BULLETIN OF CZECH ECONOMETRIC SOCIETY
SP. 1
www.bulletin.ces.cz
ISSN 1212-074X | VOLUME 33 | SPECIAL ISSUE 1 | 2026

Surface-Dependent Variability in Force Plate-Derived Countermovement Jump Metrics

Abir Guha (corresponding author)
Research Scholar, Department of Physical Education, National Sports University, Imphal, India

Dr. N. Amitrasen Singh
Assistant Professor, Department of Physical Education, National Sports University, Imphal, India

Suraj Kumar Bharali
Research Scholar, Department of Physical Education, Lakshmibai National Institute of Physical Education, NERC Guwahati, India

Tiyasa Hoom
Research Scholar, Department of Physical Education, Lakshmibai National Institute of Physical Education, NERC Guwahati, India

Dr. Pulen Das
Assistant Professor, Department of Physical Education, Lakshmibai National Institute of Physical Education, NERC Guwahati, India

Received: 15th September, 2026
Accepted: 25th September, 2026
Published: 15th October, 2026
https://doi.org/10.5281/zenodo.23718645

Abstract

The force plate has become a standard tool for assessment of neuromuscular readiness in athletes; however, most validation and testing protocols assume a fixed, rigid surface. That luxury is seldom afforded by field-based testing. The purpose of this study was to determine if the floor on which a portable dual force plate sits influences the countermovement jump (CMJ) output of professional male footballers. Fifteen players (age 22.3 ± 2.1 years) performed maximal akimbo CMJs on six surfaces (concrete, gym mat, judo mat, natural grass, mud court and synthetic track) after a standardized warm-up. Repeated measures ANOVA with Bonferroni correction compared system weight, jump height, countermovement depth, braking rate of force development,

BULLETIN OF
CZECH ECONOMETRIC SOCIETY
SP. 1
www.bulletin.ces.cz
ISSN 1212-074X | VOLUME 33 | SPECIAL ISSUE 1 | 2026

braking phase duration, and peak propulsive and landing forces (absolute and relative) among surfaces. Three metrics changed meaningfully with surface: system weight ($p = .001$, $\eta p2 = .333$), countermovement depth ($p = .035$, $\eta p2 = .190$), and braking values for system-weight, judo mat the greatest countermovement depth, and gym mat the shortest braking phase. Braking rate of force development had a significant univariate effect that did not survive multivariate testing or post-hoc correction - noisy rather than surface-driven. Notably, jump height, peak propulsive force, and peak landing force did not differ statistically across all 6 surfaces. That split matters more than any p-value. Players experimented with the mechanics phase duration ($p = .033$, $\eta p2 = .156$). Concrete yielded the highest of entering and leaving the jump – how deep they loaded it, how quickly they changed direction – while the actual output remained the same.

The neuromuscular system seems to treat surface compliance as a parameter to be compensated for, not as a constraint that dictates performance. The takeaway for practitioners is not as broad as "surfaces don't matter": jump height and peak force appear robust to testing location, but any metric related to loading strategy — depth, braking timing, system weight — needs a consistent surface across sessions if a change in score is going to mean anything.

Keywords: countermovement jump; force plate methodology; flooring surface; neuromuscular compensation; testing standardization

BULLETIN OF CZECH ECONOMETRIC SOCIETY
SP. 1
www.bulletin.ces.cz
ISSN 1212-074X | VOLUME 33 | SPECIAL ISSUE 1 | 2026

Introduction

Force plates are commonly used testing tools for obtaining knowledge of an athlete's neuromuscular functioning, fatigue (Gathercole et al. (2015)), and asymmetries for determining injury risks (Pedley et al. (2020)). The system has become more prevalent due to the high level of established validity (Lake et al. (2017), Badby et al. (2023), Dos'Santos et al. (2024)), portability and commercial availability.

Jumping is an important athletic ability used during many sporting events. Since each task loads the neuromuscular system differently (Earl et al. 2007)), things like postural control, limb angles, leg stiffness, and muscle activation likely shape how much cushioning changes impact forces at landing. That's a plausible reason the literature is split: some studies find softer materials cut impact forces and loading rate (Fu et al. (2013), Moir (2008)), others find no change (Fu et al. (2013), Yeow et al. (2011)), and at least one finds forces going up instead (Baltich et al. (2015)) — the outcome seems to hinge on which task is being tested.

Methods

Participants

Fifteen professional male football players (age = 22.3 ± 2.1 years, height = 178.9 ± 2.3 cm, body mass = 61.71 ± 7.7 kg) volunteered to participate in the present study. All participants previously competed at the collegiate level of football competition in India (e.g., AIU) and were under professional contract at the time of data collection (e.g., Manipur State League). The testing procedures performed in this investigation were previously approved by the University's Institutional Review Board and all the participants signed an informed consent document.

Procedures

Upon arrival at the human performance lab of the university, participants performed a standardized warm-up protocol led by the team's coaching professional. The warm-up protocol comprised of 15 min of jogging followed by a set of dynamic exercises (e.g., jumping jacks, high knees, A-skips, lunge-twists). Additionally, the participants performed three sub-maximal CMJ without arm swing. After completion of the warm-up protocol, the participants stepped on a portable uniaxial dual force plate system (Hawkin Dynamics G5 Force Plate, Westbrook, United State) that demonstrated high measurement sensitivity and accuracy and perform three maximal CMJ (akimbo). The force plate was calibrated between each participant, and the sampling rate was 1000 Hz. The participants were instructed to restrict their arm on the hip

BULLETIN OF CZECH ECONOMETRIC SOCIETY
SP. 1
www.bulletin.ces.cz
ISSN 1212-074X | VOLUME 33 | SPECIAL ISSUE 1 | 2026

through the jump protocol. Each participant was verbally cued to jump explosively (high and fast) as possible. To minimize the possible influence of fatigue, each jump was separate by 15-30 s rest interval. All the flooring conditions were covered on the same day for all the participants.

Variables

Following variables were obtained of the CMJ (calculated by impulse-momentum method): system weight, jump height, countermovement depth, braking rate of force development, braking phase, peak propulsion force (absolute and relative) and peak landing force (absolute and relative). A detailed description of the mentioned CMJ metrics is presented in the Hawkin Dynamics database (https://www.hawkindynamics.com/hawkin-metric-database).

Statistical Analysis

Descriptive statistics, means and standard deviations ($\bar{x} \pm SD$), were calculated for each dependent variable. A series of one-way repeated-measures analyses of variance were conducted to examine whether each outcome metric differed across the six flooring conditions Mauchly's test was used to assess the assumption of sphericity for each metric; where sphericity was violated, Greenhouse Geisser corrected degrees of freedom and significance values are reported. Post hoc pairwise comparisons between flooring conditions were conducted using the Bonferroni correction. Partial eta squared (η_p^2) was used to calculate the measure of effect size (i.e., 0.01 is a small effect, 0.06 is a medium effect, and 0.14+ is a large effect). Statistical significance was set a priori to $p < 0.05$. All statistical analyses were completed with SPSS (Version 26.0; IBM Crop., Armonk, NY, USA).

Results

Table 1 presents descriptive statistics for each variable examined in the study. There were significant main effects of flooring for system weight, $F(2.64, 36.99) = 6.99$, $p = .001$, partial $\eta^2 = .333$, countermovement depth, $F(2.71, 37.97) = 3.28$, $p = .035$, partial $\eta^2 = .190$, and braking phase, $F(5, 70) = 2.60$, $p = .033$, partial $\eta^2 = .156$. Post hoc Bonferroni-adjusted comparisons indicated that for system weight, concrete flooring resulted in significantly higher values than gym flooring ($p = .024$) and mud flooring ($p = .047$), while mud flooring was significantly higher than natural grass ($p < .001$); for countermovement depth, Judo mat flooring differed significantly from concrete flooring ($p = .005$); and for braking phase, values were significantly lower in gym mat flooring than in synthetic track ($p = .015$). The univariate test for braking rate of force development indicated a significant effect, $F(5, 70) = 2.77$, $p = .024$,

CES CZECH ECONOMETRIC SOCIETY
BULLETIN OF CZECH ECONOMETRIC SOCIETY
SP. 1
www.bulletin.ces.cz
ISSN 1212-074X | VOLUME 33 | SPECIAL ISSUE 1 | 2026

partial η^2 =.165, but this was not supported by the multivariate test, and no pairwise comparisons remained after correction. However, there were no statistically significant main effects of flooring found for jump height, F (2.19, 30.67) = 1.48, p = .244, partial η^2 = .095, peak propulsive force, F (2.41, 33.74) = 2.65, p = .076, partial η^2 = .159, relative peak propulsive force, F (2.42, 33.85) = 2.77, p = .068, partial η^2 = .165, peak landing force, F (5, 70) = 1.25, p = .294, partial η^2 = .082, or relative peak landing force, F (5, 70) = 1.38, p = .243, partial η^2 = .090. There were no significant pairwise differences found among these metrics.

Table 1. Descriptive statistics ($\bar{x} \pm SD$)

	SW	JH	CMD	B_RFD	BP	PPF	R_PPF	PLF	R_PLF
Concrete	61.82 ± 7.98	0.36 ± 0.05	0.34 ± 0.07	5205.59 ± 1612.30	0.18 ± 0.03	1529.78 ± 240.37	24.79 ± 2.63	3064.13 ± 703.38	50.34 ± 12.55
Gym Mat	61.67 ± 7.96	0.37 ± 0.06	0.36 ± 0.08	5199.61 ± 1523.98	0.18 ± 0.03	1527.24 ± 262.08	24.82 ± 2.87	2930.96 ± 727.84	48.68 ± 15.08
Judo Mat	61.69 ± 7.86	0.37 ± 0.06	0.37 ± 0.08	5160.80 ± 1783.54	0.18 ± 0.03	1551.22 ± 287.46	25.17 ± 3.11	2809.49 ± 649.65	46.24 ± 11.58
Natural Grass	61.43 ± 7.77	0.37 ± 0.05	0.35 ± 0.07	4833.77 ± 1498.82	0.18 ± 0.03	1478.09 ± 242.33	24.07 ± 2.50	3172.76 ± 763.56	52.88 ± 15.73
Mud Court	61.92 ± 7.87	0.36 ± 0.05	0.34 ± 0.07	4826.09 ± 1267.83	0.18 ± 0.03	1494.69 ± 200.53	24.2 ± 1.98	2993.18 ± 510.88	49.36 ± 11.45
Synthetic Track	61.7 ± 7.98	0.37 ± 0.06	0.36 ± 0.07	4563.49 ± 1437.13	0.19 ± 0.03	1473.58 ± 248.16	23.9 ± 2.59	3072.76 ± 794.44	50.76 ± 15.4

Note: SW – System Weight [kg]; JH – Jump Height [cm]; CMD – Countermovement Depth [cm]; B_RFD – Braking Rate of Force Development[N/s]; BP – Braking Phase[s], PPF- Peak Propulsive Force [N]; R_PPF – Relative Peak Propulsive Force [N/kg]; PLF- Peak Landing Force [N]; R_PLF – Relative Peak Landing Force [N/kg].

CES CZECH ECONOMETRIC SOCIETY
BULLETIN OF CZECH ECONOMETRIC SOCIETY
SP. 1
www.bulletin.ces.cz
ISSN 1212-074X | VOLUME 33 | SPECIAL ISSUE 1 | 2026

Discussion

Some aspects of the countermovement jump are clearly affected by the flooring surface while others are not. Weight, countermovement depth and duration of the braking phase varied with the substrate underneath the athlete, whereas jump height and peak force output were quite consistent over the different surfaces. That division is worth considering.

The weight of the system is usually defined during calibration or the first weighing stage. It appears to reflect an individual's ability to maintain the stability of their centre of mass on a given surface. Concrete is not resilient. It is rigid. This means that the body must take the impact in a rigid way. This often leads to a greater initial force measurement. Vegetation does the reverse. It is compliant and soaks up energy before the plate feels it and thus attenuates the signal.

The change in countermovement depth can be understood in the context of body adaptation to a surface. When an athlete is put on a judo mat, their lower-limb stiffness almost instinctively adjusts. To take advantage of the stretch-shortening cycle on such a compliant surface, they must go lower – both to store enough elastic energy and to compensate for what the mat absorbs. Concrete is the opposite. There is no flexibility at all so you can very quickly and easily turn things around on the surface. You don't need to chase compliance that does not exist.

The braking phase duration tells a similar story. The shorter braking window on the gym mats indicates a faster eccentric deceleration, probably a function of the grip and mid-stiffness feel of the surface. The synthetic track was designed to provide a horizontal energy return while running, but this does not translate well to a vertical jump. It can prolong the deceleration phase when the movement pattern does not match the surface's intended use. RFD braking is the outlier. There was a large main effect, but the fact that the multivariate finding and the post-hoc tests are so different suggests that this variable is not simply set by surface, but rather by how everyone chooses to move on it.

These findings have real implications for practitioners standardising force plate testing as flooring condition had a large effect on force reduction, peak force, RFD and contact time. The same point is important for research practice: studies on commercial force plates should clearly specify what surface was underneath. Combined, this means that both practitioners and researchers need to think carefully about where they place a force plate and what is underneath it, if they want consistent and accurate data. The safest way is to stay in one spot and on one

BULLETIN OF CZECH ECONOMETRIC SOCIETY
SP. 1
www.bulletin.ces.cz
ISSN 1212-074X | VOLUME 33 | SPECIAL ISSUE 1 | 2026

surface for a session and from session to session, otherwise a change in scores might just be a change in flooring rather than an actual change in performance.

The results imply that human motor programming is robust as shown by motor redundancy and neuromuscular compensation. Although concrete, mud, grass, synthetic tracks and mats have very different mechanical properties, athletes were able to adjust their eccentric kinematics (e.g. depth and timing) to keep ultimate kinetic output (peak propulsive forces) and task performance (jump height). Whatever the environment requires, the neuromuscular system dynamically adjusts the stiffness of the joints and recruitment patterns during the preparation phase of a movement to achieve the desired outcome. Furthermore, the absence of statistical differences in peak landing forces indicates that athletes were able to predict the transition between surfaces and modulate the compliance of their lower body during the touchdown phase to maintain impact forces within a safe and uniform range.

Conclusion

Flooring surface doesn't touch how high these players jumped or how much force they generated at push-off — but it clearly touched how they got there. System weight, countermovement depth, and braking phase duration all shifted with the substrate underfoot, while jump height and peak propulsive and landing forces held steady across all six conditions. That pattern points to a movement system that's adjusting its strategy in real time: deeper countermovement on compliant mats to bank the elastic energy the surface would otherwise absorb, faster reversals on concrete because there's no give to wait for, longer braking on a track built for horizontal running rather than vertical loading. The output stays protected; the path to it doesn't. For anyone running CMJ testing on a portable force plate, this cuts a specific way — jump height and peak force look reasonably trustworthy wherever you happen to set up, but depth, braking timing, and system weight are only comparable across sessions if the surface underneath stays the same. Treat flooring as a variable worth reporting, not a footnote, and a lot of otherwise-confusing session-to-session drift in kinetic profiles becomes a lot less mysterious.

References:

Badby, A. J., Mundy, P. D., Comfort, P., Lake, J. P., & McMahon, J. J. (2023). The validity of Hawkin Dynamics wireless dual force plates for measuring countermovement jump and drop jump variables. *Sensors*, *23*(10), Article 4820. https://doi.org/10.3390/s23104820

BULLETIN OF CZECH ECONOMETRIC SOCIETY
SP. 1
www.bulletin.ces.cz
ISSN 1212-074X | VOLUME 33 | SPECIAL ISSUE 1 | 2026

Baltich, J., Maurer, C., & Nigg, B. M. (2015). Increased vertical impact forces and altered running mechanics with softer midsole shoes. *PLoS ONE*, *10*(4), Article e0125196. https://doi.org/10.1371/journal.pone.0125196

Dos'Santos, T., Evans, D. T., & Read, D. B. (2024). Validity of the Hawkin Dynamics wireless dual force platform system against a piezoelectric laboratory grade system for vertical countermovement jump variables. *Journal of Strength and Conditioning Research*, *38*(6), 1144–1148. https://doi.org/10.1519/JSC.0000000000004785

Earl, J. E., Monteiro, S. K., & Snyder, K. R. (2007). Differences in lower extremity kinematics between a bilateral drop-vertical jump and a single-leg step-down. *Journal of Orthopaedic & Sports Physical Therapy*, *37*(5), 245–252. https://doi.org/10.2519/jospt.2007.2202

Fu, W., Liu, Y., & Zhang, S. (2013). Effects of footwear on impact forces and soft tissue vibrations during drop jumps and unanticipated drop landings. *International Journal of Sports Medicine*, *34*(6), 477–482. https://doi.org/10.1055/s-0032-1327696

Gathercole, R., Sporer, B., Stellingwerff, T., & Sleivert, G. (2015). Alternative countermovement-jump analysis to quantify acute neuromuscular fatigue. *International Journal of Sports Physiology and Performance*, *10*(1), 84–92. https://doi.org/10.1123/ijspp.2013-0413

Lake, J., Mundy, P., Comfort, P., McMahon, J. J., Suchomel, T. J., & Carden, P. (2018). Concurrent validity of a portable force plate using vertical jump force-time characteristics. *Journal of Applied Biomechanics*, *34*(5), 410–413. https://doi.org/10.1123/jab.2017-0371

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.

Pedley, J. S., Lloyd, R. S., Read, P. J., Moore, I. S., De Ste Croix, M., Myer, G. D., & Oliver, J. L. (2020). Utility of kinetic and kinematic jumping and landing variables as predictors of injury risk. *Journal of Science in Sport and Exercise*, *2*(4), 287–304. https://doi.org/10.1007/s42978-020-00090-1

Yeow, C. H., Lee, P. V. S., & Goh, J. C. H. (2011). Shod landing provides enhanced energy dissipation at the knee joint relative to barefoot landing from different heights. *The Knee*, *18*(6), 407–411. https://doi.org/10.1016/j.knee.2010.07.011