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Different Cues Leading to Meaningful Differences in Contact Mat Countermovement Jump Assessment in Collegiate Team Sport Athletes: A Preliminary Study

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Abstract

Contact mats estimate countermovement jump (CMJ) height via flight time, assuming consistent body positioning at take-off and landing. However, foot landing technique, specifically soft versus stiff landings, may alter ankle and joint angles, potentially biasing jump height measurements. This study investigated the effect of externally cued ankle-focused landing styles- specifically ball-of-foot ("soft") versus heel-first ("stiff") landings on CMJ height measured by a contact mat in collegiate male team sport athletes. One hundred male team sport athletes (age 21.4 years; height 182.3 cm; weight 78.6 kg) performed CMJs under randomized, counterbalanced soft (ball-of-foot, greater plantar flexion) and stiff (heel-first, minimal plantar flexion) landing conditions. Jump height was measured with the Just Jump contact mat using the Bosco protocol. Participants completed three trials per condition; average jump heights obtained under the soft and stiff landing conditions were compared using paired t-tests, while Pearson correlation and Bland-Altman analysis assessed the relationship and agreement between two landing styles. CMJ height was significantly greater during stiff landings (48.50 ± 5.51 cm) compared to soft landings (45.62 ± 5.80 cm), with a mean difference of 2.88 cm ($p = 0.001$, Cohen's $d = 1.28$). A strong positive correlation ($r = 0.92$) indicated consistent ranking across conditions, but Bland-Altman analysis revealed systematic bias and moderate variability between landing styles. Landing technique substantially influences CMJ height measurements using a contact mat, with stiff landings producing inflated jump heights. However, this preliminary study did not include biomechanical verification of landing mechanics, which should be considered in future research.These findings highlight the need for standardized, explicit ankle landing instructions during CMJ testing to ensure accuracy and comparability of results in sport performance assessment and monitoring.

Keywords: *countermovement jump, ankle joint, athletes, plantar flexion*

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Introduction

Jumping ability is considered to be one of the most important performance characteristics regarding team sport performance. Many athletic skills such as the rebounding in basketball, the blocking in volleyball as well as the header in soccer require high levels of vertical jumping ability (Battaglia et al., 2014; Matsuda et al., 2015). Improved jumping performance has been associated not only with higher vertical jump heights but also with enhanced sprinting speed, agility, and deceleration (Gisladottir et al., 2024; Bishop & Girard, 2013). Previous research has indicated that jumping ability differs between starters and non-starters (Gonzalez et al., 2013; Yamaguchi et al., 2022) and between different levels of team sport athletes (Ferioli et al., 2018). With this in mind, regular testing of jumping ability is regarded as mandatory in team sport settings (Asimakidis et al., 2024).

To effectively assess jumping ability, numerous testing protocols have been developed, with the countermovement jump (CMJ) widely recognized as the preferred method (Anicic et al., 2023; Bobbert et al., 1996). The CMJ involves a preparatory downward movement followed by an explosive upward leap, closely resembling dynamic actions observed in team sports. Its straightforward administration, minimal required familiarization, and the common practice of placing hands on the hips to eliminate arm swing contribute to the high standardization and reproducibility of CMJ testing to assess lower-body power. Consequently, CMJ performance testing is widely implemented for athlete selection, performance monitoring, and evaluating training outcomes in team sport populations (Barker et al., 2021).

CMJ performance is most often expressed by reporting jump height as a key performance-related outcome metric (Bishop et al., 2023). Various instruments are available to measure CMJ performance, each with unique advantages and limitations. Among these, force plates are considered the gold standard due to their ability to capture detailed kinetic variables such as ground reaction forces, impulse, and rate of force development, offering in-depth insight into neuromuscular capabilities (Lake et al., 2018). Nonetheless, their considerable cost, limited portability, and technical complexity often restrict their widespread use outside laboratory settings. As a more practical alternative for field assessments, contact mats estimate jump height by calculating flight time during the airborne phase (Linthorne, 2001). These devices strike a useful compromise between accuracy, affordability, and ease of use, providing relatively valid and reliable jump height measurements with minimal setup requirements (Tenelsen et al., 2019).

Accurate jump height estimation via flight time relies on the fundamental assumption that the body's centre of mass occupies consistent positions at take-off and landing. In reality, subtle variations in body positioning can induce substantial measurement errors (Bui et al., 2015). Specifically, deviations in joint angles at the hip, knee, and ankle during landing can inflate or deflate flight time, thereby biasing jump height calculations by as much as 6 to 10 cm in average adult males (Bui et al., 2015; Moran & Wallace, 2007). While CMJ protocols and device manuals emphasize standardizing hip and knee positioning during take-off and landing to reduce such errors, little attention has been given to ankle joint alignment and foot posture despite their potential influence on flight-time derived metrics (McMahon et al., 2016). During take-off, the foot is generally pointed downward (ankle plantar flexion) with an angle of around 55 degrees to produce maximal power output. However, ankle plantar flexion during landing was reported to be around 22 degrees (Hollville et al., 2020). Additionally, some participants tend to land with their toes pointed downward, exhibiting so-called soft landing, while others land with their feet nearly flat, often striking the heels first, referred to as stiff landing. This change in foot posture upon landing can potentially increase flight time estimates and thereby compromise the accuracy of jump height measurements (Kibele, 1998).

However, there is a notable lack of empirical research specifically examining the effects of soft versus hard landing techniques on CMJ height measured by contact mats. Previous work by Bui et al. (2015) identified ankle positioning during landing as a significant source of measurement error across various jump height metrics, estimating that ankle-related factors could contribute to approximately 50% of observed discrepancies. We were unable to find studies examining direct comparison of soft vs hard landing on contact mat CMJ height performance. Addressing this gap could provide practitioners with valuable insights into the impact of landing technique on measurement accuracy and improve the interpretability of vertical jump testing. Accordingly, this study aimed to examine the influence of different landing styles on countermovement jump height when assessed using a contact mat. We hypothesized that a landing style characterized by increased ankle plantar flexion and softer joint flexion would yield significantly different jump height measurements compared to a stiffer landing posture, highlighting the importance of including ankle landing instructions in CMJ testing protocols.

Methods and Materials

Participants and study design

An a priori power analysis, assuming a medium effect size (Cohen's d = 0.5), alpha = 0.001, and 80% power, estimated a required sample size of approximately 70 participants for detecting differences in CMJ height between landing styles. Since no previous studies specifically addressing the effect of ankle-focused landing styles on CMJ height using contact mats were available, the medium effect size was selected as an exploratory estimate. To increase robustness and account for population variability, 100 participants were recruited, ensuring sufficient power to detect meaningful effects. University male athletes involved in team sports (n=100, age= 21.4±1.0 years, height =182.3 ±7.1cm, weight =78.6±9.0 kg, training age = 9.68±1.39), competing in football (n=29), basketball(n=26), handball , (n=18) or volleyball (n=27), participated in this study. All participants were briefed on the study's objectives and provided informed consent. To qualify for participation, individuals had to meet specific inclusion criteria: they should have been free of injuries in the past 9 months and illness in the past 14 days, regularly engaged in team sports training, and possess a minimum of 7 years of training experience in their respective sport. Participants were familiar with vertical jump testing as a part of regular testing procedures in their respective clubs.

The study adopted a single-cohort, within-subjects repeated measures design with a randomized, counterbalanced crossover approach. All participants underwent a familiarization session in a week preceding initial testing. This session

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introduced both soft and stiff landing styles, accompanied by detailed verbal Instructions and live demonstrations from the investigator. Participants conducted multiple practice trials (a minimum of 2x5 for each landing type) to familiarize themselves with the movement patterns. Technique corrections feedback was provided with participants enabled to ask questions for clarification. The landing technique conditions (soft versus stiff landing) were randomized and counterbalanced among participants. Testing sessions were spaced 72 hours apart to allow for complete recovery and to minimize any fatigue-related effects on performance. All testing sessions were conducted at the same time of day (within a ±1 hour window) for each participant to eliminate circadian influences on neuromuscular performance. The testing procedures were conducted by the same investigator (N.A.) and were supervised by an experienced researcher (T.J.S) to ensure that data collection was executed with high quality and integrity. The experiments took place at the Training Expertise Laboratory. The project was approved by the ethical committee of the faculty of sport, University Union-Nikola Tesla, Belgrade, Serbia (protocol no. 28/26, date of approval 05.02.2026).

Before testing commenced, height and mass were measured using a stadiometer and a calibrated scale. Participants participated in a standardized warm-up protocol, overseen by the investigator, lasting approximately 12 minutes. This warm-up included: Low-Intensity Jogging: 5 minutes of jogging at a self-selected, comfortable pace to elevate heart rate and increase muscle temperature; Dynamic Stretching: 5 minutes of dynamic mobility exercises targeting the lower limbs and hips, including leg swings (front-to-back and side-to-side, 10 repetitions each leg), walking lunges (10 repetitions per leg), and hip circles (10 repetitions each direction). Landing Technique Drills: 2 minutes practicing both soft and stiff landing patterns at submaximal jump intensities under investigator supervision to reinforce correct joint positioning and foot contact strategies. The warm-up intensity and exercises were kept consistent for all participants across test days.

Participants were instructed to abstain from supplements which can improve short-term performance and alcohol during the study. In addition, participants were advised to eliminate high intensity training 72h before the first testing day, in order to perform while fresh. The same investigator gave all verbal cues by reading from a script to guarantee that the verbal instructions given for each cueing condition were consistent between subjects, and no extra encouragement, guidelines, or performance-related feedback were provided to subjects (Xu et al., 2026).

Procedures

Participants performed the CMJ on the Just Jump contact mat (Probotics Inc, USA) according to the Bosco standardized protocol (Komi & Bosco, 1978). Previous studies have reported near-perfect reliability of the Just Jump contact mat for jump height measurement, with ICC values between 0.999 and 1.000 (McMahon et al., 2016). Each trial began with participants standing upright on the mat, feet shoulder-width apart, and hands firmly placed akimbo. From this starting position, participants performed a rapid downward countermovement to a self-selected squat depth (McHugh et al., 2024), followed immediately by a maximal vertical jump utilizing triple extension at the ankle, knee, and hip. The downward and upward phases were executed continuously with minimal transition time between eccentric and concentric muscle actions. Participants performed countermovement jumps under two externally cued landing conditions based on foot contact strategy, labeled "soft" and "stiff" landings for clarity. Unlike traditional definitions that focus on hip and knee flexion, this study uses these terms specifically for ankle and foot contact mechanics. The "soft landing" involved ball-of-foot contact with greater ankle plantar flexion, while the "stiff landing" involved heel-first contact with the ankle near neutral plantar flexion. This classification aimed to isolate the effect of foot positioning on jump height measurements derived from flight time using contact mats.

While standardized verbal instructions were provided, no objective biomechanical verification (e.g., video analysis, kinematics, ankle angle measurement, or force plate data) was performed to confirm compliance with the landing styles. This reflects typical field-testing conditions, though future research should include such measures to validate landing mechanics more precisely.

Each participant performed three trials per landing condition, with 45 seconds of passive rest between trials. The average jump height (cm) across trials was used for analysis, as average CMJ height has been shown to be more sensitive for neuromuscular status monitoring than peak jump height (Claudino et al., 2017).

Statistical analysis

Data analyses were conducted using IBM SPSS Statistics (version 29, IBM Corp., Armonk, NY, USA). Data are presented as mean ±SD. Data were normally distributed as assessed using the Shapiro-Wilk test ($p > 0.05$). A paired sample t-test was used to determine differences in CMJ between the two landing groups (soft vs. stiff landing). Pearson correlation was further conducted to determine if there is an association between different verbal cues (soft vs. stiff) and countermovement jump height performance. Limits of agreement and systematic bias were evaluated using Bland-Altman analysis. For all statistical tests, a significance level was set at $p < 0.05$. The magnitude of the change was determined using Cohen's d effect size (ES) and interpreted using the criterion proposed by Hopkins et al. (2009): trivial <0.20; small = 0.20–0.59; moderate = 0.60–1.19; large = 1.20–2.00; and extremely large > 2.00.

Results

Intra-day reliability across the three trials was assessed using intraclass correlation coefficients (ICC), indicating excellent reliability for both landing conditions: ICC = 0.93 for

Table 1. Mean and Standard Deviation (SD) of Countermovement Jump (CMJ) Height for Soft and Stiff Landing Conditions

Variable	Mean and SD	CI 95%
CMJ soft landing (cm)	45.62 ±5.80	[44.47, 46.77]
CMJ stiff landing (cm)	48.50 ±5.51*	[47.41, 49.60]

*significantly different soft vs stiff landing ($p < 0.05$).

the soft landing and ICC = 0.95 for the stiff landing, demonstrating consistent CMJ performance within sessions for each landing style.

A paired-samples t-test revealed a significant difference between conditions (t(99) = -12.78, p=0.001), with a large effect size (Cohen's d=1.28) and confidence interval ranging from 2.43 to 3.33 cm (Table 1).

In addition, Pearson correlation analysis showed a significant (p=0.001) strong positive (r=0.922) correlation between these two conditions (Table 2.).

Table 2. Pearson Correlation between CMJ Heights under Soft and Stiff Landing Conditions

Variables	r	p
CMJ soft – CMJ stiff	0.922	0.001

A Bland-Altman analysis showed a systematic bias between conditions, with the stiff landing condition producing higher CMJ values compared with the soft landing condition (mean difference = 2.88 cm). The limits of agreement ranged from -1.54 to 7.30 indicating moderate variability between soft and stiff landing conditions (fig. 1).

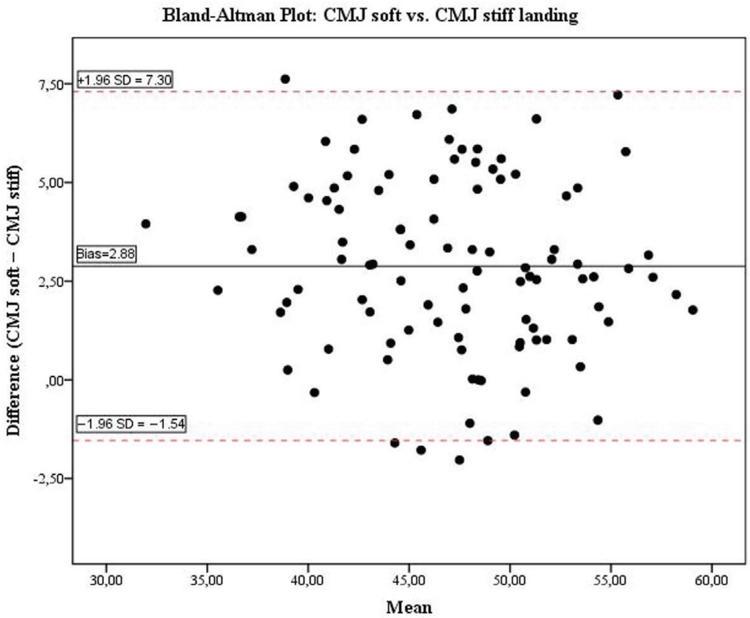

Figure 1. Bland–Altman plot showing the agreement between CMJ heights under soft and stiff landing conditions

Discussion

The study aim was to investigate the effects of different landing styles on CMJ height assessed using a contact mat. Our primary finding confirmed the hypothesis that CMJ height is significantly greater when using the stiff landing technique compared to the soft landing. The high Pearson correlation coefficient indicated a strong linear relationship between measurements from the two landing styles, reflecting consistent ranking of athletes' performances across conditions. However, Bland-Altman analysis demonstrated a systematic bias favouring stiff landings, accompanied by moderate limits of agreement, highlighting that, while related, CMJ heights obtained from soft and stiff landing protocols are not directly interchangeable. These findings emphasize the critical importance of standardized and clearly defined ankle landing instructions to ensure accurate and reliable assessment of vertical jump performance in team sport athletes.

Numerous studies have examined the biomechanical and performance implications of soft versus stiff landing techniques, particularly in the context of injury risk and movement mechanics. For instance, investigations into joint kinematics and loading patterns have highlighted distinct differences in hip, knee, and ankle contributions during landing, which relate to both injury mechanisms and performance outcomes (Leppänen et al., 2017; Pedley et al., 2025). Soft landing strategies have been shown to significantly reduce ground reaction forces, thereby diminishing injury risk, and are typically characterized by increased absorption at the hip and knee joints with relatively stable ankle mechanics (Leppänen et al., 2017; Verniba et al., 2017). Finally, studies reported both similar and different performance outcomes including jump height when conducting soft and stiff landing styles (Dai et al., 2015). It should be emphasized, however, that the aforementioned studies employed soft and stiff landing techniques that differ substantially from those used in the present investigation; therefore, their findings should be interpreted with caution.

The difference observed between the two landing styles in CMJ height reported in our study exceeded the known measurement error for jump mats reported in previous reliability studies with similar populations, which ranged from approximately 1.7 to 1.8 cm. Moreover, it surpassed the smallest worthwhile change (SWC), defined as the minimal performance improvement considered meaningful in practice (Batterham & Hopkins, 2006). Previous research suggests that the SWC for CMJ height typically lies within 3–5% of baseline values or equivalent to a small standardized effect size

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(Claudino et al., 2017). In the present study, considering the average CMJ height of approximately 47 cm across conditions, this translates to an SWC ranging from about 1.4 to 2.4 cm, which is lower than the observed difference between landing styles.Therefore, the effect of landing style on jump height in our study is greater than both typical measurement variability and thresholds for practical significance, indicating that this difference is substantive rather than a result of measurement noise or biological variability.

The observed superiority of the stiff landing technique in achieving greater CMJ height may be attributed to differences in flight time measurement inherent to the landing styles. Concisely, contact mats estimate jump height from the duration that the athlete is airborne ("flight time"), using standard kinematic equations that assume identical take-off and landing body positions. However, it has been reported that ankle plantar flexion during push off is double the angle than during landing, leading to longer airborne phase and inflated jump heights obtained with contact mats in comparison to other testing modalities (Cameron et al., 2025). The same explanation likely holds true for our study findings, with landing mechanics, particularly foot placement and joint angles, directly influence these flight time measurements. Soft landings, characterized by greater ankle plantar flexion upon landing, likely result in earlier ground contact or altered timing cues detected by the mat, leading to shorter recorded flight times. In contrast, stiff landings with no ankle joint plantar flexion likely prolong flight time, thus inflating calculated jump heights. Indeed, previous mathematical modelling proposed a CMJ height measurement error of around 45% of the center of gravity height offset (9cm) between take-off and landing (Bui et al., 2015). This corresponds to around 4cm jump height differences, closely in range to our study findings. These biomechanical nuances cause systematic discrepancies in jump height assessments that are unrelated to true difference in jump effort or ability but rather reflect methodological sensitivity to landing technique.

Certain limitations of this study should be acknowledged. The sample consisted exclusively of male university athletes involved in team sports, which may limit the generalizability of findings to female athletes or individuals from other sports and performance levels. Although a familiarization session was performed, residual learning or adaptation effects to the landing instructions cannot be completely ruled out. Additionally, the use of a contact mat, while practical and widely accepted, limits biomechanical insight into joint kinematics and kinetics during landing and take-off phases. The inclusion of motion capture in future studies would provide a more comprehensive understanding of the observed differences.

Conclusion

Stiff landing results in significantly greater jump height measurements in comparison to soft landing, with moderate limits of agreement, highlighting that contact mat CMJ heights obtained from soft and stiff landing protocols are not directly interchangeable.These findings emphasize the necessity of providing clear, standardized ankle landing instructions during CMJ testing to ensure consistency and reliability of results. Variability in landing style could introduce systematic bias and obscure true changes in an athlete's neuromuscular status over time. For practitioners, this highlights the potential pitfalls of comparing jump heights across sessions or between athletes when landing instructions are not rigorously controlled. Therefore, standardizing landing mechanics seems important when using flight-time derived devices, such as contact mats, to ensure valid and comparable vertical jump measurements across testing sessions and athletic populations.

Conflicts of interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as potential conflicts of interest.

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