

significance for all tests was set at $p \leq .05$. Statistical analyses were performed using freely available MS Excel charts (Hopkins 2007) and SPSS®24.0 (IBM SPSS Statistics, New York, USA) for Windows.

RESULTS

CMJ JH in CM indicated %RE = 12.3, r (CI) = .91 (.83, .96), %CV = 4.77, ICC = 0.87, TE = 1.72, and SWC = 2.00. CMJ FT in CM showed %RE = 5.08, r = .92 (.83, .96), %CV = 2.93, ICC = 0.77, TE = 2.00, SWC = 2.00.

SJ JH in CM displayed %RE = 9.48, %CV = 4.59, r = .93 (.83, .97), ICC = 0.88, TE = 1.50, SWC = 1.80. SJ FT presented %RE = 4.78, r = .93 (.85, .96), %CV = 2.56, ICC = 0.84, TE = 2.00, SWC = 2.00. Table 1 depicts the measures of validity, reliability, and usefulness in CM and FP.

DISCUSSION

The purpose of this study was to determine the validity, reliability and functionality of JH and FT from CMJ and SJ using a low-cost CM, with FP as criterion reference. The main findings of the study are: a. JH and FT in CMJ and SJ in CM presented poor criterion validity; b.) JH and FT in CMJ and SJ in CM displayed acceptable concurrent validity; c.) JH and FT in CMJ and SJ in CM indicated acceptable within-subject test variability; d.) JH and FT in CMJ and SJ in CM showed adequate test reproducibility; e.) JH and FT in CMJ and SJ in CM exhibited equipment functionality.

Criterion validity

CMJ and SJ values in CM displayed poor criterion validity. JH and FT in CMJ and SJ obtained through CM were 'inaccurate' which overestimated the criterion values. The results were similar to the findings discovered by previous researchers that detected overestimation using CM (Enoksen, Tønnessen, & Shalfawi, 2009; García-López et al. 2005; Reeve & Tyler, 2013; Rogan et al., 2015; Whitmer et al., 2015). The inaccuracies of values in CM may be attributed to the violation in the assumption that take-off and landing mechanics are identical (Bosco, Luhtanen, & Komi, 1983; Hatze, 1998). In other words, take-off and landing time should be the same (Aragón-Vargas, 2000). However, there seems to be a possibility that knee flexion during landing was greater than take off which contributes to higher JH and FT values. To support this, Kibele (1998) found out that the position of the centre of gravity was longer at landing than at take-off. Similarly, Aragón-Vargas (2000) also determined a difference in the centre of mass traveling downwards than take-off with average difference of 0.016 sec. On the other hand, the take-off velocity method in calculating JH is not affected by this postulation (Moir et al., 2008).

Another possible explanation for overestimation may be due to methodological definitions of jump height, wherein start of the FT in CM was detected right after plantar flexion while FT in FP is computed between the highest point during the jump and standing using double integration method (Baumgart, Honisch, Freiwald, & Hoppe, 2017). To put it simply, the FP method starts to record a FT prior a jumper takes-off (i.e. remove feet from the plate). This was confirmed by studies that showed double integration method calculated vertical jump displacement of the centre of mass before take-off (Aragón-Vargas, 2000; Moir, 2008).

Concurrent validity

Concurrent validity was determined from Pearson's correlation coefficient. Results showed that the relationship of JH and FT in CMJ and SJ between CM and FP showed a 'very strong' correlation. Thus,

implications for JH and FT in CMJ and SJ with CM present high concurrent validity. In other words, CMJ and SJ measured by CM and FP assess the same physical capacity (i.e. jump performance) in the current sample.

Reliability

Previous studies have frequently reported the absolute and relative reliability of different methods for assessing VJH using %CV and ICC, respectively. Absolute and relative reliability of CMJ and SJ in CM were also assessed. Absolute reliability represents the precision of individual scores within a test (Weir, 2005). In this study, %CV was utilized to depict within-subject reliability. Researchers suggested that a %CV < 10 is 'acceptable' (Atkinson, Nevill, & Edwards, 1999; Clark, Bryant, & Reaburn, 2006). It was observed that %CV JH and %CV FT in CMJ and SJ are acceptable which is in line with other studies (Attia et al., 2017; Markovic et al., 2004; Moir et al., 2008; Nuzzo, Anning, & Scharfenberg, 2011).

Relative reliability was also established using ICC. ICC refers to the ratio of variance from individual differences to the total variability of the data (Bruton et al., 2000; Weir, 2005) (10, 52). DeVellis (2016) suggested that an ICC > 0.70 reflects high test reproducibility. In this study, CMJ and SJ data presented ICC > 0.70. The findings were consistent with from previous studies that posted high ICC of JH in CM (Aragón-Vargas, 2000; Markovic et al., 2004). Thus, there is acceptable variability in measurement of JH and FT in CMJ and SJ using CM in a subject to the total variation across the CMJ and SJ data of all subjects.

Usefulness

Equipment usefulness of CM in CMJ and SJ was identified by comparing TE and SWC (Hopkins, 2004). A TE below SWC indicates equipment usefulness as 'good' while TE similar to SWC is rated 'acceptable'. If TE is higher than SWC, is deemed to have 'marginal' usefulness (Pyne et al., 2005). Results showed that usefulness of CM in CMJ JH and SJ JH is considered good. However, CMJ FT and SJ FT demonstrated acceptable usefulness.

Limitations

In this study, FP was used as the criterion reference. Utilizing other methods (e.g. video camera) in examining criterion validity of CM may facilitate reduction of systematic errors. Also, comparing CM with other available equipment in jump measurement in large population may provide information on the efficiency of CM in jump testing. Lastly, investigating other values (e.g. reactive jump index) in the low-cost CM can be helpful in presenting other aspects of lower body capabilities. Future research undertaking the aforementioned limitations should be warranted.

CONCLUSION

In conclusion, the low-cost CM connected to a mobile application can be used as an alternative method in measurement of CMJ and SJ.

AUTHOR CONTRIBUTIONS

Haris Pojskic and Jeffrey Cayaban Pagaduan: 1, conception and study design; 2, data gathering; 3, data analysis and interpretation; and 4, manuscript draft, revision, and completion. Emmanuel Ver Papa: 1, conception and study design; and 2, manuscript revision and completion. Sam Shi Xuan Wu: manuscript revision and completion.

SUPPORTING AGENCIES

No funding agencies were reported by the authors.

DISCLOSURE STATEMENT

The authors have no conflicts of interest to disclose.

ACKNOWLEDGEMENT

The researchers would like to express their gratitude to the athletes who agreed to volunteer in this study and to David Pyne, PhD from University of Canberra Research Institute for Sport and Exercise for his assistance in statistical analyses.

REFERENCES

- Abbiss, C.R., Quod, M.J., Levin, G., Martin, D.T., & Laursen, P.B. (2009). Accuracy of the Velotron ergometer and SRM power meter. *International Journal of Sports Medicine* 30(2): 107-112. <https://doi.org/10.1055/s-0028-1103285>
- Abdelkrim, N.B., Chaouachi, A., Chamari, K., Chtara, M., & Castagna, C. (2010). Positional role and competitive-level differences in elite-level men's basketball players. *Journal of Strength and Conditioning Research* 24(5): 1346-1355. <https://doi.org/10.1519/jsc.0b013e3181cf7510>
- Aragón-Vargas, L.F. (2000). Evaluation of four vertical jump tests: methodology, reliability, validity, and accuracy. *Measurement in Physical Education and Exercise Science* 4(4): 215-22. https://doi.org/10.1207/s15327841mpee0404_2
- Atkinson, G., Nevill, A., & Edwards, B. (1999). What is an acceptable amount of measurement error? The application of meaningful 'analytical goals' to the reliability of sports science measurements made on a ratio scale. *Journal of Sports Sciences* 17: 18.
- Attia, A., Dhahbi, W., Chaouachi, A., Padulo, J., Wong, D.B., & Chamari, K. (2017). Measurement errors when estimating the vertical jump height with flight time using photocell devices: the example of Optojump. *Biology in Sport* 34(1): 63-70. <https://doi.org/10.5114/biolsport.2017.63735>
- Balsalobre-Fernandez, C., Glaister, M., & Lockey, R.A. (2015). The validity and reliability of an iPhone app for measuring vertical jump performance. *Journal of Sports Sciences* 33(15): 1574-1479. <https://doi.org/10.1080/02640414.2014.996184>
- Baumgart, C., Honisch, F., Freiwald, J., & Hoppe, M.W. (2017). Differences and trial-to-trial reliability of vertical jump heights assessed by ultrasonic system, force-plate, and high-speed video analyses. *Asian Journal of Sports Medicine* 8(4): e12921. <https://doi.org/10.5812/asjasm.12921>
- Borges Júnior, N.G., Borges, L., Dias, J.A., Wentz, M.D., Mattos, D.J.dS., Petry, R., & Domenech, S.C. (2011). Validity of a new contact mat system for evaluating vertical jump. *Motriz: Revisita de Educação Física* 17(1): 26-32.
- Bosco, C., Luhtanen, P., & Komi, P.V. (1983). A simple method for measurement of mechanical power in jumping. *European Journal of Applied Physiology* 50(2), 273-282. <https://doi.org/10.1007/bf00422166>
- Bruton, A., Conway, J.H., & Holgate, S.T. (2000). Reliability: what is it, and how is it measured? *Physiotherapy* 86(2): 94-99. [https://doi.org/10.1016/s0031-9406\(05\)61211-4](https://doi.org/10.1016/s0031-9406(05)61211-4)
- Buckthorpe, M., Morris, J., & Folland, J.P. (2012). Validity of vertical jump measurement devices. *Journal in Sports Sciences* 30(1), 63-69. <https://doi.org/10.1080/02640414.2011.624539>

- Clark, A., Bryant, A.L., & Reaburn, P. (2006) The acute effects of a single set of contrast preloading on a loaded countermovement jump training session. *Journal of Strength and Conditioning Research* 20(1): 162-166. <https://doi.org/10.1519/00124278-200602000-00026>
- Cordova, M.L., & Armstrong, C.W. (1996). Reliability of ground reaction forces during a vertical jump: implications for functional strength assessment. *Journal of Athletic Training* 31(4): 342-345.
- Cronin, J.B., Hing, R.D., & McNair, P.J. (2004). Reliability and validity of a linear position transducer for measuring jump performance. *Journal of Strength and Conditioning Research* 18(3): 590-593.
- Delextrat, A., & Cohen, D. (2008). Physiological testing of basketball players: toward a standard evaluation of anaerobic fitness. *Journal of Strength and Conditioning Research*, 22(4): 1066-1072. <https://doi.org/10.1519/jsc.0b013e3181739d9b>
- DeVellis, R.F. (2016). *Scale Development: Theory and Applications* (pp. 31-58). Thousand Oaks, CA: SAGE Publications.
- Dias, J.A., Dal Pupo, J., Reis, D.C., Borges, L., Santos, S.G., Moro, A.R., Borges Jr, N.G. (2011). Validity of two methods for estimation of vertical jump height. *Journal of Strength and Conditioning Research* 25(7): 2034-2039. <https://doi.org/10.1519/jsc.0b013e3181e73f6e>
- Enoksen, E., Tønnessen, E., & Shalfawi, S. (2009). Validity and reliability of the Newtest Powertimer 300-series® testing system. *Journal of Sports Sciences* 27(1): 77-84. <https://doi.org/10.1080/02640410802448723>
- Ferreira, L.C., Schilling, B.K., Weiss, L.W., Fry, A.C., & Chiu, L.Z.F. (2010). Reach height and jump displacement: implications for standardization of reach determination. *Journal of Strength and Conditioning Research* 24(6): 1596-1601. <https://doi.org/10.1519/jsc.0b013e3181d54a25>
- García-López, J., Morante, J.C., Ogueta-Alday, A., & Rodríguez-Marroyo, J.A. (2013). The type of mat (contact vs. photocell) affects vertical jump height estimated from flight time. *Journal of Strength and Conditioning Research* 24(7): 1162-1167. <https://doi.org/10.1519/jsc.0b013e31826520d7>
- García-López, J., Peleteiro, J., Rodríguez-Marroyo, J.A., Morante, J.C., Herrero, J.A., & Villa, J.G. (2005). The validation of a new method that measures contact and flight times during vertical jump. *International Journal of Sports Medicine* 26(4): 294-302. <https://doi.org/10.1055/s-2004-820962>
- Hatze, H. (1998). Validity and reliability of methods for testing vertical jumping performance. *Journal of Applied Biomechanics* 14(2): 127-140. <https://doi.org/10.1123/jab.14.2.127>
- Hopkins, W.G. (2007). Understanding statistics by analyzing spreadsheets to generate and analyze samples. *Sportscience* 11: 23-26.
- Hopkins, W.G. (2004). How to interpret changes in an athletic performance test. *Sportscience* 8: 1-7.
- Hopkins, W.G. (2000). Measures of reliability in sports medicine and science. *Sports Medicine* 30(1), 1-15. <https://doi.org/10.2165/00007256-200030010-00001>
- Hopkins, W.G., Marshall, S.W., Batterham, A.M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise* 41(3): 3-13. <https://doi.org/10.1249/mss.0b013e31818cb278>
- Kenny, I.C., Cairealláin, A.Ó., Comyns, T.M. (2012). Validation of an electronic jump mat to assess stretch-shortening cycle function. *Journal of Strength and Conditioning Research* 26(6): 1601-1608. <https://doi.org/10.1519/jsc.0b013e318234ebb8>
- Kibele, A. (1998). Possibilities and limitations in the biomechanical analysis of countermovement jumps: a methodological study. *Journal of Applied Biomechanics* 14(1): 105-117. <https://doi.org/10.1123/jab.14.1.105>
- Learner J., & Goodman, N.W. (1996). Descriptions of correlation. *Lancet* 348(9021), 199-200. [https://doi.org/10.1016/s0140-6736\(05\)66149-1](https://doi.org/10.1016/s0140-6736(05)66149-1)
- Malone, J.J., Murtagh, C.F., Morgans, R., Burgess, D.J., Morton, J.P., & Drust, B. (2015). Countermovement jump performance is not affected during an in-season training microcycle in elite

- youth soccer players. *Journal of Strength and Conditioning Research* 29(3): 752-757. <https://doi.org/10.1519/jsc.0000000000000701>
- Markovic, G., Dizdar, D., Jukic, I., & Cardinale, M. (2004). Reliability and factorial validity of squat and countermovement jump tests. *Journal of Strength and Conditioning Research* 18(3): 551-555.
- McLean, B.D., Coutts, A.J., Kelly, V., McGuigan, M.R., & Cormack, S.J. (2010). Neuromuscular, endocrine, and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. *International Journal of Sports Physiology and Performance* 5(3): 367-383. <https://doi.org/10.1123/ijspp.5.3.367>
- McMahon, J.J., Jones, P.A., & Comfort, P. (2016). A correction equation for jump height measured using the just jump system. *International Journal of Sports Physiology and Performance* 11(4): 555-557. <https://doi.org/10.1123/ijspp.2015-0194>
- Moir, G.L. (2008). Three different methods of calculating vertical jump height from force platform data in men and women. *Measurement in Physical Education and Exercise Science* 12(4): 207-218. <https://doi.org/10.1080/10913670802349766>
- Moir, G., Shastri, P., & Connaboy, C. (2008). Intersession reliability of vertical jump height in women and men. *Journal of Strength and Conditioning Research* 22(6): 1779-1784. <https://doi.org/10.1519/jsc.0b013e318185f0df>
- Nuzzo, J.L., Anning, J.H., & Scharfenberg, J.M. (2011). The reliability of three devices used for measuring vertical jump height. *Journal of Strength and Conditioning Research* 25(9): 2580-2590, 2011. <https://doi.org/10.1519/jsc.0b013e3181fee650>
- Ostojic, S.M., Mazic, S., & Dikic, N. (2006). Profiling in basketball: physical and physiological characteristics of elite players. *Journal of Strength and Conditioning Research* 20(4): 740-744. <https://doi.org/10.1519/00124278-200611000-00003>
- Pojskić, H., Šeparović, V., Užičanin, E., Muratović, M., & Mačković, S. (2015). Positional role differences in the aerobic and anaerobic power of elite basketball players. *Journal of Human Kinetics*, 49: 219-227. <https://doi.org/10.1515/hukin-2015-0124>
- Pojskic, H., Sisic, N., Separovic, V., Sekulic, D. (2018). Association between conditioning capacities and shooting performance in professional basketball players: an analysis of stationary and dynamic shooting skills. *Journal of Strength and Conditioning Research* 32(7): 1981-1992. <https://doi.org/10.1519/jsc.0000000000002100>
- Pyne, D., Hopkins, W., Batterham, A., Gleeson, M., Fricker, P. (2005). Characterising the individual performance responses to mild illness in international swimmers. *British Journal of Sports Medicine* 39: 752-756. <https://doi.org/10.1136/bjism.2004.017475>
- Reeve, T.C., & Tyler, C.J. (2013). The validity of the SmartJump contact mat. *Journal of Strength and Conditioning Research* 27(6): 1597-1601. <https://doi.org/10.1519/jsc.0b013e3182697f1f>
- Rogan, S., Radlinger, L., Imhasly, C., Kneubuehler, A., & Hilfiker, R. (2015). Validity study of a jump mat compared to the reference standard force plate. *Asian Journal of Sports Medicine* 6(4): e25561. <https://doi.org/10.5812/asjism.25561>
- Sallet, P., Perrier, D., Ferret, J., Vitelli, V., & Baverel, G. (2005). Physiological differences in professional basketball players as a function of playing position and level of play. *The Journal of Sports Medicine and Physical Fitness* 45(3): 291-294.
- Street, G., McMillan, S., Board, W., Rasmussen, M., & Heneghan, J.M. Sources of error in determining countermovement jump height with the impulse method. *Journal of Applied Biomechanics* 17(1): 43-54. <https://doi.org/10.1123/jab.17.1.43>
- Thorpe, R.T., Strudwick, A.J., Buchheit, M., Atkinson, G., Drust, B., & Gregson, W. (2015). Monitoring fatigue during the in-season competitive phase in elite soccer players. *International Journal of Sports Physiology and Performance* 10(8): 958-964. <https://doi.org/10.1123/ijspp.2015-0004>

- Walsh, M.S., Ford, K.R., Bangen, K.J., Myer, G.D., Hewett, T.E. (2006). The validation of a portable force plate for measuring force-time data during jumping and landing tasks. *Journal of Strength and Conditioning Research* 20(4): 730-734. <https://doi.org/10.1519/00124278-200611000-00001>
- Weir, J.P. (2005). Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. *Journal of Strength and Conditioning Research* 19(1): 231-240. <https://doi.org/10.1519/00124278-200502000-00038>
- Whitmer, T.D., Fry, A.C., Forsythe, C.M., Andre, M.J., Lane, M.T., Hudy, A., & Honnold, D.E. (2015). Accuracy of a vertical jump contact mat for determining jump height and flight time. *Journal of Strength and Conditioning Research* 29(4): 877-881. <https://doi.org/10.1519/jsc.0000000000000542>
- Ziv, G., & Lidor, R. (2010). Vertical jump in female and male volleyball players: A review of observational and experimental studies. *Scandinavian Journal of Medicine and Science in Sports*, 20(4): 556-567. <https://doi.org/10.1111/j.1600-0838.2009.01083.x>

