International Journal of Strength and Conditioning

Berberet, D., Petway, A., Bell, K., Gillen, Z., Mundy, P., Barrera, H., Kabo, J., Walker, D., Modenwald, G., Welsh, B., & McMahon, J. J. (2025). Unlocking Basketball Athletic Performance: Countermovement Jump Rebound (CMJ-RE) Normative Reference Values Derived from Force Plate Data Across Seven NCAA Division-I Power Five Men's College Basketball Teams.
International Journal of Strength and Conditioning
https://doi.org/10.47206/ijsc.v5i1.555

Unlocking Basketball Athletic Performance: Countermovement Jump Rebound (CMJ-RE) Normative Reference Values Derived from Force Plate Data Across Seven NCAA Division-I Power Five Men's College Basketball Teams

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ABSTRACT

Purpose: This study examined the emerging countermovement rebound jump (CMJ-RE) test as an alternative to the drop jump (DJ) to grade reactive strength abilities in elite basketball players. Normative percentile data, rebound jump filter criteria, novel effort metrics, and reliability statistics were analyzed in order to better define the standards for a high-quality CMJ-RE test and to democratize the measurement of reactive jump testing. **Methods:** 96 NCAA Division-I men's college basketball players from seven teams performed the CMJ-RE (bounce-method) on bilateral force plates with hands on hips during the 2023-2024 pre-season. Only 87 players met the quality filter criteria for further analysis (three centers, 31 forwards, 53 guards); the center position was not compared in depth due to the limited sample size. **Results:** Between forwards and guards, positional differences were found for 37% of the 38 reported jump metrics, with guards showing higher rebound jump heights (JH), all other metrics ($p < 0.05$) favored forwards. Mean ground contact times (GCT) for both positions were >250 ms. On average for both positions, the first jump in the CMJ-RE was completed at 94% JH of a previously collected standalone CMJ JH; and the second jump was completed at 98% JH of the first CMJ-RE JH. Furthermore, percentile ranges (3rd to 97th) accompanied by qualitative descriptors and a traffic light classification system were reported. **Conclusion:** Overall, the CMJ-RE (bounce-method) is a reliable alternative to the DJ for assessing reactive strength qualities in elite basketball players and may be more sport-specific, due to players frequently performing subsequent jumps rather than one single effort jump. The normative data prepared in this study should serve as a reference point throughout the evaluation of reactive strength for basketball performance coaches and in the return to play process for sports medicine professionals. Those administering the CMJ-RE should use the filter criteria measures outlined in this paper to ensure quality and effort are being met.

INTRODUCTION

Rebound jump testing (RJT) has long been a key component of athletic performance testing, particularly in sports like basketball that involve significant use of the stretch-shortening cycle (SSC). In basketball, about 16.2% of the game involves high-intensity movements, of which are crucial for sporting success (1). Among these high-intensity movements, are changes of direction (COD) which occur every 1 to 3 seconds, highlighting their importance as a key demand of the sport (1). Research indicates that athletes who achieve higher jumps and minimize ground contact time (i.e. effective SSC usage) in RJT tend to excel in COD performance tests (2, 27). The RJT leverages the SSC, a natural neuromuscular function, involving a stretch, a brief pause, and then a contraction. This type of jump testing stresses the athlete's braking demands, as it involves falling from an elevated surface before execution. For a deeper understanding of RJT and the SSC, readers are encouraged to refer to the 2024 review by Xu et al. (2). Classification of RJT is often split between fast or slow movements, defined by the time it takes to execute the jump - also known as ground contact time (GCT). In RJT, GCT is composed of a braking phase (i.e. eccentric), transfer point (i.e. amortization, switch phase), and propulsive phase (i.e. concentric). The transfer point, previously proposed in the countermovement jump (CMJ) is the brief period of time after the braking phase and immediately before the propulsive phase (3). The goal of this phase is to maximize the braking momentum generated from unweighting, and transfer that into propulsion and thus flight to move the center of mass vertically. The classification of fast SSC movements are generally those greater than 250 ms, and slow less than 250 ms. Historically, the drop jump (DJ) has been commonly used as a test for fast SSC performance, while the CMJ is used to assess slow SSC performance. This center mark of 250 ms for fast vs. slow SSC testing is somewhat arbitrary, and is traced back to DJ work of Bobbert in the late 1980's (4,5,6). Traditionally, researchers and practitioners have relied on the 250 ms benchmark to make assertions regarding reactive human movement; however, in recent times this has been challenged (26).

Somewhat recently, a novel hybrid RJT was introduced combining the CMJ and DJ and coined the countermovement rebound jump (CMJ-RE) (7,8). The two jumps that make up the CMJ-RE are composed of eight total phases illustrated in Figure 4 compared to six key CMJ phases (9) and five DJ phases (10). Given the number of jump phases and available metrics for each test, fully validated, modern-day commercially available force plates are best suited to access RJT in the applied setting (11,12). Proponents of CMJ-RE are that it is time-efficient, yields a low skill acquisition barrier to entry, and provides insights on two SSC qualities in one test - of which occur in succession in most sports. Additionally, the fall height for the second jump is automatically scaled based on the athlete's vertical displacement in the first jump; therefore simplifying the regulation of fall height across different athletes, eliminating the need for varying box heights in the DJ. A recommendation that was further voiced in a 2024 RJT review (2). Currently there are two researched CMJ-RE testing procedures. The most common procedure includes the first jump (i.e. CMRJ1) be completed with maximal effort as an athlete would complete a stand-alone CMJ test. The second jump (i.e. CMRJ2) be completed as a DJ would be cued with fast GCT, smaller joint angular displacements, and with athlete instruction to be fast off the ground. This procedure (bounce-method) exhibits strong test-retest reliability for both magnitude (13,14,15,25) and direction of asymmetry (13). Another less common procedure involves two maximal jumps, known as the 'double-countermovement strategy' (15). This makes the rebound jump in CMJ-RE similar to a depth jump with longer GCT, greater knee and hip flexion, and more contractile dependency. Figure 1 shows where each of these fall on the SSC continuum with other test types. Only one study has compared these two procedures, finding significant differences in angular displacements, jumping strategies (i.e. spatio-temporal), and output metrics (i.e. jump height) in recreational athletes (15). In this present study, the first, more extensively researched CMJ-

RE procedure is used to produce a short, fast rebound jump, aiming to maximize reactive strength - graded by the ratio of jump height to GCT (i.e. RSI, modified-RSI). Others have used this procedure and investigated lower body joint work (e.g. ankle, knee, hip) in college-aged sport science students between the DJ from a 30-cm box height and CMJ-RE rebound jump, with an average CMRJ1 jump height of ~28-cm, and found contributions to be similar for both positive and negative work - DJ and CMRJ2 jump heights were also similar (16). This provides some justification that the CMRJ2 in a CMJ-RE may be used as a proxy to a standalone DJ. Alternatively, Talpey et al. (2024) found that in a subgroup of 20 NCAA DI American Football players a DJ from a 30-cm and 45-cm drop height did not show strong correlations to CMRJ2 with an average CMRJ1 jump height of ~41cm (17). However, RE-mRSI values showed no significant difference (small-effect) to mRSI values collected in the DJ from 30cm and 45cm (17). The major limitations of both studies is the familiarization of the test subjects.

Considering the limited publications on the CMJ-RE, especially in elite populations, the primary aim of this paper is to report CMJ-RE normative force plate data by basketball position (i.e. centers, forwards, guards) and provide insight for using the CMJ-RE in practice. It is hypothesized that body weight will impact absolute metrics similar to that of the CMJ in a similar population (3), thus most metrics favoring forwards. This paper also questions the SSC classification "250 ms" landmark's validity for CMJ-RE, and hypothesizes that guards will exhibit a quicker ground contact time than forwards due to the demands of the guard position vs. forwards. By knowing this information, practitioners will better be able to identify athleticism, prescribe training, monitor neuromuscular readiness, and return athletes back to play post injury. This information may be used alongside NCAA DI MCBB CMJ normative data that was surfaced in 2024 by Berberet et al. showing that positional differences do exist in slow SSC test types (3). By knowing both CMJ-RE and CMJ normative data in elite basketball players the benchmarking process becomes clearer with both slow and fast SSC tests integrated into a testing battery for a comprehensive view of each player. Lastly, the CMJ-RE may be preferred in this specific population due to limitations in experience with the DJ and short skill acquisition period considering NCAA time restrictions for physical preparation, and the recent introduction of the NCAA transfer portal.

MATERIALS AND METHODS

Experimental Approach to the Problem

During the 2023-2024 pre-season, each participant underwent a single CMJ-RE testing session at their respective university over a 26-day period. A designated tester collected all data, traveling by car to each site between September-October 2023. The same bilateral force plates, collection tablet, and three-inch perimeter foam surround were used at all locations. The force plates were transported in a hard travel case with a custom foam insert to prevent movement and maintain calibration. Upon arrival at each site, the tester set up the force plates in an open area of the weight room on a hard, level surface. The plates were acclimatized to the environment for at least 45-minutes before testing began. The tester ensured the plates were level by checking for instability in all four corners and adjusting the feet as needed. Before

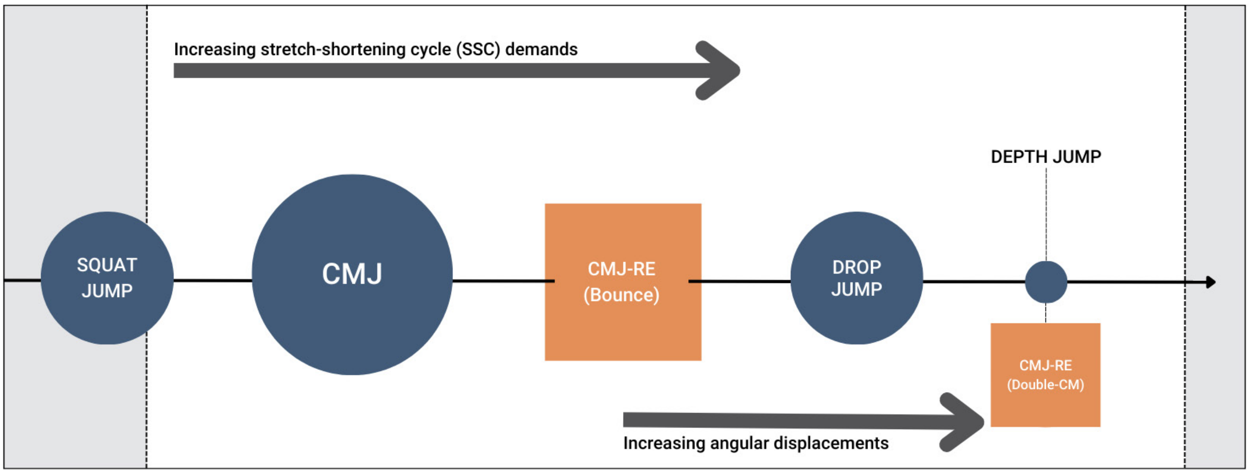

Figure 1. SSC continuum highlighting various force plate test types and their SSC demands, increasing as it moves to the right. The two methods of CMJ-RE shown in orange squares: bounce and double-countermovement (Double-CM). CMJ = countermovement jump; CMJ-RE = countermovement rebound jump.

testing, athletes received a verbal overview of the study, a visual demonstration of the test, and participated in a standardized dynamic warm-up (detailed in Appendix A) by the test collector. All participants were familiar with the force plate manufacturer and software workflow since it was used at their respective universities. Immediately before the CMJ-RE testing session commenced, the athletes completed three CMJ trials as part of a previous study (3). No warm-up CMJ-RE tests were conducted.

Participants

Seven NCAA DI MCBB teams composed of 96 players volunteered to participate in this study. All of the players were healthy and injury-free at the time of collection. Of the 96 possible players, only 87 met the rebound jump filter criteria (see statistical analysis) to be included; three centers (age = 19.98 ± 1.60 years, height on website = 219.29 ± 3.88 cm, body mass on plates = 118.34 ± 17.94 kg), 31 forwards (age = 21.20 ± 1.67 years, height on website = 205.49 ± 5.46 cm, body mass on plates = 104.78 ± 10.55 kg), and 53 guards (age = 20.97 ± 1.53 years, height on website = 191.03 ± 7.49 cm, body mass on plates = 86.98 ± 7.08 kg). Age, position and height were sourced from the team's official website. In cases where the birthdate was not available, the team's strength and conditioning coach provided the necessary information upon request to calculate the player's age. Figures 2 and 3 illustrate the effects of test results based on the time of day and the day of the week for all three positions after the rebound jump criteria filter was implemented. This study represents the second part of a series of comprehensive analysis on NCAA DI MCBB players biomechanical performance; further descriptive player information can be found in a previous CMJ normative data paper by Berberet et al. (2024) (3). The Institutional Review Board at Mississippi State University (IRB-23-322) approved this study, and all participants provided informed consent before data collection began.

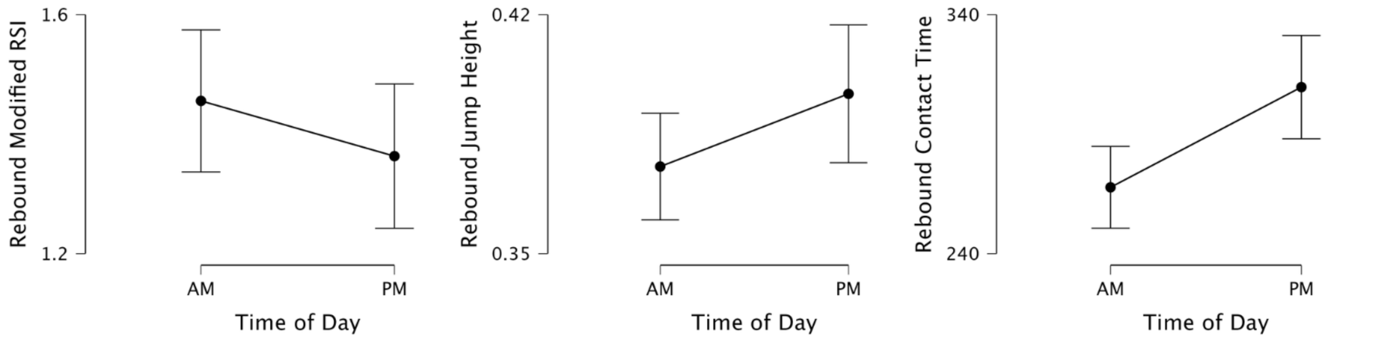

Figure 2. Time of day testing effects for all three MCBB positions for CMJ-RE modified reactive strength index (RE-mRSI), CMJ-RE jump height (RE-JH), and CMJ-RE contact time (RE-GCT). Tests collected in the AM (n = 36) occurred between 8:14:30 and 11:38:16 and PM (n = 51) between 12:11:52 and 14:25:56, respectively. RE-mRSI is calculated by dividing RE-JH (calculated from takeoff velocity) by RE-GCT (sum of rebound braking and propulsive phase durations).

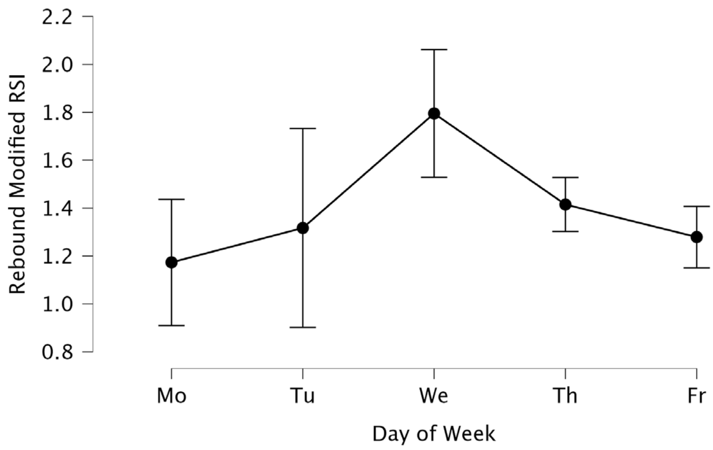

Figure 3. Day of week testing effects for all three MCBB positions (n = 87) analyzing CMJ-RE mRSI as a measure of readiness. Mo = Monday (one team tested, n = 9); Tu = Tuesday (one team tested, n = 5); We = Wednesday (one team tested, n = 15); Th = Thursday (two teams tested, n = 27); Fr = Friday (two teams tested, n = 31). All data was included in the study.

Force Plate-Derived CMJ-RE Test

In this study, the CMJ-RE with hands on hips immediately followed the CMJ with hands on hips reported in the study by Berberet et. al (3) using Hawkin Dynamics Gen5 wireless one-dimensional bilateral force plates manufactured in Westbrook, ME, USA (sampling at 1000 Hz and filtered with a Butterworth filter set at a cut-off frequency of 50 Hz). Paired with Hawkin Dynamics validated software interface (Hawkin Capture Version 8.6.1) (11,12) on a Samsung Galaxy A8 tablet operated by the test collector who was positioned roughly 3-feet away and off-centered from the participant presenting the tablet at eye-level. In this study and the previous investigation, subjects were given instruction to stand motionless with hands placed firmly on their hips and to first execute a maximal jump (i.e. CMRJ1) upon the flash/beep and then jump quick and high on the second jump (i.e. CMRJ2) with the intent of being reactive. Subjects were provided with a strong verbal cue of "get up" from the test collector as they approached their CMRJ1 landing and immediately before initiating CMRJ2, aiming to provide additional encouragement to maximize CMRJ2 quickness. An inter-test rest period of at least ten seconds was provided and feedback was given verbally to each athlete between attempts of rebound GCT (i.e. 220 ms) and the force plates were zeroed between each athlete. To mitigate any potential numerical integration drift, one CMJ-RE test was saved per trial. Following the collection of all tests, all athletes engaged in a scheduled basketball practice session. Subsequently, six out of the seven teams took part in a scheduled weight training session following force plate testing and preceding practice.

Table 1. Novel, researcher-generated, CMJ-RE metric definitions used in this investigation.

CMJ-RE Metric	Abbreviation	Definition
Rebound Braking Force Absolute Asymmetry (N)	RE-BFAA	Absolute difference between left and right average braking forces
Rebounf Propulsive Force Absolute Asymmetry (N)	RE-PFAA	Absolute difference between left and right average propulsive forces
Rebound Braking Phase (ms)	RE-BP	Duration of time spent in the braking phase
Rebound Propulsive Phase (ms)	RE-PP	Duration of time spent in the propulsive phase
Relative Rebound Depth	RE-RDEPTH	Rebound depth divided by the subject height
Rebound Impact Peak%	RIP%	The percentage of total contact time that peak braking force occurred at
Rebound Phase Duration Ratio	RE-PDR	The ratio of propulsive phase and braking phase durations

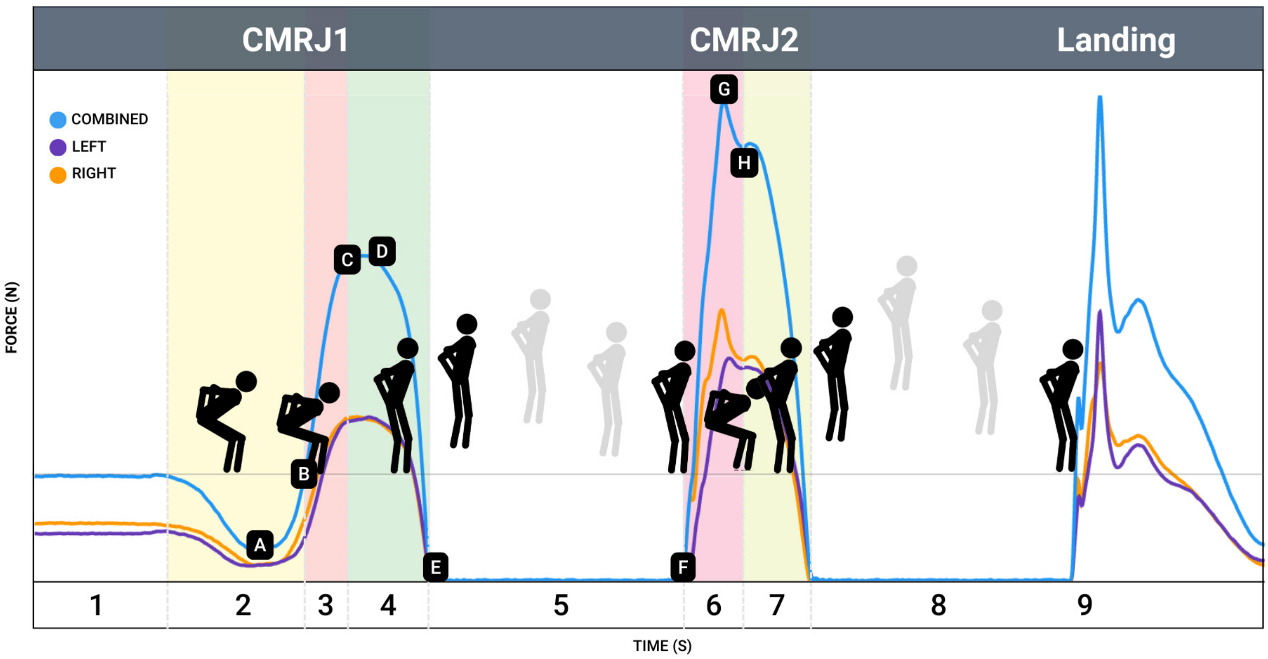

Figure 4. CMJ-RE force-time curve showing the nine key phases; (1) weighing, (2) CMRJ1 unweighing, (3) CMRJ2 braking, (4) CMRJ1 propulsion/propulsive, (5) CMRJ1 flight, (6) CMRJ2 rebound braking, (7) CMRJ2 rebound propulsion, (8) CMRJ2 rebound flight, and (9) CMRJ2 rebound landing. A-B is back to bodyweight deceleration, B-C is center of mass (COM) deceleration, C is the CMRJ1 transfer point which may help explain amortization abilities, C-D is COM reacceleration to propel vertically, E is when flight begins at the instant of take-off, F is the instant of touch-down when CMRJ2 braking begins. F-G is impact deceleration after flight to regain COM control, G is impact peak force, G-H is the discrepancy between impact peak force and force at zero velocity (this could be the same) , H is the CMRJ2 transfer point when velocity is zero.

Figure 4 annotates the phases of the CMJ-RE as reported in the manufacturer's software. The first half of the CMJ-RE test is a CMJ which encompasses all six key phases as first reported by McMahon et. al (2018) with the exception of CMJ landing (9). The second portion is the rebound jump whereas the landing of the first CMJ becomes the second braking phase (i.e. rebound braking), propulsive phase (i.e rebound propulsive), flight phase (i.e. rebound flight), and landing phase (i.e. rebound landing) resulting in a total of nine key CMJ-RE phases. With each new phase comes the potential for additional metrics. At the time of collection, there were 106 possible CMJ-RE metrics reported in the commercial software - definitions for each can be found at the link: www.hawkindynamics.com/hawkin-metric-database. Seven novel metrics (see Table 1) and three effort metrics were also analyzed (refer to 'CMJ-RE Effort Metrics' section). For descriptive purposes, the CMJ-RE metrics were split up into categories based on elements of the "ODS System" and their respective rebound phases (18). Percentile visualization categories were compared by position and split into three groups -output, braking, and transfer - propulsive. GCT and phase durations were visualized by use of bar plots by position.

Statistical Analysis and Rebound Jump Filter Criteria

After CMJ-RE data was collected on the mobile app it was automatically pushed to the Hawkin Cloud (cloud.hawkindynamics.com) for warehousing and exportation as CSV files for data cleaning in Google Sheets. We employed a novel method for cleaning CMJ-RE data gathered using commercially available force plate software. We adapted a CMJ cleaning protocol from a recent study by Berberet et al. (2024), where the researchers averaged the top two CMJs (determined by the highest JH - "best") from a set of three CMJ trials. In the current investigation, instead of using JH as the qualifier for "best" (3), we used RE-mRSI because the goal of the CMJ-RE is to measure quickness and height jumped. CMRJ1 of the CMJ-RE was not analyzed in-depth as the researchers did in Berberet et. al (2024) because no CMRJ1 spatio-temporal metrics were used for filtering, analysis, or reporting. After the best two CMJ-RE trials were identified for each subject, we used a multi-step process to further clean the CMJ-RE data to ensure all analyzed trials met standards. This multi-step process involved mathematically identifying "jump effort" during the CMRJ1 comparative to the stand alone CMJ collected immediately before CMJ-RE collection. CMRJ1 jump height must have been within 85% of the average of the best two stand alone CMJ trials JH. This was further known as "CMRJ1 85% Effort". Furthermore, CMRJ2 JH of the CMJ-RE must be at least 60% of CMRJ1 JH from the CMJ-RE - a statistical attempt to rule out fluke trials of an athlete's SSC function. Ideally, CMRJ2 is higher because of the drop from CMRJ1 height and greater potential for enhanced elastic energy usage. After jump effort and effective demonstration of the SSC were met, we then set out to identify if any extreme body shifting occurred in air, thus causing the subject to not fully land on the force plates after CMRJ1 and before CMRJ2. The metric used to identify this was rebound L/R braking impulse index and the value must not have been beyond ± 50% - this was further known as the "CMJ-RE Body Shift Filter". If an individual had a trial that did not meet the above three filters, the trial was removed. The remaining best two CMJ-RE trials for each athlete were then averaged together and used for statistical analysis. If an athlete only had one trial that met all criteria (n=6), that single trial was used. Of the 96 athletes tested, 87 (90.6%) met these criterias. While not used, it is worth noting that when a "CMRJ1 90% Effort" cutoff was used instead of 85%, only 68 (70.8%) of the athletes met all criteria. Of the 87 that passed, only three played the center position. Considering this, due to a small sample size, only anthropometric descriptive data was reported for centers. Forward and guard CMJ-RE data was used for further positional comparative analysis. Time of day and day of week testing effects were analyzed using an independent t-test and one-way ANOVA before comparisons.

31 of the possible 106 CMJ-RE metrics (*see Table 4, Table 5, and Figure 6 for full metric names*) in the Hawkin Dynamics software were used for analysis, plus seven novel jump metrics (RE-BFAA, RE-PFAA, RE-BP, RE-PP, RE-RDEPTH, RIP%, RE-PDR) , and three predictive effort metrics (CMRJ1 Effort %, CMRJ2:CMRJ1, CMRJ2:CMJ) were selected for positional comparison. Normality was analyzed using Shapiro-Wilks tests plus Q-Q plots and 14 metrics (RE-TPBF, RE-GCT, RE-DEPTH, RE-RDEPTH, RE-PRPP, RE-PRBF, RE-ARBP, RE-BFAA, RE-GCT, RE-BP, RE-PP, RE-PPP, RE-FMD, RE-ABF) were non-normally distributed for one of two positional-groups; seven CMJ-RE metrics (RE-PBF, RE-PBP, RE-PRBP, RE-PFAA, RE-SPRING, RE-STIFF, RE-PDR) were found to be non-parametric for both positional-groups, therefore a Mann-Whitney U Test was used for further comparison. Additionally, Rank-Biserial Correlation was used to calculate the magnitude of effect for the seven

non-parametric metrics. An independent t-test was conducted for the parametric jump metrics, anthropometrics, and jump effort metrics. Cohen's *d* effect size was employed to determine the magnitude of differences; trivial (d < 0.19), small (d = 0.2), moderate (d = 0.5), and large (d > 0.80) (19). Statistical significance was predetermined at p<0.05. Jeffreys's Amazing Statistics Program (JASP version 0.18.3) was used for these analyses.

To streamline our percentile chart creation, we first pruned our initial list of CMJ-RE metrics. We excluded metrics that might favor mid-range performance and those showing high correlation with other output metrics. We then organized the remaining metrics into three categories: braking, transfer, and propulsive. Within the braking and propulsive categories, we conducted correlation analyses to identify closely related metrics, using a threshold of r ≥ 0.85 or ≤ to -0.85, following guidelines set by Bird et al. (2022) (20) and Berberet et al. (2024) (3). In cases where metrics within the same category showed high correlation, the Coefficient of Variation Percentage Comparison Method (CVCM) was used to select the metric with the lowest intra-session coefficient of variation percentage. Individual CV% values were computed by dividing each athlete's standard deviation by their means from their two best CMJ-RE trials and multiplying by 100. Finally, we calculated the average CV% for each metric, as depicted in Figure 5.

We utilized JASP to generate position-specific CMJ-RE percentile charts (see Figures 7-9). Percentiles ranging from the 3rd to the 97th were produced at intervals of 5, which were then exported to Google Sheets for formatting and visual representation. To provide qualitative context, descriptors such as "poor," "below average," "average," "above average," and "good" were adapted from McMahon et al. (22), with color-coded traffic light systems applied. This involved converting T-scores to corresponding percentile values. Table 6 demonstrates the alignment of percentiles with Z-scores and T-scores, alongside their respective colors as originally outlined by Berberet et. al (3). The final analysis and visualization were conducted within Google Sheets.

RESULTS

Time of Day and Day of Week

No significant effects (p = 0.29 , ES = 0.23) on the time of day were shown when comparing AM (n = 36) and PM (n = 51) RE-mRSI for all three positions across seven teams. Although non-significant, AM (M = 1.46, SD = 0.35) was slightly higher than PM (M = 1.36, SD = 0.43) RE-mRSI. Additionally, a one-way ANOVA was used to analyze day of week testing effects by comparing RE-mRSI values for Monday (n = 14), Tuesday (n = 6), Wednesday (n = 16), Thursday (n = 28), and Friday (n = 32). The results of Levene's test indicated that the variances were equal across groups (F = 0.62, p = 0.65), suggesting that the assumption of homogeneity of variances was not violated. Normality was assessed using a Q-Q plot, no significant deviations were documented. A large effect was found when comparing the five days RE-mRSI values, F(4,82) = 6.48, p = <0.001, η^2 = 0.24. Tukey's post hoc testing revealed significant differences between Wednesday (1.79 ± 0.48) - Monday (1.17 ± 0.34), Wednesday - Thursday (1.41 ± 0.28), and Wednesday - Friday (1.28 ± 0.35).

Anthropometric Characteristics

There was no significant difference in the ages of forwards and guards at the time of their jumps (p = 0.52, ES = 0.15). Guards were notably shorter than forwards based on height data from the official team website (p < 0.001, ES = 2.12) and also weighed less on the force plates during testing (p < 0.001, ES = 2.09). While anthropometric data for centers were not compared, these variables are listed in Table 2 along with data for forwards and guards.

Table 2. Anthropometric measures for centers, forwards, and guards; and comparisons for forwards and guards. F = forward; G = guard. M = mean; SD = standard deviation; ES = effect size; 95%CI = 95% confidence interval lower to upper.

	Group					Magnitude FvG		
	M ± SD	M ± SD	M ± SD					
Variables	**Centers (n=3)**	**Forwards (n=31)**	**Guards (n=53)**	**Mean Difference FvG**	**95%CI**	**ES**	**ES Descriptor**	***p*-value**
Age at Jump (years)	19.98 ± 1.60	21.20 ± 1.67	20.97 ± 1.53	0.23	-0.48 to 0.94	0.15	Trivial	0.52
Height on Website (cm)	219.29 ± 3.88	205.49 ± 5.46	191.03 ± 7.49	14.46	11.4 to 17.54	2.12	**Large**	**< .001****
Weight on Plates (kg)	118.34 ± 17.94	104.78 ± 10.55	86.98 ± 7.08	17.80	13.97 to 21.63	2.09	**Large**	**< .001****

*Bold, underline, and ** p values = p ≤ 0.001; Bold and underlined ES = Moderate to Large effect*

CMJ-RE Force-Time Metrics

Prior to the analysis of CMRJ2 metrics, CMRJ1 jump heights were analyzed as reference values for CMRJ2 jump heights, and to compare to previously published research using a similar population set (3). CMRJ1 jump height values for guards (0.41 ± 0.06) was significantly higher than forwards (0.38 ± 0.05) at p=0.04, ES = -0.46.

Of the selected CMRJ2 metrics, 31 were analyzed for positional group comparisons using an independent sample t-test and guards displayed a significantly higher average with small between group effects for RE-JH only. Forwards displayed significantly higher averages with moderate between group effects for RE-ABP, RE-FMD, RE-PPF, RE-APP, RE-PPP, and large between group effects for RE-JM, RE-POSNI, RE-BNI, RE-ABF, RE-PNI, RE-APF (see Table 4). Seven CMJ-RE metrics (RE-PBF, RE-PBP, RE-PRBP, RE-PFAA, RE-SPRING, RE-STIFF, RE-PDR) were non-normal, thus were analyzed using a Mann-Whitney U Test. RE-PBF and RE-PBP displayed between-group differences at $p < 0.05$.

Prior to creating percentile charts, a reduction technique was applied to identify highly correlated metrics (Table 3). Using the CVCM, the list of braking metrics was narrowed down to four (RE-BNI, RE-ABF, RE-ABP, RE-ARBF). In the propulsive category, the metrics were reduced to three (RE-PNI, RE-APF, RE-RPF). All transfer metrics exhibiting polarity were charted (RE-FMD, RE-RFMD, RE-SPRING). These metrics, along with five output metrics (RE-JH, RE-JM, RE-POSNI, RE-RSI, RE-mRSI), were used for percentile comparison. Additionally, it is important to note that RE-PNI and RE-JM will have approximately the same numerical value, but with different units of measurement.

CMJ-RE Effort Metrics

All jump data is only as good as the effort provided. In order for the CMJ-RE test to hold real-life value, the athlete must provide high jump effort on CMRJ1 to challenge the demands for CMRJ2. Ideally, CMRJ1 JH is comparable to the JH registered by the athlete in a standalone CMJ. Figure 6 highlights three novel effort metrics which can be used to grade the effort level that the athlete gives during a CMJ-RE. There were no significant between group effects for any of the effort metrics; mean CMRJ1 Effort % values for both guards and forwards was 0.94 (both SD = ±0.04), mean CMRJ2:CMRJ1 values for both guards and forwards was 0.98 (guards SD = ±0.09, forwards SD = ±0.07), and mean CMRJ2:CMJ values for guards was 0.92 ± 0.09 and forwards 0.91 ± 0.06.

Percentile Normative Reference Values

Data is frequently presented to key stakeholders, but it is not always effectively communicated. Percentiles offer a straightforward method for

Table 3. Highly correlated metrics found in MCBB athletes for braking and propulsive metric categories. Bold and underlined value indicates lower average coefficient of variation percentage (CV%) for both positions when compared.

Highly Correlated Propulsive Metrics ($r \geq 0.85$ or ≤ -0.85)

	Metric	CV% F	CV% G	Metric	CV% F	CV% G
r = 0.97	**RE-APP**	3.80	3.79	RE-PPP	3.91	3.80
r = 0.97	**RE-ARPP**	3.49	4.03	RE-PRPP	3.61	4.01
r = 0.95	**RE-APF**	3.59	3.40	RE-PPP	3.91	3.80
r = 0.95	**RE-ARPF**	3.24	3.53	RE-RPF	6.42	5.49
r = 0.95	**RE-ARPF**	3.24	3.53	RE-PRPP	3.61	4.01
r = 0.94	**RE-APF**	3.59	3.40	RE-PPF	7.21	5.31
r = 0.94	**RE-APF**	3.59	3.40	RE-APP	3.80	3.79
r = 0.94	**RE-ARPF**	3.24	3.53	RE-ARPP	3.49	4.03
r = 0.90	RE-PPF	7.21	5.31	**RE-PPP**	3.91	3.80
r = 0.89	RE-PP	6.00	5.40	**RE-ARPF**	3.24	3.53
r = 0.89	**RE-PP**	6.00	5.40	RE-RPF	6.42	5.49
r = 0.88	RE-RPF	6.42	5.49	**RE-PRPP**	3.61	4.01
r = 0.87	RE-PPF	7.21	5.31	**RE-APP**	3.80	3.79
r = 0.85	RE-PPF	7.21	5.31	**RE-RPF**	6.42	5.49
r = 0.85	RE-RPF	6.42	5.49	**RE-ARPP**	3.49	4.03

Highly Correlated Braking Metrics ($r \geq 0.85$ or ≤ -0.85)

	Metric	CV% F	CV% G	Metric	CV% F	CV% G
r = 0.95	**RE-ABF**	4.35	4.62	RE-ABP	4.42	4.83
r = 0.95	**RE-ARBF**	3.89	4.77	RE-ARBP	3.92	4.98
r = 0.91	**RE-ABF**	4.35	4.62	RE-PBF	7.99	8.43
r = 0.88	RE-BP	6.06	6.20	**RE-ARBF**	3.89	4.77
r = 0.87	RE-PRBF	7.30	8.74	**RE-ARBF**	3.89	4.77
r = 0.86	**RE-ABP**	4.42	4.83	RE-PBF	7.99	8.43

Table 4. Independent sample t-test for 31 CMJ-RE metrics between forwards and guards.

CMJ-RE Metrics		Group				Magnitude		
		M ± SD	M ± SD					
	Abbrv.	Forwards (n=31)	Guards (n=53)	M Difference (95%CI)		ES	ES Descriptor	*p*-value
Rebound Output Metrics								
Rebound Jump Height (m)	RE-JH	0.37 ± 0.05	0.40 ± 0.07	0.03	-0.05 ±7.30×10-5	0.45	Small	**0.05**
Rebound Jump Momentum (Kg*m/s)	RE-JM	282.19 ± 25.25	243.18 ± 28.98	39.01	26.56 to 51.46	1.41	**Large**	< .001**
Rebound Reactive Strength Index	RE-RSI	1.99 ± 0.36	2.07 ± 0.52	0.08	-0.29 to 0.13	0.16	Trivial	0.48
Rebound Modified Reactive Strength Index	RE-m-RSI	1.34 ± 0.27	1.46 ± 0.45	0.12	-0.3 to 0.06	0.31	Small	0.18
Rebound Positive Net Impulse	RE-POSNI	577.61 ± 53.78	496.60 ± 58.94	81.01	55.32 to 106.7	1.41	**Large**	< .001**
Rebound Strategy Metrics								
Rebound Braking Force Absolute Asymmetry (N)	RE-BFAA	228.52 ± 131.20	213.87 ± 114.14	14.64	-39.62 to 68.93	0.12	Trivial	0.59
Rebound Contact Time (ms)	RE-GCT	288.02 ± 54.49	293.27 ± 77.71	5.25	-36.79 to 26.28	0.07	Trivial	0.74
Rebound Depth (m)	RE-DEPTH	-0.15 ± 0.05	-0.17 ± 0.06	0.02	-0.01 to 0.04	0.27	Small	0.24
Relative Rebound Depth	RE-RDEPTH	-0.08 ± 0.03	-0.09 ± 0.03	0.01	-3.87×0-4 to 0.03	0.44	Small	0.06
Rebound Braking Metrics								
Rebound Braking Phase Duration (ms)	RE-BP	133.48 ± 26.43	137.15 ± 38.69	3.67	-19.28 to 11.95	0.11	Trivial	0.64
Rebound Braking Net Impulse (N.s)	RE-BNI	292.75 ± 29.60	251.14 ± 31.10	41.61	27.87 to 55.36	1.36	**Large**	< .001**
Rebound Peak Relative Braking Force (%)	RE-PRBF	519.79 ± 98.71	534.67 ± 113.73	14.88	-63.67 to 33.91	0.14	Trivial	0.55
Rebound Avg. Braking Force (N)	RE-ABF	3322.71 ± 544.65	2828.16 ± 551.68	494.55	247.55 to 741.55	0.9	**Large**	< .001**
Rebound Avg. Relative Braking Force (%)	RE-ARBF	323.54 ± 41.67	332.04 ±62.97	8.5	-33.74 to 16.75	0.15	Trivial	0.51
Relative Avg. Braking Power (W)***	RE-ABP	-5147.53 ± 831.57	-4514.24 ± 1079.87	633.29	-1081.40 to -185.18	0.64	**Moderate**	6.17x10-3**
Rebound Avg. Relative Braking Power (W/Kg)***	RE-ARBP	-49.27 ± 7.08	-51.95 ±12.10	2.68	-2.06 to 7.43	0.25	Small	0.26
Rebound Transfer Metrics								
Rebound Force At Min Displacement (N)	RE-FMD	4475.58 ± 1062.79	3821.34 ± 972.89	654.24	201.42 to 1107.07	0.65	**Moderate**	5.16x10-3**
Rebound Relative Force At Min Displacement (%)	RE-RFMD	436.48 ± 98.57	448.56 ± 111.68	12.08	-60.25 to 36.07	0.11	Trivial	0.62
Rebound Impulse Ratio	RE-IR	0.98 ± 0.04	0.98 ± 0.05	0	-0.03 to 0.02	0.09	Trivial	0.68
Rebound Time To Peak Braking Force (ms)	RE-TPBF	85.66 ± 20.26	81.89 ± 23.46	3.77	-6.27 to 13.82	0.17	Trivial	0.46
Rebound Impact (%)	RIP%	0.31 ± 0.09	0.29 ±0.08	0.02	-0.02 to 0.06	0.19	Trivial	0.40
Rebound Propulsive Metrics								
Rebound Propulsive Phase Duration (ms)	RE-PP	154.53 ± 29.75	156.12 ± 40.24	1.59	-18.12 to 14.94	0.04	Trivial	0.85
Rebound Propulsive Net Impulse (N.s)	RE-PNI	284.85 ± 25.32	245.46 ± 29.19	39.39	26.88 to 51.92	1.42	**Large**	< .001**
Rebound Avg. Propulsive Force (N)	RE-APF	2916.85 ± 390.22	2501.12 ± 413.80	415.73	233.42 to 598.05	1.03	**Large**	< .001**
Rebound Avg. Relative Propulsive Force (%)	RE-ARPF	284.73 ± 34.11	293.80 ± 47.03	9.07	-28.31 to 10.16	0.21	Small	0.35
Rebound Peak Propulsive Force (N)	RE-PPF	4565.85 ± 1021.37	3890.25 ± 955.32	675.41	234.60 to 1116.23	0.69	**Moderate**	3.10x10-3**
Rebound Peak Relative Propulsive Force (%)	RE-RPF	445.36 ± 94.77	456.66 ± 109.18	11.3	-58.14 to 35.55	0.11	Trivial	0.63
Rebound Avg. Propulsive Power (W)	RE-APP	4504.93 ± 610.14	3983.35 ± 824.73	521.58	182.72 to 860.44	0.69	**Moderate**	2.97x10-3**
Rebound Avg. Relative Propulsive Power (W/Kg)	RE-ARPP	43.23 ± 6.03	45.87 ± 9.23	2.64	-6.33 to 1.05	0.32	Small	0.16
Rebound Peak Propulsive Power (W)	RE-PPP	7529.25 ± 1168.70	6517.18 ± 1341.38	1012.07	435.91 to 1588.23	0.79	**Moderate**	< .001**
Rebound Peak Relative Propulsive Power (W/Kg)	RE-PRPP	72.19 ± 11.12	75.08 ± 15.02	2.89	-9.07 to 3.23	0.21	Small	0.35

*M = mean; SD = standard deviation; ES = effect size; 95%CI = 95% confidence interval lower to upper; F = forward; G = guard; *** Lower is generally better, Bold and underlined p values = p ≤ 0.05, Bold, underlined and * p values = p ≤ 0.01, Bold, underlined and ** p values = p ≤ 0.001, Bold and underlined ES = Moderate to Large effect*

Table 5. Mann-Whitney U Test for seven CMJ-RE metrics between forwards and guards. M = mean; SD = standard deviation; Mdn = median; 95% CI = 95% confidence interval

			Group					Magnitude		95% CI for Rank-Biserial Corr.	
			M ± SD	Mdn	M ± SD	Mdn					
	Abbrev.	Category	Forwards (n=31)		Guards (n=53)		Mdn Difference	Rank-Biserial Correlation	*p*-value	Lower	Upper
Non-Normal Distribution Metrics											
Rebound Peak Braking Force (N)	RE-PBF	Braking	5340.61 ± 1161.69	4852.50	4558.83 ± 1026.82	4559	293.5	0.38	4.20×10-3	702.5	250
Rebound Braking Power (W)***	RE-PBP	Braking	-10166.88 ± 1817.16	-10092.53	-9122.6 ± 2196.88	-8864.54	1227.99	-0.35	7.81×10-3	-1113.94	-1961.21
Rebound Peak Relative Braking Power (W/kg)***	RE-PRBP	Braking	-97.42 ± 16.63	-93.03	-104.79 ± 23.05	-100.5	7.47	0.21	0.12	5.78	-1.97
Rebound Propulsive Force Absolute Asymmetry (N)	RE-PFAA	Strategy	114.44 ± 93.37	75.97	85.95 ± 54.69	66.28	9.69	0.20	0.13	-3.87	33.08
Rebound Spring Like Correlation***	RE-SPRING	Transfer	-093 ± 0.08	-0.96	-0.91 ± 0.10	-0.95	0.01	-0.04	0.78	-2.69×10-3	-0.02
Rebound Stiffness (N/m)***	RE-STIFF	Transfer	-25476.58 ± 50471.11	-26296.83	-28219.6 ± 16535.99	-26289.7	7.13	-0.14	0.29	-3141.39	-10477.34
Rebound Phase Duration Ratio	RE-PDR	Transfer	1.17 ± 0.13	146.50	1.15 ±0.10	147	0.50	0.07	0.57	1.24×10-5	-6.45×10-5

**** Lower is generally better*

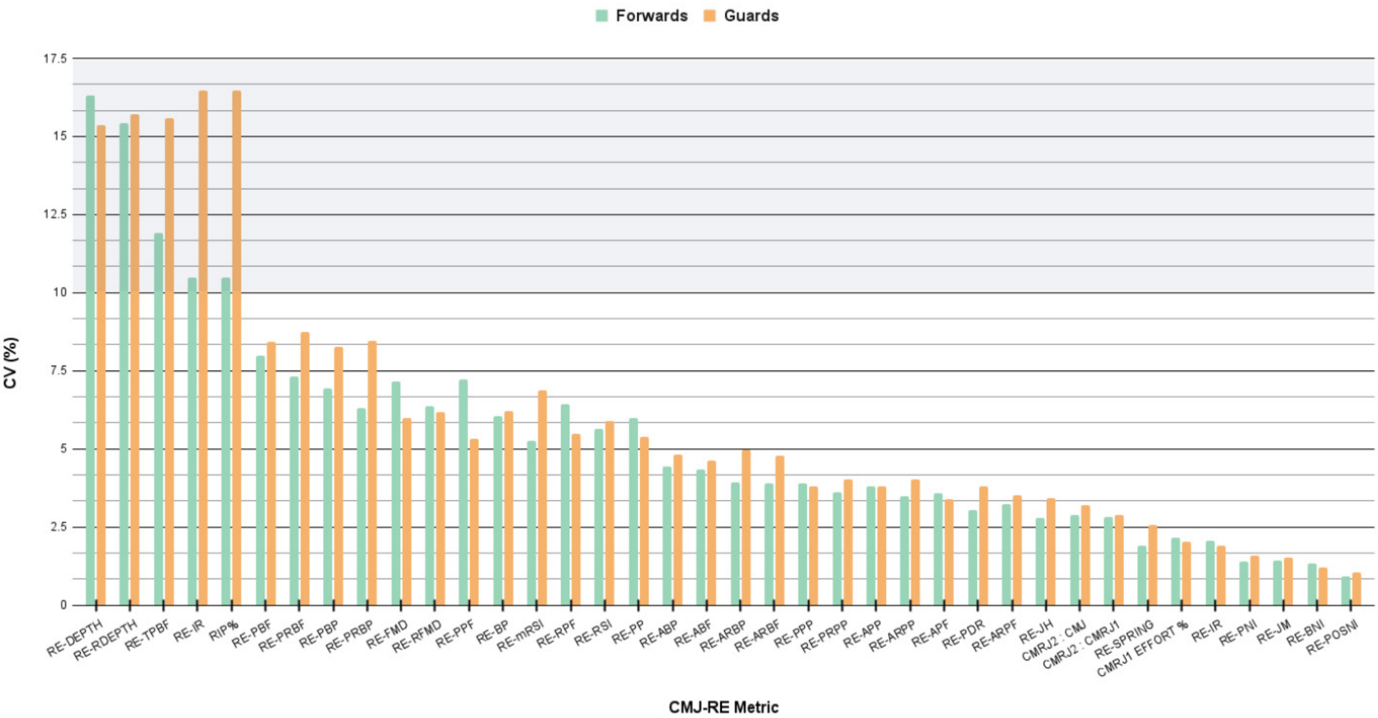

Figure 5. Coefficient of Variation (CV%) for 35 CMJ-RE metrics and three effort-grading metrics (CMRJ1 EFFORT %, CMRJ2:CMRJ1, CMRJ2:CMJ); excluding outliers RE-BFAA (Forwards CV% = 83.76, Guards CV% = 60.48), RE-PFAA (Forwards CV% = 74.25, Guards CV% = 102.84) and RE-STIFF (Forwards CV% = 109.45, Guards CV% = 24.40). Forwards are color-coded green; guards are color-coded orange. Generally speaking, CV% 0-10% is considered very good and 11- 30% is considered acceptable.

illustrating a player's ranking relative to their peers. Consequently, using percentiles for communication and standard scores (such as Z-scores and T-scores) for determining statistical significance is a sensible approach. The metrics selected for percentiles were chosen based on reduction techniques detailed in the statistical analysis section of this paper and their biological relevance to the sport of basketball.

Reactive Strength and Phase Duration Characteristics

Arguably the most reported metric in all RJT is RSI or mRSI. RSI is flight time divided by GCT, whereas, mRSI is JH divided by GCT - JH ideally is calculated from the takeoff velocity method as it is in this investigation. Figure 10 provides positional comparison of RE-GCT split up into two respective phases, braking phase (RE-BP) and propulsive

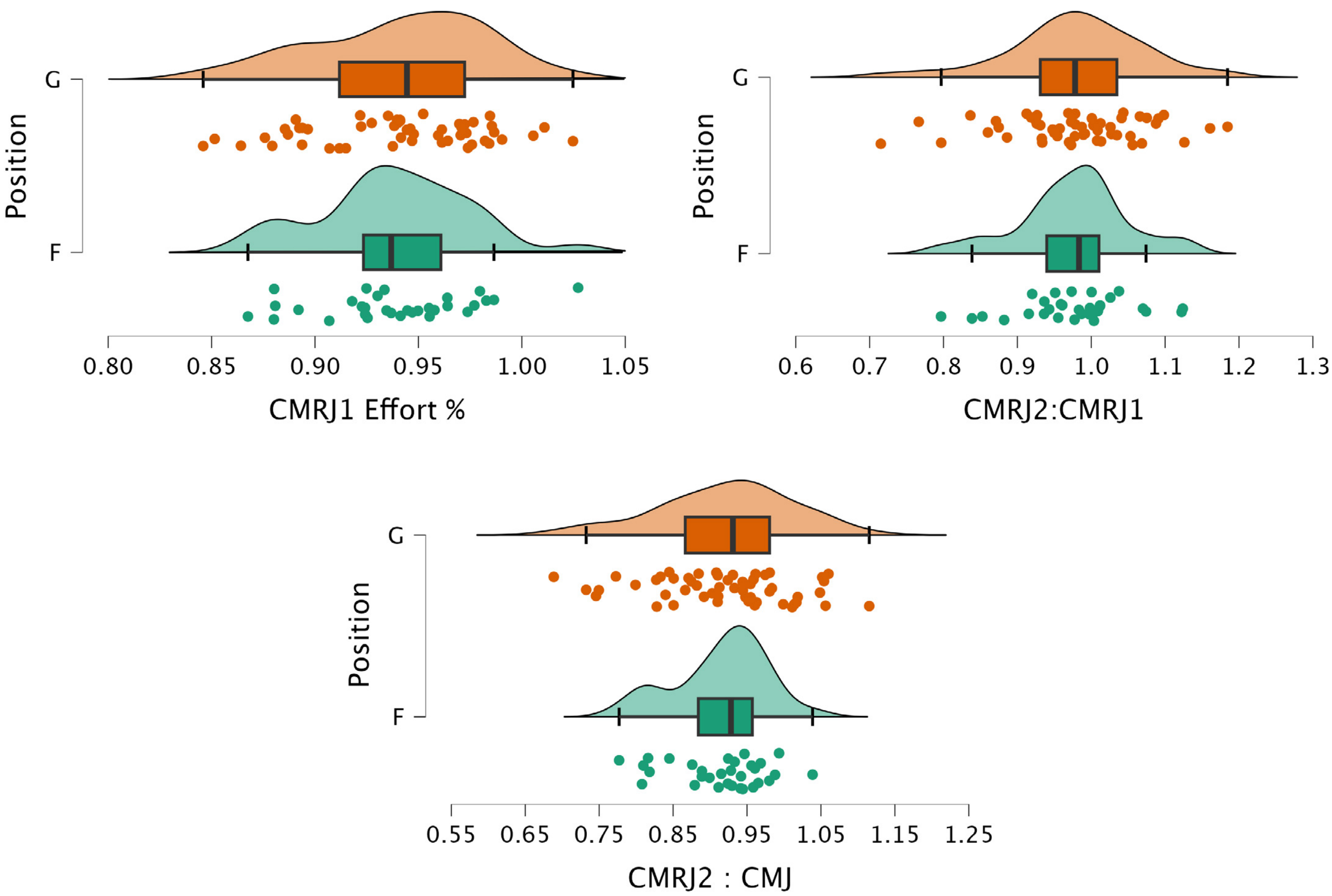

Figure 6. Rain cloud plots for CMJ-RE effort-based metrics by position. G = Guard, F = Forward. CMRJ1 Effort % is the percentage that the first CMJ in the CMJ-RE (i.e. CMRJ1) is compared to the athlete's standalone CMJ average of the best two JH collected immediately before; the average for both positions was 94%. CMRJ2:CMRJ1 is the ratio of CMRJ2 JH compared to CMRJ1 JH (i.e. the first CMJ of the pair); the average for both positions was 98%. CMR-J2:CMJ is the ratio of CMRJ2 JH compared to the athlete's previously collected standalone CMJ JH.

Table 6. The alignment of percentiles with Z-scores (Z) and T-scores (T) uses descriptors and colors consistent with those in Professional Rugby League T-score benchmarking (18). Here, pth denotes percentile, and D represents descriptor.

D	GOOD				ABOVE AVG.			AVERAGE							BELOW AVG.			POOR			
pth	97	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	3
Z	1.881	1.645	1.282	1.036	0.842	0.674	0.524	0.385	0.253	0.126	0	-0.126	-0.253	-0.385	-0.524	-0.674	-0.842	-1.036	-1.282	-1.645	-1.881
T	68.81	66.45	62.82	60.36	58.42	56.74	55.24	53.85	52.53	51.26	50	48.74	47.47	46.15	44.76	43.26	41.58	39.64	37.18	33.55	31.19

Table reproduced from Berberet et al. 2024 with permission (3).

Output Metrics

		Rebound Jump Height (m)		Rebound Jump Momentum (kg*m/s)		Rebound RSI		Rebound mRSI		Rebound Positive Net Impulse (N.s)	
pth	D	Forward	Guard	Forward	Guard	Forward	Guard	Forward	Guard	Forward	Guard
97	GOOD	0.47	0.52	329	287	2.71	3.20	1.82	2.51	675	586
95		0.46	0.50	322	282	2.65	3.01	1.80	2.35	665	585
90		0.43	0.48	311	275	2.41	2.55	1.74	1.91	630	565
85		0.42	0.47	304	271	2.36	2.52	1.64	1.77	627	556
80	ABOVE	0.42	0.46	300	269	2.27	2.44	1.56	1.75	624	541
75		0.41	0.45	297	264	2.20	2.36	1.53	1.72	613	539
70		0.39	0.44	295	261	2.15	2.33	1.47	1.64	601	533
65	AVERAGE	0.38	0.42	290	257	2.13	2.23	1.37	1.59	591	529
60		0.38	0.42	287	254	2.00	2.16	1.34	1.53	587	519
55		0.38	0.41	283	250	1.98	2.11	1.32	1.49	582	510
50		0.37	0.40	282	249	1.96	2.08	1.31	1.43	580	503
45		0.37	0.40	279	243	1.93	2.03	1.30	1.36	571	499
40		0.36	0.39	278	236	1.91	1.97	1.27	1.34	564	493
35		0.35	0.38	273	233	1.83	1.86	1.25	1.28	547	481
30	BELOW	0.35	0.37	267	232	1.75	1.78	1.16	1.27	543	467
25		0.34	0.36	265	222	1.74	1.73	1.15	1.20	542	457
20		0.34	0.35	262	218	1.67	1.67	1.11	1.09	541	446
15	POOR	0.33	0.33	259	214	1.66	1.59	1.10	1.00	521	435
10		0.33	0.31	253	204	1.64	1.46	1.02	0.94	520	414
5		0.30	0.30	246	189	1.47	1.13	0.91	0.78	501	383
3		0.28	0.28	243	187	1.37	1.09	0.89	0.71	497	378

Figure 7. Output metric percentiles for MCBB forwards (n = 31) and guards (n = 53). D = descriptor; pth = percentile. Net = above system weight; rebound positive net impulse = the combination of braking net impulse and propulsive net impulse.

Braking Metrics

		Rebound Braking Net Impulse (N.s)		Rebound Avg. Braking Force (N)		Rebound Avg. Braking Power (W)		Rebound Avg. Relative Braking Force (%)	
pth	D	Forward	Guard	Forward	Guard	Forward	Guard	Forward	Guard
97	GOOD	343	299	4240.65	3923.6	-6670.43	-6755.38	399.21	462.08
95		340	293	4119.45	3784.78	-6502.77	-6299.67	392.31	423.14
90		330	288	3992.62	3491.62	-6241.94	-6051.13	385.77	401.46
85		321	283	3897.91	3250.28	-6004.37	-5354.17	373.71	386.72
80	ABOVE	315	278	3752.84	3206.05	-5809.46	-5138.49	364.05	383.06
75		311	274	3615.9	3142.59	-5650.92	-4991.08	358.36	377.18
70		305	271	3596.78	3042	-5488.5	-4863.38	349.11	365.06
65	AVERAGE	301	266	3488.57	2968.53	-5376.93	-4668.44	326.74	354.74
60		298	261	3396.93	2939.93	-5367.17	-4561.86	324.39	338.34
55		297	257	3187.64	2872.06	-5223.28	-4497.09	315.12	330.63
50		290	254	3120.93	2750.45	-5097.92	-4416.65	311.2	323.65
45		288	253	3108.24	2709.14	-4911.04	-4290.27	308.96	318.79
40		281	249	3053.26	2689.52	-4761.14	-4210.42	307.2	315.08
35		279	247	3037.72	2600.6	-4649.6	-4157.38	304.2	306.91
30	BELOW	275	240	3014.16	2551.21	-4574.68	-4079.27	303.7	299.25
25		272	231	2944.78	2533.89	-4477.52	-3859.53	299.33	293.38
20		269	221	2883.67	2440.98	-4421.26	-3736.9	295.18	280.23
15	POOR	264	213	2769.3	2393.46	-4323.15	-3625.28	289.84	272.49
10		256	208	2759.32	2305.71	-4175.59	-3425.95	278.19	262.89
5		250	195	2707.57	2048.61	-4116.66	-2983.25	263.99	234.5
3		248	190	2688.82	1769.59	-4055.07	-2634.91	251.5	222.95

Figure 8. Braking metric percentiles for MCBB forwards (n = 31) and guards (n = 53). Negative is better for RE-ABP. RE-ARBF (%) is expressed as the percentage of system weight. D = descriptor; pth = percentile.

		Transfer Metrics						Propulsive Metrics					
		Rebound Force at Min Displacement (N)		Rebound Relative Force at Min Displacement (%)		Rebound Spring Like Correlation		Rebound Propulsive Net Impulse (N.s)		Rebound Avg. Propulsive Force (N)		Rebound Avg. Relative Propulsive Force (%)	
pth	D	Forward	Guard	Forward	Guard	Forward	Guard	Forward	Guard	Forward	Guard	Forward	Guard
97	GOOD	6554	5921	616	681	-0.99	-0.98	333	289	3662.6	3298.28	357.29	390.31
95		6379	5453	586	633	-0.99	-0.99	325	284	3567.31	3169.42	339.99	379.23
90		6006	4971	561	604	-0.99	-0.99	314	278	3370.03	2983.49	321.22	337.79
85		5848	4775	541	544	-0.98	-0.97	307	273	3338.46	2895.16	313.13	333.24
80	ABOVE	5579	4502	524	511	-0.98	-0.98	303	272	3323.93	2773	305.8	328.26
75		5260	4280	487	499	-0.98	-0.98	299	266	3160.65	2734.42	300.15	324.72
70		4718	4215	454	487	-0.97	-0.96	298	264	3087.81	2704.22	299.58	312.76
65	AVERAGE	4526	4092	445	479	-0.97	-0.97	294	260	3012.28	2614.18	296.5	304.85
60		4444	4045	443	471	-0.97	-0.97	289	256	2988.93	2600.96	293.27	301.45
55		4254	3910	440	465	-0.96	-0.95	285	254	2952.72	2589.62	292.62	299.15
50		4159	3710	433	446	-0.96	-0.95	284	251	2808.72	2485.63	287.86	297.58
45		4143	3658	431	436	-0.94	-0.94	282	245	2788.57	2429.84	284.41	295.45
40		4061	3549	408	416	-0.94	-0.95	280	238	2683.29	2378.32	284.25	288.38
35		3940	3386	389	411	-0.93	-0.94	275	236	2667.8	2354.32	273.01	275.62
30	BELOW	3843	3360	371	386	-0.91	-0.93	271	234	2661.51	2330.64	260.63	268.95
25		3627	3237	355	379	-0.9	-0.91	267	224	2642.32	2276.06	253.47	263.78
20		3518	3167	340	370	-0.88	-0.88	264	220	2601.76	2226.82	250.08	259.79
15	POOR	3497	3095	337	357	-0.86	-0.85	262	216	2561.78	2131.32	248.85	243.16
10		3295	2643	335	310	-0.85	-0.78	256	206	2518.11	2003.37	245.12	233.91
5		3231	2232	320	256	-0.8	-0.68	249	191	2412.01	1851.83	238.16	211.39
3		3160	2031	307	252	-0.76	-0.67	246	189	2367.56	1651.69	231.38	207.69

Figure 9. Transfer and Propulsive metric percentiles for MCBB forwards (n = 31) and guards (n = 53). D = descriptor; pth = percentile. Negative is better for RE-SPRING. RE-RFMD (%) and RE-ARPF (%) are expressed as a percentage of system weight.

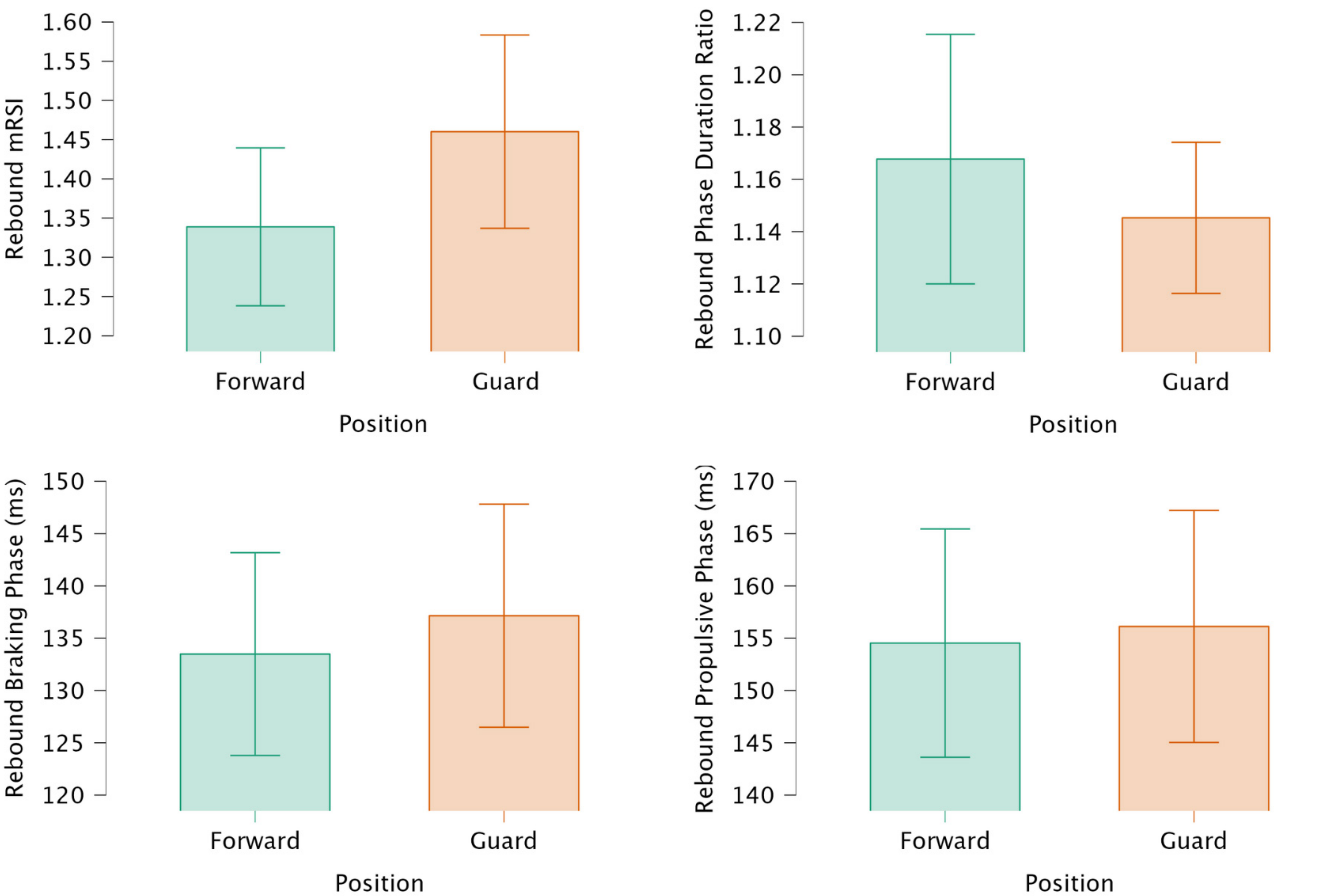

Figure 10. Bar plots for RE-mRSI, RE-BP, RE-PP, and RE-PDR by position with error bars indicating 95%CI of the mean.

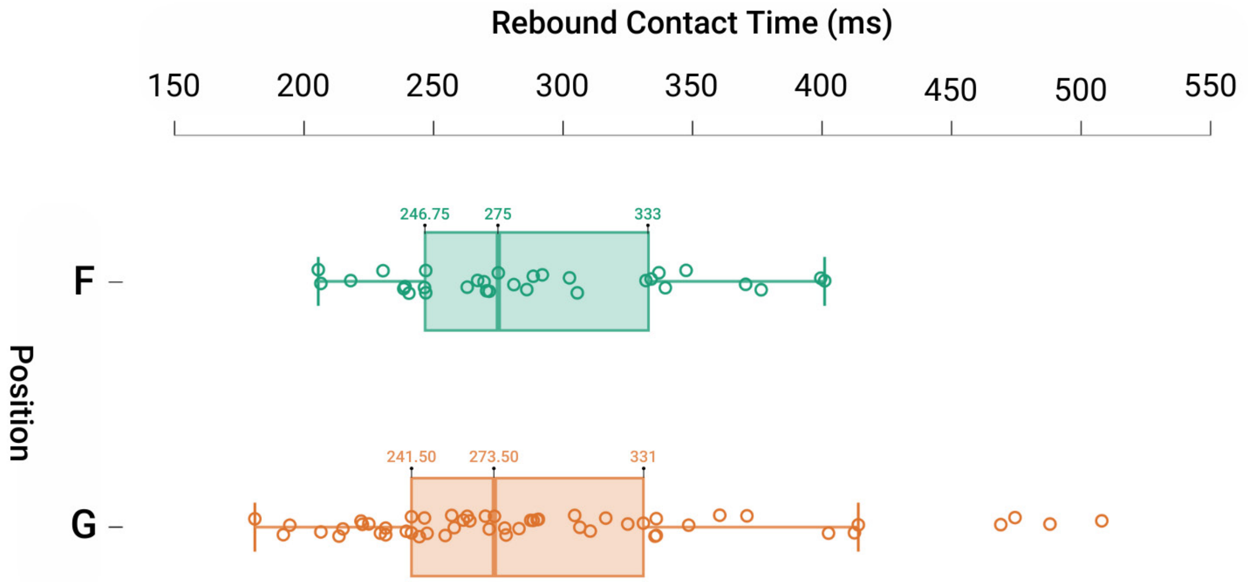

Figure 11. Box plots for RE-GCT by position with minimum and maximum outlier whiskers. Quartile 1, 2, and 3 are represented by dark lines and annotated with their respective values. G = Guards; F = Forwards. 50% of the measures fall within 246.75 - 333 ms for G, and within 241.50 - 331 ms for F.

phase (RE-PP) duration. Additionally, a ratio of RE-PP to RE-BP is presented (RE-PDR). Figure 11 provides a RE-GCT positional comparison. On average, guards spend a longer time on the ground compared to forwards, although non-significant ($p \leq 0.05$). Guards have a higher RE-mRSI ($p = 0.19$) due to RE-JH being significantly higher.

DISCUSSION

This research is pioneering in providing CMJ-RE normative percentile data and positional comparisons within a NCAA DI MCBB Power Five multi-team cohort. To investigate the primary aim we compared guards and forwards, 36.8% (14 of 38) of the reported jump metrics showed significance ($p \leq 0.05$). Of which, RE-JH showed a small effect and the remaining 13 resulted in moderate to large effect sizes indicating that positional differences do exist in the CMJ-RE (bounce-method) with hands on hips. Interestingly, of the 14 total significant metrics, no strategy metrics (i.e. spatio-temporal) yielded differences between positions. The closest strategy metric approaching significance was relative rebound depth ($p = 0.06$, ES = 0.44), compared to absolute rebound depth ($p = 0.24$, ES = 0.27). Although the moderate effect size may indicate underlying positional differences, it did not reach statistical significance. As such, the finding remains suggestive rather than conclusive and should be interpreted with caution, particularly in the context of multiple comparisons. Relative rebound depth was calculated (see definition in Table 1) in an attempt to normalize the large anthropometric differences that were shown in Table 2 -+ on average forwards outweigh guards by 17.80 kg and are 14.46 cm taller. These body type differences did not seem to impact spatio-temporal CMJ-RE metrics. It was hypothesized that disparities in weight, height, and limb length may influence differences in absolute metrics. To further investigate this, the CVCM method was used to rule out the influence of system weight on significant metrics and not one metric showed Pearson's correlation above ±0.85. Table 7 suggests that athlete weight has some influence on absolute CMJ-RE metrics, but not as much as previously thought. Of the five transfer (i.e. amortization) metrics, one showed moderate-effect between groups - RE-FMD, which is the absolute force at the point of zero velocity when displacement is lowest. Furthermore, RE-FMD only showed a moderate correlation to system weight indicating that it is only moderately impacted by increases in body weight favoring forwards. Phase specific metrics showed significant positional differences, of which five braking metrics and five propulsive metrics. These metrics involve similar calculations but are applied to different sides of the zero velocity landmark (i.e. braking & propulsive phase) indicating that consistent differences exist between positions throughout multiple phases of the CMJ-RE. Notably, zero significant phase-specific metrics were relative metrics, nor did any of them favor the guard position. This is contrary to research found in the CMJ comparing guards and forwards in a similar population set, whereas significant phase-specific guard-favoring metrics were peak relative braking force, relative force at minimum displacement, and stiffness (3). The only significant CMJ-RE metric that favored guards in this investigation was RE-JH.

Reactive strength index metrics (i.e. RSI and mRSI) are calculated by dividing JH or flight time by GCT. In this study, both RSI metrics showed no significant differences between positions, although guards had a slight advantage on average. Further analysis of RE-mRSI, revealed that while RE-GCT (p = 0.74, ES = 0.07) was not significant, it slightly favored forwards by an average of -5.25 ms. As previously mentioned, RE-JH favored guards (p = 0.05, ES = 0.45). This may suggest that forwards spend less time on the ground during the CMJ-RE, but do not jump as high as guards, which is why guards on average have higher RE-mRSI values. This is not consistent with findings from a similar population set in the CMJ, whereas guards jumped higher and faster than forwards (3). Linking these suggestive findings to on-court demands, it has been shown in elite basketball that different player positions have unique characteristics in terms of acceleration, deceleration, jumping, and changes of direction; more specifically, forwards are generally exposed to higher frequencies and intensities of deceleration and COD, whereas guards are generally exposed to higher frequencies and intensities of acceleration. Which could help explain why in this study forwards are quicker off the ground (non-significant) despite more body mass. However the impact of such on-court findings is still conflicting, and more load-monitoring research is needed with larger sample sizes for each position (28, 29). Additional reactive strength comparative studies are also needed to support this suggestive interpretation.

Table 7. The correlations between System Weight (N) and the 14 CMJ-RE metrics that showed significance (sig.) between guards and forwards.

CMJ Metrics	System Weight (N)	
	r	*sig.*
Rebound Positive Net Impulse (N.s)	0.83	******
Rebound Jump Momentum (kg*m/s)	0.82	***
Rebound Braking Net Impulse (N.s)	0.82	***
Rebound Propulsive Net Impulse (N.s)	0.82	***
Rebound Avg. Propulsive Force (N)	0.57	***
Rebound Avg. Braking Force (N)	0.56	***
Rebound Peak Braking Force (N)	0.5	***
Rebound Peak Propulsive Power (W)	0.45	***
Rebound Avg. Braking Power (W)	-0.44	***
Rebound Peak Propulsive Force (N)	0.42	***
Rebound Avg. Propulsive Power (N)	0.42	***
Rebound Peak Braking Power (W)	-0.42	***
Rebound Force At Min Displacement (N)	0.41	***
Rebound Jump Height (m)	-0.24	*

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

The findings in this study on RE-GCT are arguably the most practical finding from this analysis because CMRJ2 is positioned to mimic the demands of a DJ and on average does not classify as a fast SSC test in this population per traditional timestamp standards. On average RE-GCT for both positions was >250 ms (forwards: 288.02 ± 54.49 vs. guards: 293.27 ± 77.71 ms) (refer to Figure 11) investigating our second aim. No significant differences in RE-GCT or phase contact times existed between positions. These GCT values are consistent with a recent analysis on NCAA DI football players (n=20, not including lineman) with an average RE-GCT of 297 ± 0.067 ms (17). This calls into question whether or not the 250 ms landmark should be used as the center mark for slow vs. fast SSC classification in the CMJ-RE, especially when classifying anthropometrically abnormal athletes such as those participating in NCAA DI Power Five MCBB. Furthermore, in this population, it would be naive to say that these players do not exhibit reactive strength due to the nature of the sport and positional demands of both guards and forwards. Moreover, reaching this level of college basketball is exceptionally rare. Players competing at this stage have undergone rigorous evaluations of their skills and athletic performance, narrowing down the selection process; considering that only 1% of high school basketball players make it to the NCAA Division I level, and even fewer to the Power Five conferences, this achievement is remarkable (22).

Equally important, not one of the findings in this paper matter unless athlete effort was provided for the CMJ-RE test (*see Figure 6*). To account for effort mathematically, a novel approach was used by analyzing CMRJ1 of the CMJ-RE to that of a standalone CMJ collected immediately before. On average, both positions jumped at 94% their average in the CMJ collected by Berberet et al. (2024) (guards: CMRJ1-JH = 0.41 m vs. CMJ-JH = 0.44 m; forwards: CMRJ1-JH = 0.38 m vs. CMJ-JH = 0.41 m) (3). In consideration of the low CV of CMJ-JH (<3%) found by Berberet et al., the 6% difference is likely due to athletes anticipating the CMRJ2 immediately upon landing from CMRJ1, thus limiting CMRJ1 jump height so that they can handle the fall and accentuated braking demands to jump again. This is consistent with a 4.8% difference found in a 2024 study of 20 NCAA DI football players by Talpey et al. (17). Furthermore, CMRJ2:CMRJ1 ratio was analyzed to determine if the accentuated braking demands induced from the fall in CMRJ1 were maximally harnessed for CMRJ2. On average for both positions, 98%

jump height was obtained in CMRJ2 compared to CMRJ1 indicating that not all athletes effectively harnessed the energy from the fall and reproduced it; a measure of SSC efficiency and neuromuscular confidence. Additional measures of SSC efficiency in this study were RE-IR, RE-TPBF, RIP%, RE-SPRING, and RE-PDR. Not one of these metrics showed significance between positions (although slightly forward-favoring), however are important to investigate alongside RSI metrics based on the second aim of this paper. Notably, RE-IR was the same numerical value for both positions indicating that guards and forwards on average use a similar push-off to braking ratio when executing CMRJ2.

Asymmetry metrics are often analyzed while viewing jump data collected on bilateral force plates. In this investigation, asymmetry metrics were adjusted for statistical comparison by taking the absolute difference of left and right average braking forces (RE-BFAA), and left and right average propulsive forces (RE-PFAA). The positional differences were non-significant and displayed high CV% as found in previous studies with a similar population (3). However, it is important to note that on average forwards displayed higher RE-BFAA (228 ± 131.20 N) than guards (213.87 ± 114.14 N) and RE-PFAA (forwards: 114.44 ± 93.37 N, guards: 85.95 ± 54.69 N). This is consistent with data found in a similar population by Berberet et al. (2024) whereby CMJ-BFAA and CMJ-PFAA were higher in forwards compared to guards (3). Additionally, CMJ-BFAA (forwards: 136.31 ± 86.62 N, guards: 111.73 ± 86.81 N) and CMJ-PFAA (forwards: 72.93 ± 56.72 N, guards: 61.87 ± 45.28 N) (3) was less than that collected in the CMJ-RE possibly indicating that the CMJ-RE is more taxing on the lower body neuromuscular system.

When practitioners are selecting CMJ-RE metrics to use in practice, they should consider adopting the methods laid out by Bishop et al. in 2021, whereas metrics have a low CV, exhibit a biological basis to the sport and position, and are feasible to collect (23). Considering this, Figure 5 presents the CV% for each CMJ-RE metric analyzed in the study. Eight metrics had a CV% >10%, indicating higher test-to-test variation, which makes detecting real changes more challenging in practice. These high CV% metrics may be used, but with this context in mind. Practitioners must also consider the time of day, and day of week that CMJ-RE tests are being collected when interpreting results. In this investigation, RE-mRSI was used as a measure of "freshness", and data showed that no significant effects exist between AM and PM collections. However, significant effects did exist between day of the week collections, suggesting that values are higher on Wednesday compared to Monday, Thursday, and Friday. The reason for this is tough to pinpoint, but could also be due to the fact that only one of the seven teams tested on Wednesday, so the increases could be due to increased athleticism for the respective team rather than increased freshness. Results from the 2024 CMJ study by Berberet et al. utilizing a similar population set showed comparable results (3).

CONCLUSION

The CMJ-RE is a relatively new test type, and its value is likely not yet fully understood. However, basketball practitioners should strongly consider using the bounce-method instead of the DJ to benchmark reactive strength and monitor freshness in NCAA Division I MCBB, where the sport demands extensive use of the SSC. Considering that 83% of jumps in elite basketball games occur from two feet, and DJ reactive strength index correlates favorably with both one-foot and two-foot jumps (24). It is likely that a similar relationship exists for CMRJ2 of the CMJ-RE, given its connection to the DJ. This provides further justification for its sport-specificity and advantages over the DJ, particularly in terms of reduced skill acquisition and test collection time in group settings for practitioners. The positional differences that exist in CMJ-RE metrics justify interpositional reporting. Taking this into consideration, practitioners can confidently use the provided normative data to make critical decisions regarding athletic performance between players of the same position.

This study has several strengths, including a relatively large sample size of NCAA D1 MCBB players from seven teams across four Power Five conferences for CMJ-RE metrics. Of which, all athletes were well-trained, having participated in their team's strength and conditioning program for at least three months, and regularly using the Hawkin Dynamics force plate system. This uniform data collection ensures comparability across collection times and environmental conditions. Additionally, CMJ-RE data was collected for output, driver, and strategy metrics with measures of statistical dispersion around the mean reported for each metric. Jump effort and jump quality filters were also proposed in order to enhance data value. This allows a data scientist to mathematically account for effort and judge quality without the need to actually administer the test. To the researchers' knowledge, this is the first study to calculate "effort metrics" in a reactive jump assessment.

This study is not without its limitations. The data was collected over a 26-day period across six U.S. states during the pre-season, a time when basketball practice schedules can be quite variable. This variability could impact neuromuscular readiness. The center position was also removed from the positional comparison as there were only four centers in the dataset and only three passed the quality control filters for further analysis; only anthropometric data was reported. The authors contend that centers display distinct biomechanical characteristics compared to forwards and guards, likely due to the unique physical demands of their position. To support more robust interpositional comparisons, future research should examine the center position in greater detail.

Although not analyzed in this study, the CMJ-RE 'double-countermovement' strategy (15) should also be considered when the goal is to evaluate injury risk or return an athlete back from injury, as it is likely more demanding on the neuromuscular system than both the CMJ and CMJ-RE (bounce-method) and is one of the most challenging jumps practitioners can perform in a standardized and controlled environment. Future research should look to evaluate this further.

ACKNOWLEDGEMENTS

Thank you to the coaching staff of each team for the time and opportunity to collect this data during the pre-season.

CONFLICTS OF INTEREST

Drake Berberet, Dr. John McMahon, and Dr. Peter Mundy are employees at Hawkin Dynamics, the company whose force plate technology was used in this study. This affiliation is disclosed in the interest of transparency. No financial incentives were received in relation to this publication. The authors affirm that the integrity of the research and its findings have not been compromised by any commercial interests.

FUNDING

Funding for transportation and lodging costs associated with this study was provided by Hawkin Dynamics.

ETHICAL APPROVAL

The Institutional Review Board at Mississippi State University (IRB-23-322) approved this study, and all participants provided informed consent before data collection began.

AUTHOR CONTRIBUTIONS

Drake Berberet - methodology, data curation, formal analysis, writing, visualizations; Adam Petway - reviewing and editing; Karah Bell - data collection lead; Zach Gillen - statistical guidance; Peter Mundy - methodology; Henry Barrera - data collection support; Jason Kabo - data collection support; Dom Walker - data collection support; Garrett Medenwald - data collection support; Braden Welsh - data collection support; John J. McMahon - advisor, reviewing and editing.

DATES OF REFERENCE

Submission - 20/04/2025
Acceptance - 02/08/2025
Publication - 03/10/2025

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