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Unlocking Basketball Athletic Performance: Force Plate-Derived Countermovement Jump Normative Reference Values From Seven NCAA Division-I Power Five Men's College Basketball Teams

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ABSTRACT

This study represents a pioneering effort in establishing normative benchmarking for countermovement jump (CMJ) metrics on Hawkin Dynamics dual wireless force plate within a substantial cohort ($n = 96$) of NCAA Division-I (DI) Power Five Men's College Basketball (MCBB) players. This cohort comprised four centers (age = 20.01 ± 1.31 years, height on website = 216.32 ± 5.27 cm, body mass on plates = 115.11 ± 16.13 kg), 37 forwards (age = 21.09 ± 1.68 years, height on website = 203.84 ± 5.45 cm, body mass on plates = 103.67 ± 10.42), and 55 guards (age = 20.92 ± 1.54 years, height on website = 190.49 ± 7.44 cm, body mass on plates = 87.04 ± 6.98 kg) from seven teams that performed three CMJ trials with hands on hips during the pre-season period of the 2023-2024 season over a span of 26 days and seven testing sites. All data was uniformly collected by a single designated tester who implemented consistent instructions, procedures, and equipment at all test sites. Comparing forwards and guards, 45% (18/40) of the reported metrics showed significance ($p < 0.05$) and 35% (14/40) yielded moderate-large effect sizes (e.g., > 0.50). Additionally, percentiles (3-97th) with qualitative descriptors and a traffic light system were provided. Such normative data can serve as a valuable reference point for coaches, scouts, and players alike, facilitating the evaluation of both individual and team performance while also guiding the development of tailored strength and

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conditioning strategies specific to the demands of NCAA DI MCBB.

INTRODUCTION

Portable force plates are tools to objectively measure biomechanical characteristics in applied settings. These instrumented platforms collect data at an exceptionally rapid rate (e.g. 1000 Hz) and are used to assess ground reaction forces with respect to time and body position depicted by movement phase. With the rise in validation studies comparing historical industry gold standard lab-based force plate systems to modern-day portable systems (1), the adoption rate has increased in sports of all levels and is likely to continue as they become more cost effective (2, 3). This holds particularly true for sports that involve extensive jumping, where the efficacy of jump performance significantly influences successful sport outcomes, such as basketball - a sport that is broadly composed of three positions, centers, forwards, and guards. In National Collegiate Athletics Association (NCAA) Division-I (DI) men's college basketball (MCBB), it has been reported that in practice between 30-110 jumps occur for guards, 26-88 for forwards, and 30-88 for centers (4). In games, over the course of a full NCAA DI MCBB season, center's averaged between 31-77 jumps per game, forwards 47-93, and guards 49-90 (4). Most of these jumps are completed at repeat submaximal efforts and scattered between high intensity movements (i.e. repeat accelerations and decelerations) and low intensity movements (i.e. standing, walking, and jogging) (5). One study looked at the percentage breakdown of live game time in elite under-19 basketball players and found that roughly 16.2% is spent in high intensity movement with jumping accounting for 2.1% (6). Moreover, research indicates variations in vertical jump outputs across different levels of play, with higher jump heights observed in more elite leagues (7). Furthermore, distinctions in countermovement jump (CMJ) braking force-time characteristics have been demonstrated between high-contributing and low-contributing players within a single NCAA DI MCBB team (8). Accompanying jumping as a critical component of basketball is the ability to change direction and beat an opponent up and down the court. Force plate metrics have been shown in previous literature to explain one's ability to decelerate horizontally (9, 10) and also move their mass faster over 5-20 meters (11). This is insightful considering the length of a college basketball court is roughly 28.6 meters (94-feet) long and horizontal decelerations in close quarters are an essential component of basketball. The aforementioned literature is not to be misconstrued as jumping being the most important factor when judging the effectiveness of a college basketball player, however, jump analysis (especially force plate-derived) has great potential to serve as an indicator of other important biomechanical qualities that are important to the sport of basketball (i.e. biological basis).

Drawing parallels between force plate metrics and sport characteristics is important because force plates are non-invasive, portable, have minimal setup time, and can gather large amounts of objective data in seconds. Furthermore, force plate metrics may be used as proxies to establish characteristics of movement in a controlled environment about movement characteristics in uncontrolled environments (i.e. basketball specific movement). For example, a center that jumps higher and is faster off the ground - scored by force plate CMJ-derived modified reactive strength index (mRSI) in theory would value a higher likelihood of securing a rebound over a center with a lower mRSI value, assuming similar reaction times, spatial awareness, and anthropometrics. Likewise, a guard who has a significantly higher CMJ-derived jump momentum at the same body weight as the opposition is likely to win a fast-break and shoot a higher percentage uncontested layup.

Of the wide range of force plate test types, the CMJ is by far the most popular test among force plate practitioners (12, 13). This test is a variation of the vertical jump, a test that dates back to 1921 when Dudley Sargent, a physical educator, first recommended it for the "physical test of man" (14). The CMJ is a great indicator of lower body stretch-shortening cycle function because it involves a sequence of stretch (i.e. braking) and shortening (i.e. propulsion), plus it is rather easy to standardize and reproduce (1). The CMJ is preferred on force plates because it comprises six key phases (15) that inform practitioners about what is occurring within the neuromuscular system in relation to time and body position with inferences of joint position (16). It is often completed with hands on hips (i.e. akimbo) to eliminate upper body contribution and highlight the lower body neuromuscular strategies needed to execute a trial with maximal effort. This test may also be completed with arm swing (CMJ-AS), but with lower reliability (17). All-in-all, the CMJ provides the most bang-for-your-buck in regard to time efficiency, proxies of basketball performance, and reproducible comparative data across all levels of play.

A basketball practitioner may choose to use the CMJ (alongside other force plate tests) for many different purposes throughout a competitive basketball season. The three most common opportunities a practitioner would use a force plate in MCBB are to (1) monitor neuromuscular fatigue induced by game, training, or travel, (2) to benchmark/profile current athletes or screen future talent (i.e. talent identification), and (3) return an athlete back to training and competition post-injury. In regard to benchmarking (the key focus of this paper), the primary objectives are to identify talent, prospect physiological potential, identify at-risk athletes, and show changes in adaptation over time. Benchmarking is a recurring practice throughout a college basketball season. It involves assessing new players upon joining a team to identify any biomechanical risk factors and determine if they possess the necessary biomechanical attributes for the team's style of play. This evaluation also occurs early in the off-season for returning players to shape the upcoming training regimen and is again repeated at the end of each training phase to monitor progress. Additionally, benchmarking is conducted throughout the competitive season to gauge how players are adapting to match loads and the schedule. The seasonality in the benchmarking testing schedule is similar to that of which was proposed by Shuster et al. (2020), in NBA basketball (18). Benchmarking data is typically gathered in two ways, either by pinpointing and averaging a cluster of data points within a period of time or by analyzing a single session from a period of time when the player is expected to be the freshest. This is conceptually different from routine data tracking (i.e. monitoring), often completed on a daily or weekly basis in MCBB season. Although return to play (RTP) testing is not inherently benchmarking, it does follow similar principles. If a player is injured during the basketball season, force plates can be used to guide the return back to play by using pre-injury data as a guide or using healthy reference values of players of similar age, position, and playing style (i.e. peer-comparison). Peer-comparisons should be used if an athlete does not have healthy force plate data available and should be selected based on biological age, training age, and position.

No study to date has published position-specific percentile normative force plate-derived CMJ data in NCAA DI MCBB players. Although several studies have published positional-group differences as part of larger findings (8, 19, 20, 21, 22); fewer have presented normative data without positional distinctions within this unique population (17, 23). Considering this, a multi-team study with a large sample size is of utmost importance to serve as a starting point in the benchmarking process for MCBB, and also to outline reference values to help guide injured athletes returning back to play. Establishing standards and linking together existing studies that show force plate metrics as on-court proxies of basketball movement will help basketball practitioners and researchers begin to understand what force-time metrics truly matter in MCBB. Therefore, the constructs of this paper will focus on benchmarking CMJ metrics in NCAA DI MCBB players.

MATERIALS AND METHODS

Experimental Approach to the Problem

Each subject participated in a single CMJ testing session at their respective university during the 2023-2024 pre-season period over a span of 26 days. All data was collected by a single designated tester who travelled via automobile to all testing sites between September-October using the same bilateral force plates, tablet, and three-inch perimeter foam surround. In transit, the force plates were secured in a hard travel case with custom foam insert to create an airtight seal and eliminate any excessive movement that may affect the internal components and manufacturer calibration. Upon arriving, the test collector ensured the force plates were set up in an open space in the weight room on a hard level surface and acclimatized to the environment for at least 45-minutes before the first test was collected. In order to ensure levelness, the test collector checked for instability in all four corners of each force plate, and adjusted the force plate feet until there was no instability. Prior to test collection, all athletes were given a verbal overview of the study design, a visual demonstration of the test, and participated in a standardized dynamic warm up (listed in Appendix A). No warm up CMJ tests were completed because all participants had extensive experience using the force plates and software at their respective universities.

Participants

A total of 96 healthy NCAA DI MCBB players across seven teams volunteered to participate in this study:

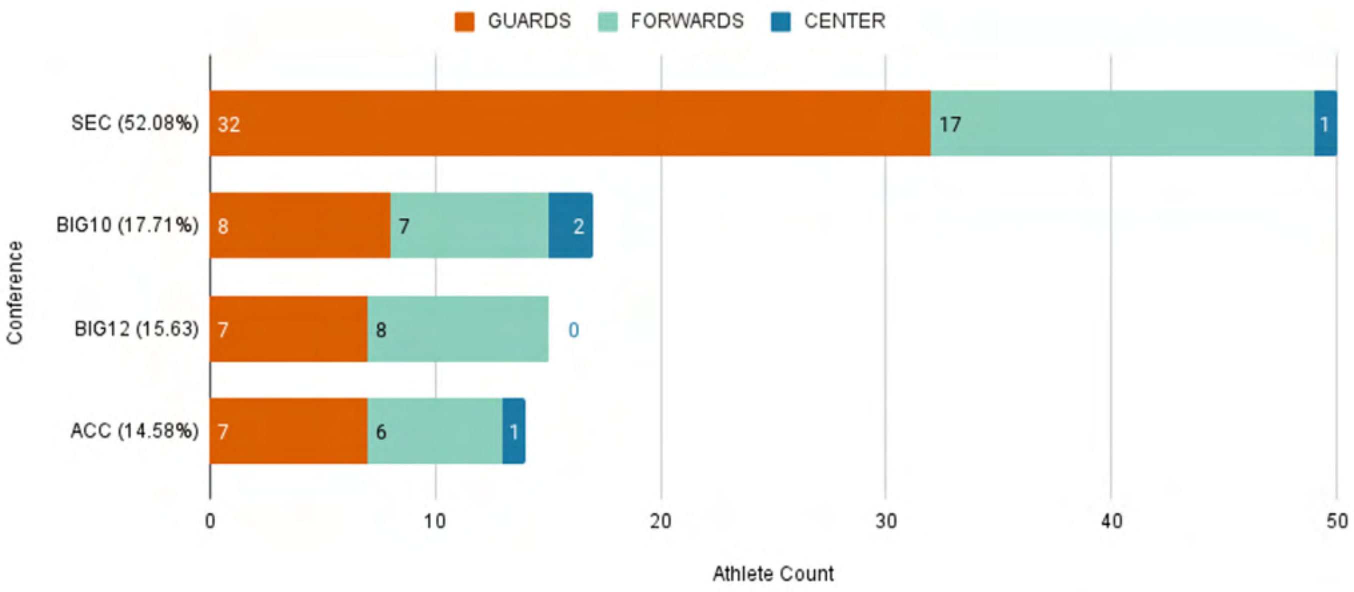


Figure 1. Breakdown of MCBB positions by conference. SEC = Southeastern Conference; BIG10 = Big 10 Conference; BIG12 = Big 12 Conference, ACC = Atlantic Coast Conference

four centers (age = 20.01 ± 1.31 years, height on website = 216.32 ± 5.27 cm, body mass on plates = 115.11 ± 16.13 kg), 37 forwards (age = 21.09 ± 1.68 years, height on website = 203.84 ± 5.45 cm, body mass on plates = 103.67 ± 10.42), and 55 guards (age = 20.92 ± 1.54 years, height on website = 190.49 ± 7.44 cm, body mass on plates = 87.04 ± 6.98 kg). Position, age, and height were retrieved from the publicly available official team website (i.e. height on website). If birth-date was not listed, the team's strength and conditioning coach provided the information upon request to derive player age. Centers were an under-represented population of this sample, possibly due to the current style of play and body archetype demands in elite basketball (24). This is further indicated with the removal of positions on NBA All-Star teams effective during the 2024-2025 season, hence moving towards a "position-less" league (25). Figure 1 outlines the four Power Five conferences represented in this study along with positional splits of each. Time of day and day of week testing effects are presented in Figure 3 and Figure 4. This study was approved by Mississippi State University's Institutional Review Board (IRB-23-322) and all participants signed an informed consent document prior to data collection.

Force Plate-Derived CMJ Test

Following the instruction and warm up period, participants performed three maximal-effort CMJs with hands affixed to hips using a self-selected countermovement depth (CMD). Each jump was separated by a brief rest period of at least ten seconds. A visual (i.e. flash) and auditory cue (i.e. beep) was provided via validated software interface (Hawkin Capture Version 8.6.1) (26) on a Samsung Galaxy A8 tablet operated by the test collector signaling that a valid one second quiet weighing period was captured and the CMJ test was ready to begin. The test collector stood >3 feet offset in front of the participant and displayed the tablet to the athlete at eye-level. The data were collected using Hawkin Dynamics (Westbrook, ME, USA) Gen5 wireless one-dimensional bilateral force plates sampling at 1000 Hz (filtered using a Butterworth filter with a cut-off frequency of 50 Hz). One CMJ test was saved per trial to eliminate any possible numerical integration drift. Prior to testing, athletes were instructed to stand still with hands glued to their hips and jump as high as possible on the flash/beep; and again strongly cued to "get up" immediately before movement initiation (i.e. time period between flash/beep and unweighting start of minus five standard deviations below system weight collection) to provide extra encouragement to maximize effort. Verbal feedback on jump height (JH) calculated from take-off velocity was given to each athlete between jumps and the force plates were zeroed between each athlete. After all tests were collected, all athletes participated in a regularly planned basketball practice. Six of the seven teams participated in a regularly planned weight training session following CMJ testing and before practice.

Figure 2 shows the six key phases of the CMJ as proposed by McMahon et al. (2018) (15) and reported in the manufacturer's software. The number of possible metrics in commercially available force plate softwares are plentiful, therefore it becomes imperative to narrow down the list in order to use these metrics in an applied-setting. At the time of this collection, there were 79 available CMJ metrics in the Hawkin Dynamics software - definitions for each can be found at the link: www.hawkindynamics.com/hawkin-metric-database. A common framework to narrow down the list of metrics is the "*ODS System*", which splits metrics into three categories: output, driver, and strategy (27, 28). Output metrics are those that are easily understood by participants and key stakeholders. They help explain the biomechanical limits of a participant's kinetics, but don't explain how (i.e. strategy) they arrived there or what they used to create it (i.e. driver). Output and driver metrics typically exhibit polarity and those are commonly ranked among teams and positional groups. However, strategy metrics typically do not exhibit polarity; generally the goal is to be within a range of optimal that allows the athlete to maximize their individual output. For example, countermovement depth (CMD) is the displacement that the athlete travels downward on the descending portion of the CMJ - often labeled by practitioners as the "range of motion" metric. Mandic et al. (2014) found that CMD correlates negatively to JH during the CMJ with hands on hips (*r* = -0.67) and also that preferred CMD was less than the modelled optimum (29). Therefore, it makes sense to conclude that there is an acceptable range of CMD, somewhere between self-selected and optimum. Furthermore, in this study the CMJ metrics for descriptive purposes were split into six categories: output, strategy, braking, transfer, propulsive, and landing. For percentile representation, the CMJ metrics were split into four categories: output, braking, transfer, and propulsive to paint a picture for a comprehensive vertical jump analysis. For strategy metrics, rain cloud plots and bar plots were used to show a range of common values by position.

STATISTICAL ANALYSIS

After mobile capture, CMJ tests were automatically uploaded to the Hawkin Cloud (cloud.hawkindynamics.com) for storage and later exported as CSV files into Google Sheets for data cleaning. The data cleaning process involved removal of tests if the unweighting phase was initiated early (i.e. early initiation) due to MCBB athlete's movement artifact. The average of the highest two JH tests were used for further analysis. If one of the best two JH value attempts had an early initiation, the other available test was used. All MCBB athletes had at least two CMJ tests that met the quality control filter. Due to a low sample size for the center position, only anthropometric descriptive data was reported.

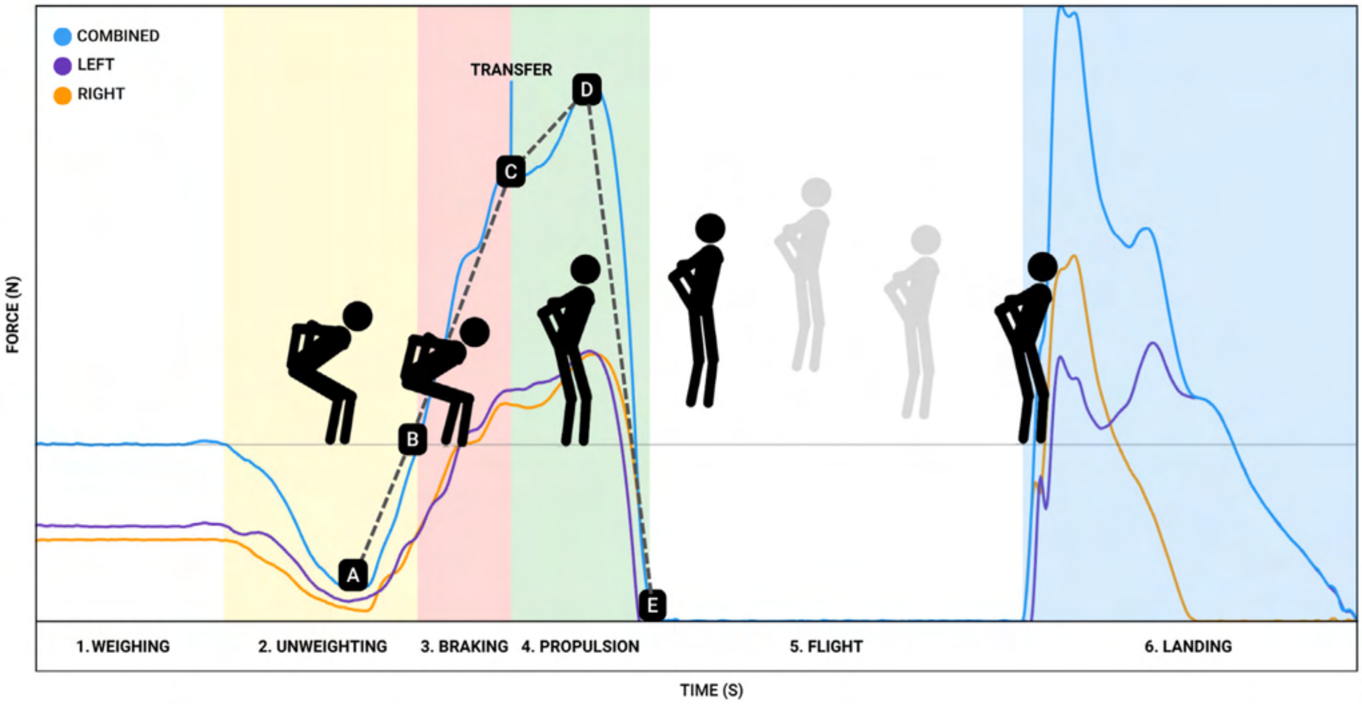


Figure 2. CMJ force-time curve showing the six key phases; weighing, unweighting, braking, propulsion/propulsive, flight, and landing. A-B is deceleration back to bodyweight, B-C is deceleration to stop center of mass (COM), C-D is reacceleration to propel COM vertically, E is the instant of take-off and when flight begins. The proposed transfer point (C) is between braking and propulsive phases when displacement is the lowest and velocity is zero. Comparing force at the transfer point to peak force, if not the same, may help explain amortization abilities.

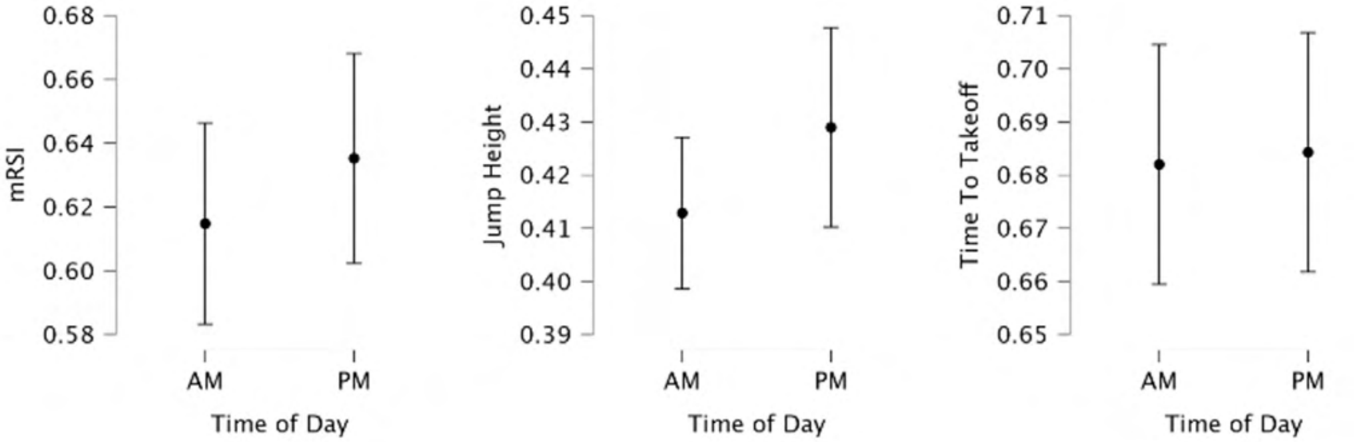


Figure 3. Time of day testing effects for all three MCBB positions for modified reactive strength index (mRSI), jump height (JH), and time to takeoff (TTT). AM collected tests occurred between 8:13:35 and 11:37:38 and PM collected tests occurred between 12:30:00 and 14:26:39, respectively. mRSI is calculated by dividing takeoff velocity derived jump height by TTT. TTT is the total time it takes to complete the jump from movement initiation to flight.

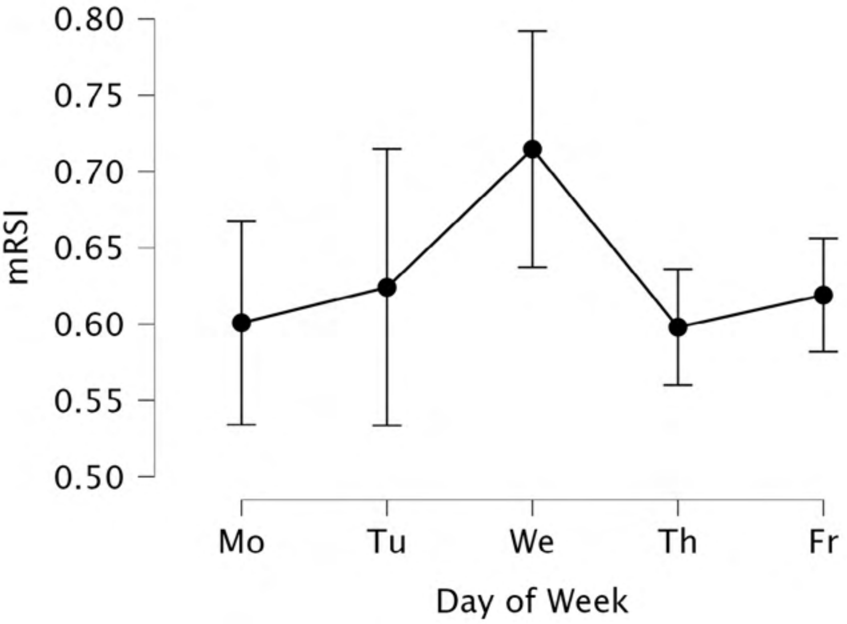


Figure 4. Day of week testing effects for all three MCBB positions analyzing mRSI as a measure of freshness. Mo = Monday (one team tested, *n* = 14); Tu = Tuesday (one team tested, *n* = 6); We = Wednesday (one team tested, *n* = 16); Th = Thursday (two teams tested, *n* = 28); Fr = Friday (two teams tested, *n* = 32).

Forward and guard CMJ testing data was used for further comparative analysis. Before comparisons, time of day and day of week testing effects were analyzed using an independent t-test and one-way ANOVA.

Of the possible metrics (*see Table 3 and Table 4 for metric abbreviations*) in the Hawkin Dynamics software plus three novel metrics (NPI, BFAA, PFAA), 40 metrics were selected for positional comparison. Shapiro-Wilk tests and Q-Q plots were used to check for normality and ten metrics (forward: mRSI, NPI, PPF, STIFF, PPP, PRPP, APF, ARPF; guard: IR, RPLF) were found to be non-normally distributed for one of the two positional-groups. Four metrics were non-normally distributed for both positional-groups (BRDF, BFAA, PFAA, PRPF). A Mann-Whitney U Test was used for comparison of the four metrics that violated normality for both positional-groups and Rank-Biserial Correlation was used to calculate the magnitude of effect. An independent t-test was performed for the remaining jump metrics and anthropometrics. Cohen's d effect size was used to calculate the magnitude (*d* < 0.19 — trivial, *d* = 0.2 — small, *d* = 0.5 — moderate, *d* > 0.80 — large) (30). Common language effect size (CLES) (31) was also calculated (32) to provide a percentage probability that a player chosen at random from either respective positional-group will have a more favourable metric value. Statistical significance was set a priori to $p<0.05$. These statistical tests were completed using Jeffreys's Amazing Statistics Program (JASP version 0.18.3).

In order to narrow down the list of 40 metrics for percentile charts we removed metrics where mid-range performance may be preferred (i.e. IR, STIFF, CMD, TTT, NP, RPLF, BFAA, PFAA) and highly correlated output metrics (PV, NPI). Next we split the metrics up into categories of braking and transfer-propulsion with 13 metrics in each category, and ran correlations to identify highly correlated metrics within categories. Highly correlated metrics criterion was set at $r > 0.85$ or < -0.85 as outlined by Bird et al. (2022) (33). If one of the metrics within the same category was highly correlated, then the metric with the lowest intra-session coefficient of variation percentage (CV%) was selected, known in this paper as the CV% Comparison Method (CVCM). Individual CV% was derived by dividing each athlete's standard deviation by their means from the two CMJ trials. All individuals CV% values were then averaged by metric for metric CV% reported in Figure 5.

To create position specific CMJ percentile charts (see Figures 6-9) JASP was used to generate 3rd, 5th-95th at intervals of 5, and 97th percentiles and then exported into Google Sheets for formatting and visual presentation. Qualitative descriptors (i.e. poor, below average, average, above average, good) and color coding traffic light systems were adopted from McMahon et al. (2022) (34), converting T-scores to corresponding percentile values (35). Table 5 shows the alignment of percentiles to Z-scores and T-scores along with the corresponding color. Final data analysis and visualizations were completed in Google Sheets.

RESULTS

Time of Day and Day of Week

Time of day testing effects were analyzed for all three positions by comparing mRSI for AM (n = 41) and PM (n = 55) collected tests and showed no significant effects (p = 0.39, ES = 0.18). Day of week testing effects were analyzed by comparing mRSI for Monday (n = 14), Tuesday (n = 6), Wednesday (n = 16), Thursday (n = 28), and Friday (n = 32) using one-way ANOVA. Lavene's test was non-significant (p = 0.48), indicating that the assumption of homogeneity of variance was not violated. Normality was checked with a Q-Q plot; no deviations were noted. There was a significant difference among the five days on mRSI values, F(4,91) = 3.23, p = 0.02, η^2 = 0.12 indicating a moderate-large effect. Tukey's post hoc testing revealed significant differences between Wednesday (0.71 ± 0.15) - Monday (0.60 ± 0.12), Wednesday - Thursday (0.60 ± 0.10), and Wednesday - Friday (0.62 ± 0.10).

Anthropometric Characteristics

There was no significant difference between age at the time of jumps for forward and guards (p = 0.61, ES=0.11). Guards were significantly shorter than forwards based on publicly available team website height data (p = <0.001, ES=1.99) and weighed

Table 1. Anthropometric variables for centers, forwards, and guards; and comparisons for forwards and guards. M = mean; SD = standard deviation; ES = effect size; CLES = common language effect size; 95%CI = 95% confidence interval lower to upper; F = forward; G = guard.

	Group					**Magnitude FvG**			
	M ± SD	**M ± SD**	**M ± SD**						
Variables	**Centers (n= 4)**	**Forwards (n=37)**	**Guards (n = 55)**	**Difference FvG**	**95% CI Mean Difference**	**ES**	**CLES**	**ES Descrip-tor**	***p*-value**
Age at Jump (years)	20.01 ± 1.31	21.09 ± 1.68	20.92 ± 1.54	0.17	-0.50 to 0.85	0.11	53%	Trivial	0.611
Height on Website (cm)	216.32 ± 5.27	203.84 ± 5.45	190.49 ± 7.44	13.35	10.57 to 16.26	1.99	92%	**Large**	**< 001****
Weight on Plates (kg)	115.11 ± 16.13	103.67 ± 10.42	87.04 ± 6.98	16.63	13.02 to 20.23	1.95	92%	**Large**	**< 001****
Weight on Website (kg)	115.10 ± 15.97	102.05 ± 9.16	87.11 ± 6.62	14.94	11.67 to 18.21	1.93	91%	**Large**	**< 001****
Reported Difference (kg)	3.21 ± 2.23	2.41 ± 2.28	1.83 ± 1.53	0.58	0.21 to 1.36	0.31	59%	Small	0.15

*Bold and ** p values = p ≤ 0.001, Bold ES = Moderate to Large effect* less on the force plates on the day of testing (p = <0.001, ES=1.95). Interestingly, but non-significant, the weight reported by team personnel on the official team website compared to the weight recorded on the force plates at the day of testing did not align for either position (*see Table 1, Reported Difference*). MCBB player's body mass is often reported on the official team website by strength and conditioning staff. Center anthropometrics variables were not compared, but are listed in Table 1 alongside forward and guards.

CMJ Force-Time Metrics

Of the 40 CMJ metrics, 36 were analyzed using an independent sample t-test and guards displayed significantly higher averages with small between group effects for JH, mRSI, NPI, ARPP, and moderate between group effect size for PRBF and RFMD. Forwards displayed significantly higher averages for JM, POSNI, BNI, PBF, ABF, FMD, STIFF, PNI, PPF, APF, PPP, and APP. Table 3 contains descriptive results for positional-group comparisons. Four CMJ metrics (BRFD, BFAA, PFAA, PRPF) were analyzed using a Mann-Whitney U Test due to non-normality and no metrics displayed between-group differences at $p < 0.05$.

Before percentile charts were created, a reduction technique was used to identify highly correlated metrics (Table 2). Interestingly, all metrics in the braking category had at least one high correlation

Table 2. Highly correlated metrics found in MCBB athletes for braking and transfer-propulsive metric categories. Bold value indicates lower average coefficient of variation percentage (CV%) for both positions when compared.

Highly Correlated Transfer and Propulsive Metrics

(*r*> 0.85 or < -0.85)

	Metric	**CV%**		**Metric**	**CV%**	
		F	**G**		**F**	**G**
r=0.93	PPF	3.35	2.86	**APF**	2.06	1.77
r=0.91	PRPF	3.37	2.87	**ARPF**	2.10	1.77
r=0.90	**APV**	1.66	1.67	ARPP	2.89	2.26
r=0.90	**PPP**	2.25	1.60	APP	2.84	2.26
r=0.89	**ARPF**	2.10	1.77	ARPP	2.89	2.26
r=0.88	**APF**	2.06	1.77	APP	2.84	2.26
r=0.87	**APF**	2.06	1.77	PPP	2.25	1.60
r=0.87	**PRPP**	2.30	1.62	ARPP	2.89	2.26
r=0.87	PP	3.43	3.21	**PRPF**	3.37	2.87
r=0.88	PP	3.43	3.21	**ARPF**	2.10	1.77

Highly Correlated Braking Metrics

(*r*> 0.85 or < -0.85)

	Metric	**CV%**		**Metric**	**CV%**	
		F	**G**		**F**	**G**
r=0.99	PBP	5.85	8.97	**ABP**	4.88	7.14
r=0.98	**ABV**	3.22	4.30	PBV	3.04	4.49
r=0.98	PRBP	5.83	8.96	**ARBP**	4.84	7.13
r=0.93	PBF	4.11	4.11	**ABF**	2.84	4.13
r=0.91	**ABV**	3.22	4.30	ARBP	4.84	7.13
r=0.91	**PBV**	3.04	4.49	ARBP	4.84	7.13
r=0.90	PRBF	4.10	4.11	**ARBF**	2.80	4.14
r=0.90	**PRBF**	4.10	4.11	BRFD	11.29	11.64
r=0.90	**PBV**	3.04	4.49	PRBP	5.83	8.96
r=0.89	PBP	5.85	8.97	**PRBP**	5.83	8.96
r=0.87	**ABV**	3.22	4.30	PRBP	5.83	8.96
r=0.87	PRBP	5.83	8.96	ABP	4.88	7.14
r=0.86	**ARBF**	2.80	4.14	BRFD	11.29	11.64
r=0.86	ABP	4.88	7.14	**ARBP**	4.84	7.13
r=0.85	PBP	5.85	8.97	**ARBP**	4.84	7.13
r=0.87	BP	5.40	6.23	**PRBF**	4.10	4.11
r=0.87	**ABF**	2.84	4.13	PBP	5.85	8.97
r=0.88	**BNI**	3.15	4.53	PBP	5.85	8.97
r=0.88	**ABF**	2.84	4.13	ABP	4.88	7.14
r=0.88	**ARBF**	2.80	4.14	PRBP	5.83	8.96
r=0.88	**ARBF**	2.80	4.14	ARBP	4.84	7.13
r=0.90	**BNI**	3.15	4.53	ABP	4.88	7.14
r=0.91	**BP**	5.40	6.23	BRFD	11.29	11.64

F = forwards; G = guards, r = Pearson correlation coefficient. PPF = Peak Propulsive Force, PRPF = Peak Relative Propulsive Force, APV = Average Propulsive Velocity, PPP = Peak Propulsive Power, ARPF = Average Relative Propulsive Force, APF = Average Propulsive Force, PRPP = Peak Relative Propulsive Power, PP = Peak Power, ARPP = Average Relative Propulsive Power, APP = Average Propulsive Power, PBP = Peka Braking Power, ABV = Average Braking Velocity, PRBP = Peak Relative Braking Power, PBF = Peak Braking Force, PBV = Peak Braking Velocity, PRBF = Peak Relative Braking Force, ARBF = Average Relative Braking Force, ABP = Average Braking Power, BP = Braking Phase, ABF = Average Braking Force, BNI = Braking Net Impulse, ARBP = Average Relative Braking Power, BRFD = Braking Rate of Force Development

Table 3. Independent sample t-test for 36 CMJ metrics between forwards and guards. CLES is used to explain the probability that one MCBB athlete chosen at random from a respective position would have a higher metric value when compared to another MCBB athlete selected from the opposite position.

		Group				**Magnitude**			
		M ± SD	**M ± SD**						
	Abbrev.	**Forwards (*n*= 37)**	**Guards (*n* = 55)**	**M Difference (95%CI)**		**ES**	**CLES**	**Descriptor**	***p*-value**
Output Metrics									
Jump Height (m)	JH	0.410 ± 0.057	0.436 ± 0.060	0.03	-0.05 to - 1.07×10-3	0.44	62%	Small	**0.04**
Jump Momentum (kg*m/s)	JM	292.46 ± 26.81	253.91 ± 26.73	38.56	27.26 to 49.86	1.44	85%	**Large**	**< .001****
Positive Net Impulse (N.s)	POSNI	432.99 ± 47.75	376.95 ± 45.01	56.05	36.56 to 75.53	1.22	81%	**Large**	**< .001****
Modified Reactive Strength Index	mRSI	0.60 ± 0.12	0.65 ± 0.11	0.05	-0.1 to -5.23×10-3	0.47	62%	Small	**0.03**
Net Phase Index	NPI	1.10 ± 0.25	1.20 ± 0.23	0.10	-0.21 to -1.85×10-3	0.43	62%	Small	**0.05**
Peak Velocity (m/s)	PV	2.96 ± 0.18	3.03 ± 0.19	0.07	-0.15 to 6.26×10-3	0.39	61%	Small	0.07
Strategy Metrics									
Time To Takeoff (s)	TTT	0.69 ± 0.09	0.67 ± 0.07	0.02	-0.01 to 0.05	0.25	57%	Small	0.24
Net Phase (s)	NP	0.39 ± 0.06	0.37 ± 0.05	0.01	-8.75*10-3 to 0.04	0.26	60%	Small	0.22
Countermovement Depth (m)	CMD	-0.29 ± 0.06	-0.30 ± 0.05	0.01	-0.01 to 0.03	0.18	55%	Trivial	0.41
Braking Metrics									
Braking Net Impulse (N.s)	BNI	138.81 ± 23.46	121.54 ± 21.33	17.26	7.88 to 26.65	0.78	71%	**Moderate**	**< .001****
Braking Phase (s)	BP	0.15 ± 0.03	0.14 ± 0.03	0.01	-3.89×10-3 to 0.02	0.28	59%	Small	0.19
Peak Braking Force (N)	PBF	2586.59 ± 306.26	2354.26 ± 364.35	232.33	87.74 to 376.92	0.68	68%	**Moderate**	**1.95x10-3****
Peak Relative Braking Force (N/kg)	PRBF	255.92 ± 32.66	275.58 ± 35.57	19.66	-34.21 to -5.11	0.57	66%	**Moderate**	**8.64x10-3****
Avg. Braking Force (N)	ABF	1993.78 ± 261.74	1759.90 ± 280.22	233.88	118.58 to 349.2	0.86	73%	**Large**	**< .001****
Avg. Relative Braking Force (N/kg)	ARBF	196.81 ± 23.58	205.79 ± 25.87	8.98	-19.54 to 1.56	0.36	60%	Small	0.09
Avg. Braking Velocity (m/s)***	ABV	-0.86 ± 0.11	0.90 ± 0.11	0.04	-3.59×10-3 to 0.09	0.39	60%	Small	0.07
Peak Braking Velocity (m/s)***	PBV	-1.35 ± 0.19	1.40 ± 0.19	0.05	-0.03 to 0.13	0.28	57%	Small	0.20
Peak Braking Power (W)***	PBP	-2161.5 ± 516.87	-1980.89 ± 550.35	180.61	-407.54 to 46.31	0.34	59%	Small	0.12
Peak Relative Braking Power (W/kg)***	PRBP	-20.92 ± 4.82	-22.66 ± 5.69	1.74	-0.52 to 4	0.32	59%	Small	0.13
Avg. Braking Power (W)***	ABP	-1538.22 ± 310.54	-1420.07 ± 348.89	118.15	-259.27 to 22.97	0.35	60%	Small	0.10
Avg. Relative Braking Power (W/kg)***	ARBP	-14.9 ±2.97	-16.25 ± 3.51	1.35	-0.05 to 2.74	0.41	61%	Small	0.06
Transfer Metrics									
Force at Min Displacement (N)	FMD	2578.27 $ 310.90	2347.47 ± 360.43	230.8	86.55 to 375.04	0.68	68%	**Moderate**	**2.03x10-3****
Relative Force at Min Displacement (N/kg)	RFMD	255.14 $ 33.39	274.81 ± 35.3	19.67	-34.26 to -5.08	0.57	66%	**Moderate**	**0.01***
Impulse Ratio	IR	2.16 $ 0.25	2.14 ± 0.28	0.02	-0.1 to 0.13	0.05	52%	Trivial	0.83
Stiffness (N/m)***	STIFF	-9367.85 $ 2629.84	-8126.34 ± 1940.21	1241.51	-2188.42 to -294.6	0.55	65%	**Moderate**	**0.01***

		Group				**Magnitude**			
		M ± SD	**M ± SD**						
	Abbrev.	**Forwards (*n*= 37)**	**Guards (*n* = 55)**	**M Difference (95%CI)**		**ES**	**CLES**	**Descriptor**	***p*-value**
Propulsive Metrics									
Propulsive Net Impulse (N.s)	PNI	294.18 ± 26.91	255.4 ± 26.87	38.78	27.42 to 50.14	1.44	85%	**Large**	**< .001****
Propulsive Phase (s)	PP	0.24 ± 0.03	0.23 ± 0.03	0.01	-6.45×10-3 to 0.02	0.22	59%	Small	0.30
Peak Propulsive Force (N)	PPF	2831.50 ± 382.76	2477.99 ± 332.03	353.51	204.31 to 502.7	1.00	76%	**Large**	**< .001****
Avg. Propulsive Force (N)	APF	2273.61 ± 231.24	1974.65 ± 204.04	298.96	208 to 389.92	1.39	84%	**Large**	**< .001****
Avg. Relative Propulsive Force (N/kg)	ARPF	224.51 ± 20.52	231.55 ± 18.71	7.05	-15.26 to 1.17	0.36	60%	Small	0.09
Avg. Propulsive Velocity (m/s)	APV	1.75 ± 0.13	1.80 ± 0.13	0.05	-0.11 to 2.03×10-3	0.41	61%	Small	0.06
Peak Propulsive Power (W)	PPP	6249.05 ± 671.31	5459.64 ± 689.82	789.41	501.12 to 1077.7	1.16	79%	**Large**	**< .001****
Peak Relative Propulsive Power (W/kg)	PRPP	60.60 ± 6.66	62.81 ± 6.79	2.21	-5.05 to 0.64	0.33	59%	Small	0.13
Avg. Propulsive Power (W)	APP	3554.23 ± 417.18	3184.46 ± 458.44	369.77	182.9 to 556.65	0.84	72%	**Large**	**< .001****
Avg. Relative Propulsive Power (W/kg)	ARPP	34.52 ± 4.57	36.61 ± 4.58	2.09	-4.02 to -0.15	0.46	63%	Small	**0.03**
Landing Metric									
Relative Peak Landing Force (%)***	RPLF	519.54 ± 135.23	571.70 ± 145.66	52.16	111.97 to 7.65	0.37	60%	Small	0.09

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

Table 4. Mann-Whitney U Test for CMJ metrics between forwards and guards. M = mean; SD = standard deviation; Mdn = median; 95% CI = 95% confidence interval

			Group					**Magnitude**		**95% CI for Tank-Biserial Cor.**	
			M ± SD	**Mdn**	**M ± SD**	**Mdn**					
	Abbrv.	**Category**	**Forwards (*n*=37)**		**Guards (*n*=55)**		**Mdn Difference**	**Rank-Biserial Correlation**	**p-value**	**Lower**	**Upper**
Non-Normal Distribution Metrics											
Braking RFD (N/s)	BRFD	Braking	11406.24 ± 4566.18	10433.17	11376.12 ± 4384.59	10774.31	341.14	-0.02	0.85	-0.26	0.22
Braking Force Absolute Asymmetry (N)	BFAA	Braking	136.31 ± 86.62	117.61	111.73 ± 86.81	76.26	41.35	0.19	0.12	-0.05	0.41
Propulsive Force Absolute Asymmetry (N)	PFAA	Propulsive	72.93 ± 56.72	54.13	61.87 ± 45.28	50.49	3.64	0.09	0.44	-0.15	0.32
Peak Relative Propulsive Force (N/kg)	PRPF	Propulsive	279.76 ± 37.28	270.86	290.39 ± 32.99	290.77	19.91	-0.23	0.06	-0.44	8.26x10-3

to another braking metric. Using the CVCM the list of braking metrics was reduced to four (ABV, ARBF, ABF, BNI). In the transfer-propulsive category three metrics (PNI, FMD, RFDMD) did not exhibit high correlation. It's also important to note that PNI and JM will have approximately the same numerical value, but with different units of measurement. Of the remaining ten metrics in this category that exhibited high correlation, the CVCM was used to further reduce to four (APV, ARPF, APF, PRPP). All-in-all seven metrics remained for the transfer-propulsive metrics category and four for the braking metrics category. These metrics along with JH, JM, POSNI, and mRSI (i.e. output metrics) were used for percentile comparison.

Percentile Normative Reference Values

Often times data is presented to key stakeholders in elite basketball and that information is not well reciprocated. Percentiles are an easily understood method of communicating where a player ranks in relation to their peers. Thus, it makes sense to communicate with percentiles and reason with standard scores (i.e. Z-scores, T-scores) for determining statistical significance. The metrics chosen for percentiles were selected based on reduction techniques outlined in the statistical analysis section of this paper and their biological basis to the sport of basketball.

Asymmetry and Strategy Metrics

Some CMJ metrics do not exhibit polarity, rather an acceptable range may be pursued; an example of this is IR (the ratio of PNI and BNI). Conceptually this metric may be thought of as the balance between propulsive and braking qualities. IR along with, BFAA, PFAA, and RPLF are presented at bar plots; CMD, TTT, NP, and STIFF are presented as rain cloud plots for visualization of high probability optimal ranges. All asymmetry and strategy metrics except for body mass showed no significant difference between positional-groups.

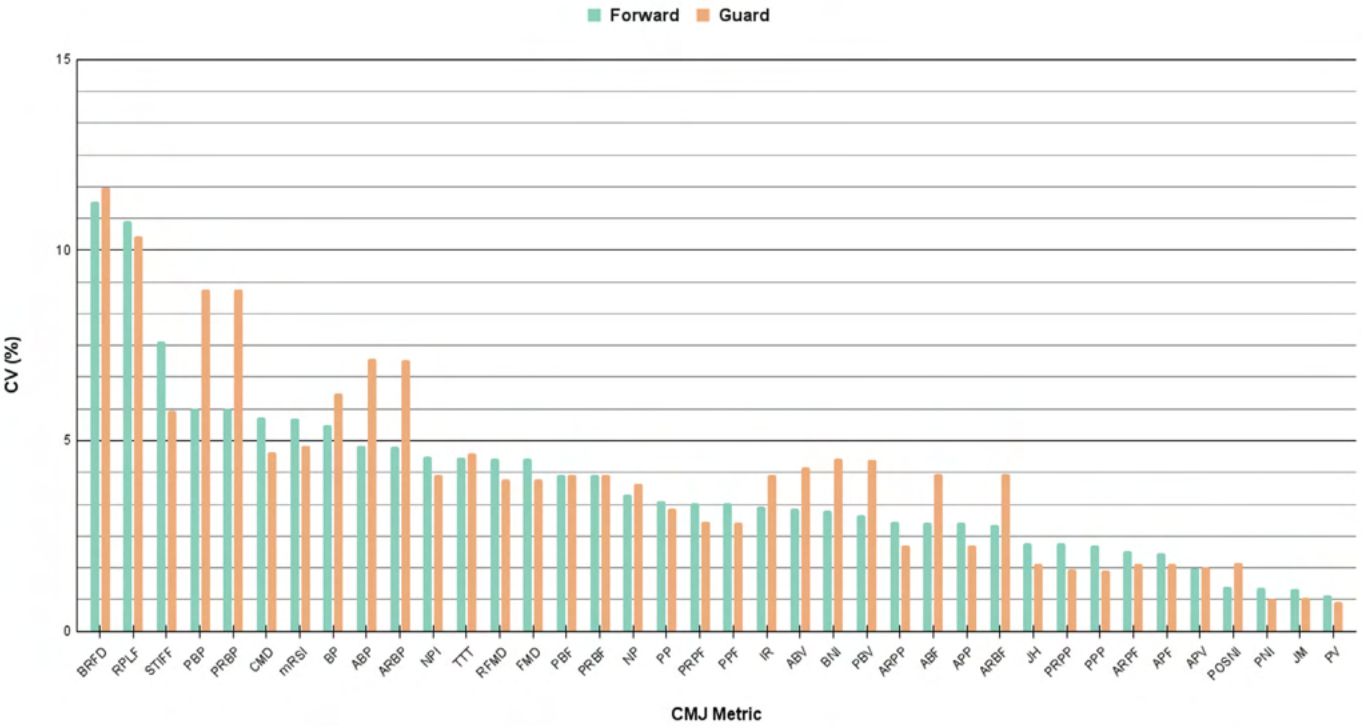
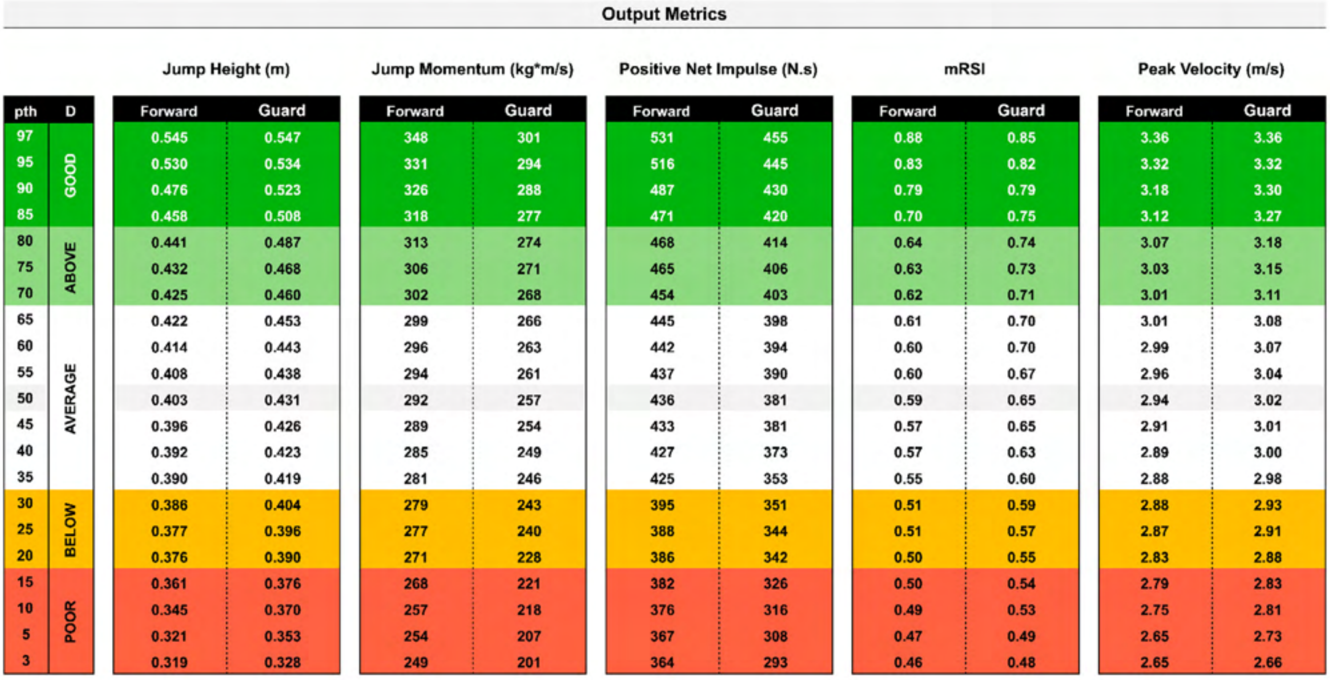


Figure 5. Coefficient of Variation (CV%) for 38 CMJ metrics; excluding outliers PFAA (Forwards CV% = 51.63, Guards CV% = 43.30) and BFAA (Forwards CV% = 37.24, Guards CV% = 45.86). Forwards are colour-coded green; guards are colour-coded orange. Generally speaking, CV% < 10% is considered very good and < 30% is considered acceptable.

Table 5. Alignment of percentiles to Z-scores (Z) and T-scores (T). Descriptor is consistent with descriptors and colours used in Professional Rugby League T-score benchmarking (34); pth = percentile; D = descriptor.

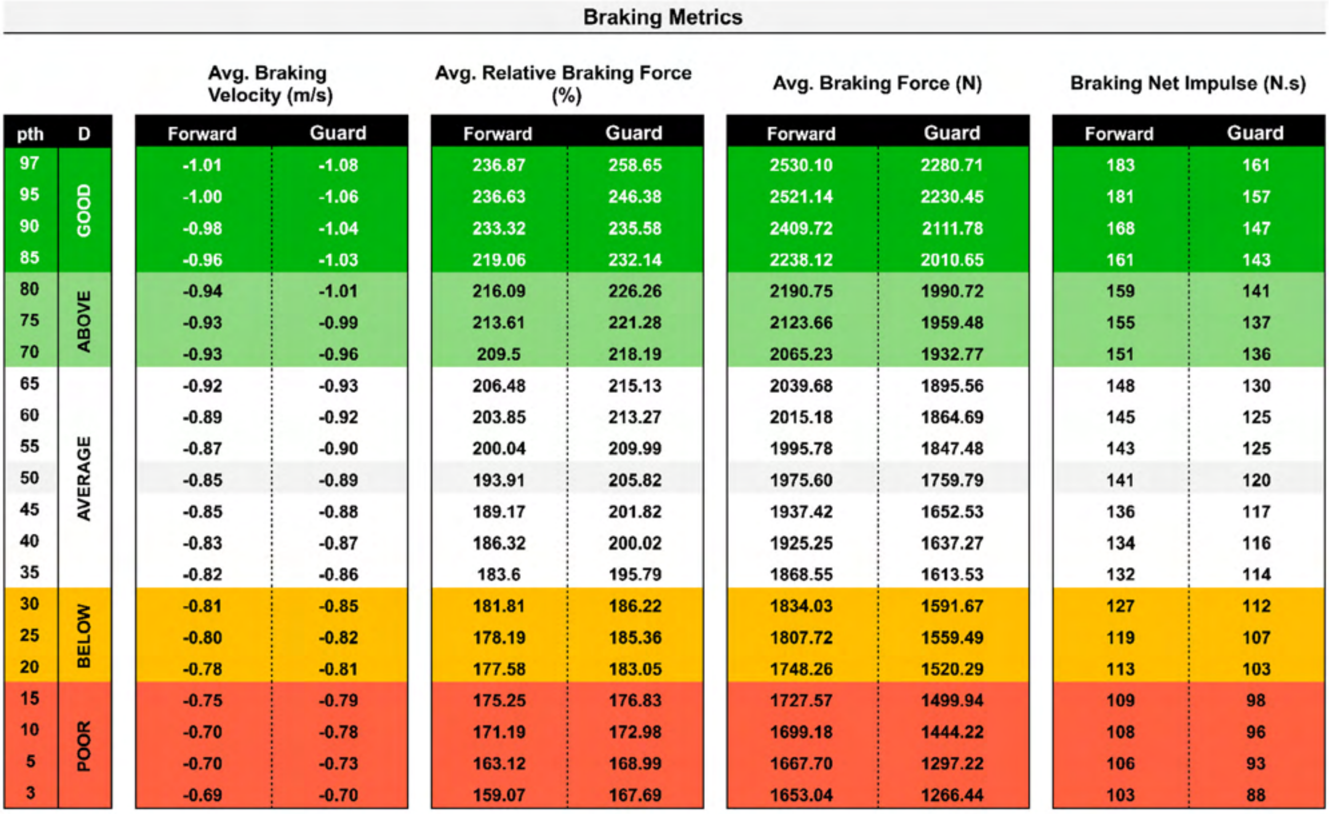
D	GOOD				ABOVE AVG.			AVERAGE							BELOW AVG.			POOR			
pth	97	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25	20	15	10	5	3
Z	1.881	1.645	1.282	1.036	0.842	0.674	0.524	0.385	0.253	0.126	0	-0.126	-0.253	-0.385	-0.524	-0.674	-0.842	-1.036	-1.282	-1.645	-1.881
T	68.81	66.45	62.82	60.36	58.42	56.74	55.24	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



Output Metrics

		Jump Height (m)		Jump Momentum (kg*m/s)		Positive Net Impulse (N.s)		mRSI		Peak Velocity (m/s)	
pth	D	Forward	Guard	Forward	Guard	Forward	Guard	Forward	Guard	Forward	Guard
97	GOOD	0.545	0.547	348	301	531	455	0.88	0.85	3.36	3.36
95		0.530	0.534	331	294	516	445	0.83	0.82	3.32	3.32
90		0.476	0.523	326	288	487	430	0.79	0.79	3.18	3.30
85		0.458	0.508	318	277	471	420	0.70	0.75	3.12	3.27
80	ABOVE	0.441	0.487	313	274	468	414	0.64	0.74	3.07	3.18
75		0.432	0.468	306	271	465	406	0.63	0.73	3.03	3.15
70		0.425	0.460	302	268	454	403	0.62	0.71	3.01	3.11
65	AVERAGE	0.422	0.453	299	266	445	398	0.61	0.70	3.01	3.08
60		0.414	0.443	296	263	442	394	0.60	0.70	2.99	3.07
55		0.408	0.438	294	261	437	390	0.60	0.67	2.96	3.04
50		0.403	0.431	292	257	436	381	0.59	0.65	2.94	3.02
45		0.396	0.426	289	254	433	381	0.57	0.65	2.91	3.01
40		0.392	0.423	285	249	427	373	0.57	0.63	2.89	3.00
35		0.390	0.419	281	246	425	353	0.55	0.60	2.88	2.98
30	BELOW	0.386	0.404	279	243	395	351	0.51	0.59	2.88	2.93
25		0.377	0.396	277	240	388	344	0.51	0.57	2.87	2.91
20		0.376	0.390	271	228	386	342	0.50	0.55	2.83	2.88
15	POOR	0.361	0.376	268	221	382	326	0.50	0.54	2.79	2.83
10		0.345	0.370	257	218	376	316	0.49	0.53	2.75	2.81
5		0.321	0.353	254	207	367	308	0.47	0.49	2.65	2.73
3		0.319	0.328	249	201	364	293	0.46	0.48	2.65	2.66

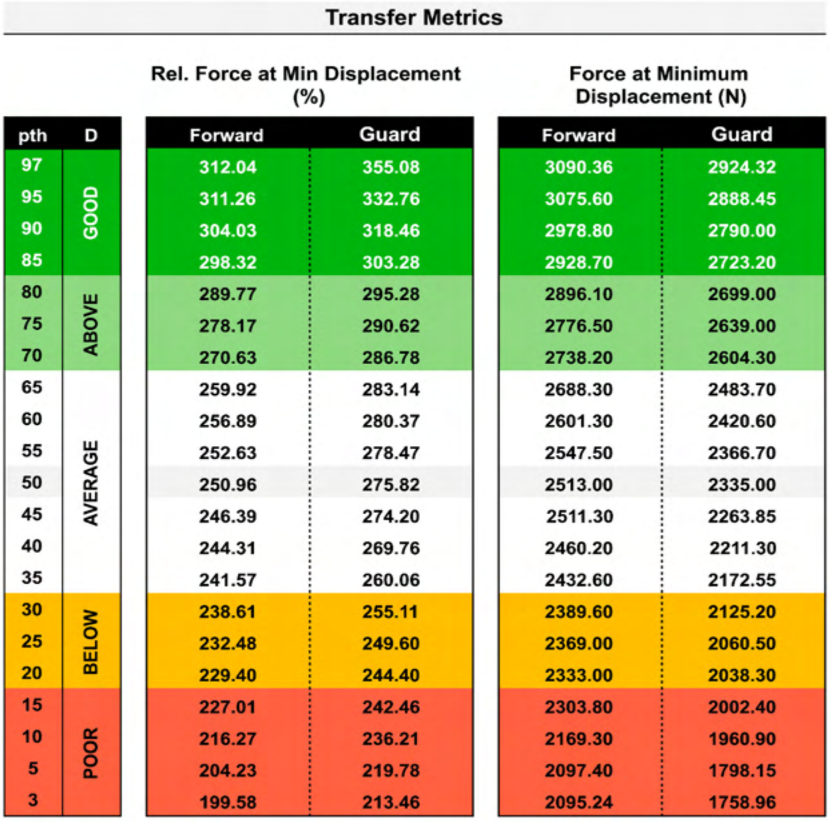
Figure 6. Output metric percentiles for MCBB forwards (n = 37) and guards (n = 55). D = descriptor; pth = percentile. Positive net impulse = the combination of braking net impulse and propulsive net impulse; net = above system weight.



Braking Metrics

		Avg. Braking Velocity (m/s)		Avg. Relative Braking Force (%)		Avg. Braking Force (N)		Braking Net Impulse (N.s)	
pth	D	Forward	Guard	Forward	Guard	Forward	Guard	Forward	Guard
97	GOOD	-1.01	-1.08	236.87	258.65	2530.10	2280.71	183	161
95		-1.00	-1.06	236.63	246.38	2521.14	2230.45	181	157
90		-0.98	-1.04	233.32	235.58	2409.72	2111.78	168	147
85		-0.96	-1.03	219.06	232.14	2238.12	2010.65	161	143
80	ABOVE	-0.94	-1.01	216.09	226.26	2190.75	1990.72	159	141
75		-0.93	-0.99	213.61	221.28	2123.66	1959.48	155	137
70		-0.93	-0.96	209.5	218.19	2065.23	1932.77	151	136
65	AVERAGE	-0.92	-0.93	206.48	215.13	2039.68	1895.56	148	130
60		-0.89	-0.92	203.85	213.27	2015.18	1864.69	145	125
55		-0.87	-0.90	200.04	209.99	1995.78	1847.48	143	125
50		-0.85	-0.89	193.91	205.82	1975.60	1759.79	141	120
45		-0.85	-0.88	189.17	201.82	1937.42	1652.53	136	117
40		-0.83	-0.87	186.32	200.02	1925.25	1637.27	134	116
35		-0.82	-0.86	183.6	195.79	1868.55	1613.53	132	114
30	BELOW	-0.81	-0.85	181.81	186.22	1834.03	1591.67	127	112
25		-0.80	-0.82	178.19	185.36	1807.72	1559.49	119	107
20		-0.78	-0.81	177.58	183.05	1748.26	1520.29	113	103
15	POOR	-0.75	-0.79	175.25	176.83	1727.57	1499.94	109	98
10		-0.70	-0.78	171.19	172.98	1699.18	1444.22	108	96
5		-0.70	-0.73	163.12	168.99	1667.70	1297.22	106	93
3		-0.69	-0.70	159.07	167.69	1653.04	1266.44	103	88

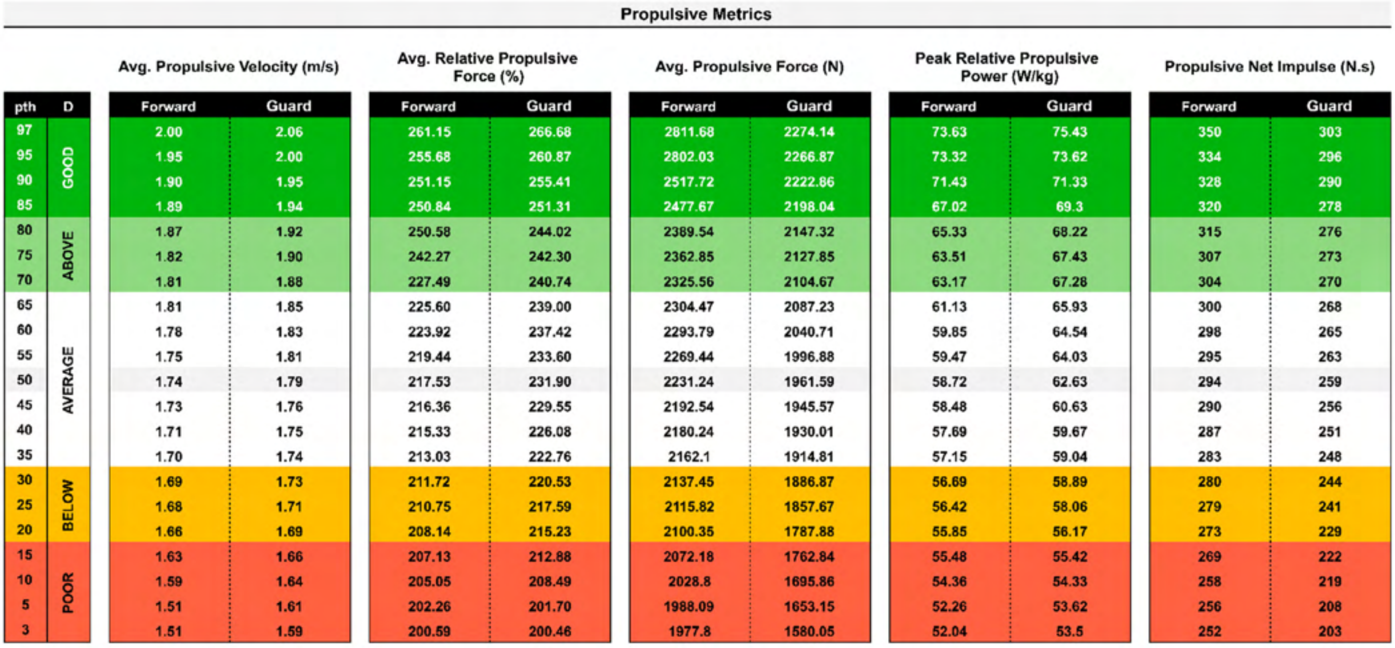
Figure 7. Braking metric percentiles for MCBB forwards (n = 37) and guards (n = 55). For ABV, more negative is better. ARBF (%) is expressed as the percentage of system weight. D = descriptor; pth = percentile.



Transfer Metrics

		Rel. Force at Min Displacement (%)		Force at Minimum Displacement (N)	
pth	D	Forward	Guard	Forward	Guard
97	GOOD	312.04	355.08	3090.36	2924.32
95		311.26	332.76	3075.60	2888.45
90		304.03	318.46	2978.80	2790.00
85		298.32	303.28	2928.70	2723.20
80	ABOVE	289.77	295.28	2896.10	2699.00
75		278.17	290.62	2776.50	2639.00
70		270.63	286.78	2738.20	2604.30
65	AVERAGE	259.92	283.14	2688.30	2483.70
60		256.89	280.37	2601.30	2420.60
55		252.63	278.47	2547.50	2366.70
50		250.96	275.82	2513.00	2335.00
45		246.39	274.20	2511.30	2263.85
40		244.31	269.76	2460.20	2211.30
35		241.57	260.06	2432.60	2172.55
30	BELOW	238.61	255.11	2389.60	2125.20
25		232.48	249.60	2369.00	2060.50
20		229.40	244.40	2333.00	2038.30
15	POOR	227.01	242.46	2303.80	2002.40
10		216.27	236.21	2169.30	1960.90
5		204.23	219.78	2097.40	1798.15
3		199.58	213.46	2095.24	1758.96

Figure 8. Transfer metric percentiles for MCBB forwards (*n* = 37) and guards (*n* = 55). RFMD is the percentage of system weight. D = descriptor; pth = percentile.



Propulsive Metrics

		Avg. Propulsive Velocity (m/s)		Avg. Relative Propulsive Force (%)		Avg. Propulsive Force (N)		Peak Relative Propulsive Power (W/kg)		Propulsive Net Impulse (N.s)	
pth	D	Forward	Guard	Forward	Guard	Forward	Guard	Forward	Guard	Forward	Guard
97	GOOD	2.00	2.06	261.15	266.68	2811.68	2274.14	73.63	75.43	350	303
95		1.95	2.00	255.68	260.87	2802.03	2266.87	73.32	73.62	334	296
90		1.90	1.95	251.15	255.41	2517.72	2222.86	71.43	71.33	328	290
85		1.89	1.94	250.84	251.31	2477.67	2198.04	67.02	69.3	320	278
80	ABOVE	1.87	1.92	250.58	244.02	2389.54	2147.32	65.33	68.22	315	276
75		1.82	1.90	242.27	242.30	2362.85	2127.85	63.51	67.43	307	273
70		1.81	1.88	227.49	240.74	2325.56	2104.67	63.17	67.28	304	270
65	AVERAGE	1.81	1.85	225.60	239.00	2304.47	2087.23	61.13	65.93	300	268
60		1.78	1.83	223.92	237.42	2293.79	2040.71	59.85	64.54	298	265
55		1.75	1.81	219.44	233.60	2269.44	1996.88	59.47	64.03	295	263
50		1.74	1.79	217.53	231.90	2231.24	1961.59	58.72	62.63	294	259
45		1.73	1.76	216.36	229.55	2192.54	1945.57	58.48	60.63	290	256
40		1.71	1.75	215.33	226.08	2180.24	1930.01	57.69	59.67	287	251
35		1.70	1.74	213.03	222.76	2162.1	1914.81	57.15	59.04	283	248
30	BELOW	1.69	1.73	211.72	220.53	2137.45	1886.87	56.69	58.89	280	244
25		1.68	1.71	210.75	217.59	2115.82	1857.67	56.42	58.06	279	241
20		1.66	1.69	208.14	215.23	2100.35	1787.88	55.85	56.17	273	229
15	POOR	1.63	1.66	207.13	212.88	2072.18	1762.84	55.48	55.42	269	222
10		1.59	1.64	205.05	208.49	2028.8	1695.86	54.36	54.33	258	219
5		1.51	1.61	202.26	201.70	1988.09	1653.15	52.26	53.62	256	208
3		1.51	1.59	200.59	200.46	1977.8	1580.05	52.04	53.5	252	203

Figure 9. Propulsive metric percentiles for MCBB forwards (*n* = 37) and guards (*n* = 55). PNI is approximately the same numeric value as JM, but with different units of measurement. ARPF (%) is the percentage of system weight. D = descriptor; pth = percentile.

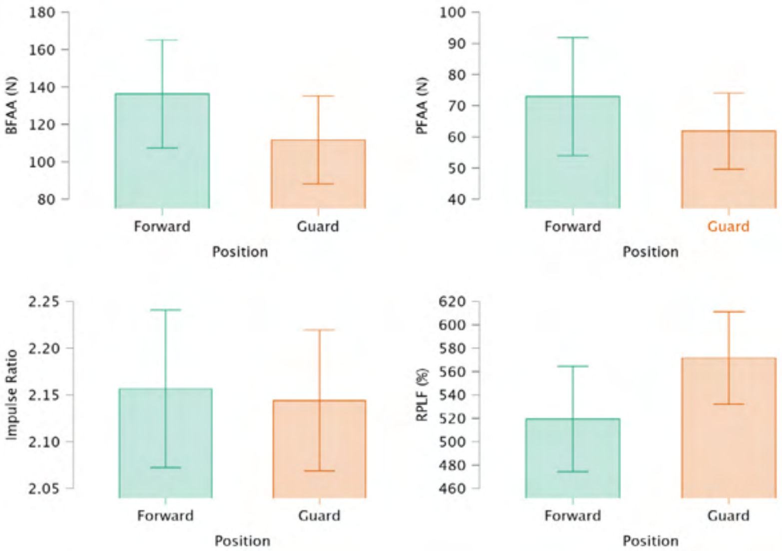


Figure 10. Bar plots for braking force absolute asymmetry (BFAA) and propulsive force absolute asymmetry (PFAA) and strategy metrics impulse ratio (IR) and relative peak landing force (RPLF) by position with error bars indicating 95%CI of the mean. BFAA = absolute value of right average braking force - left average braking force; PFAA = absolute value of right average propulsive force - left average propulsive force. Generally lower is better for BFAA and PFAA, however for certain sports and positions an accepted level of asymmetry is preferred. RPLF = force at landing relative to system weight represented as a percentage, lower is typically better; IR is a ratio metric of PNI/BNI, typically there is an accepted range based on position, biological age, and training age.

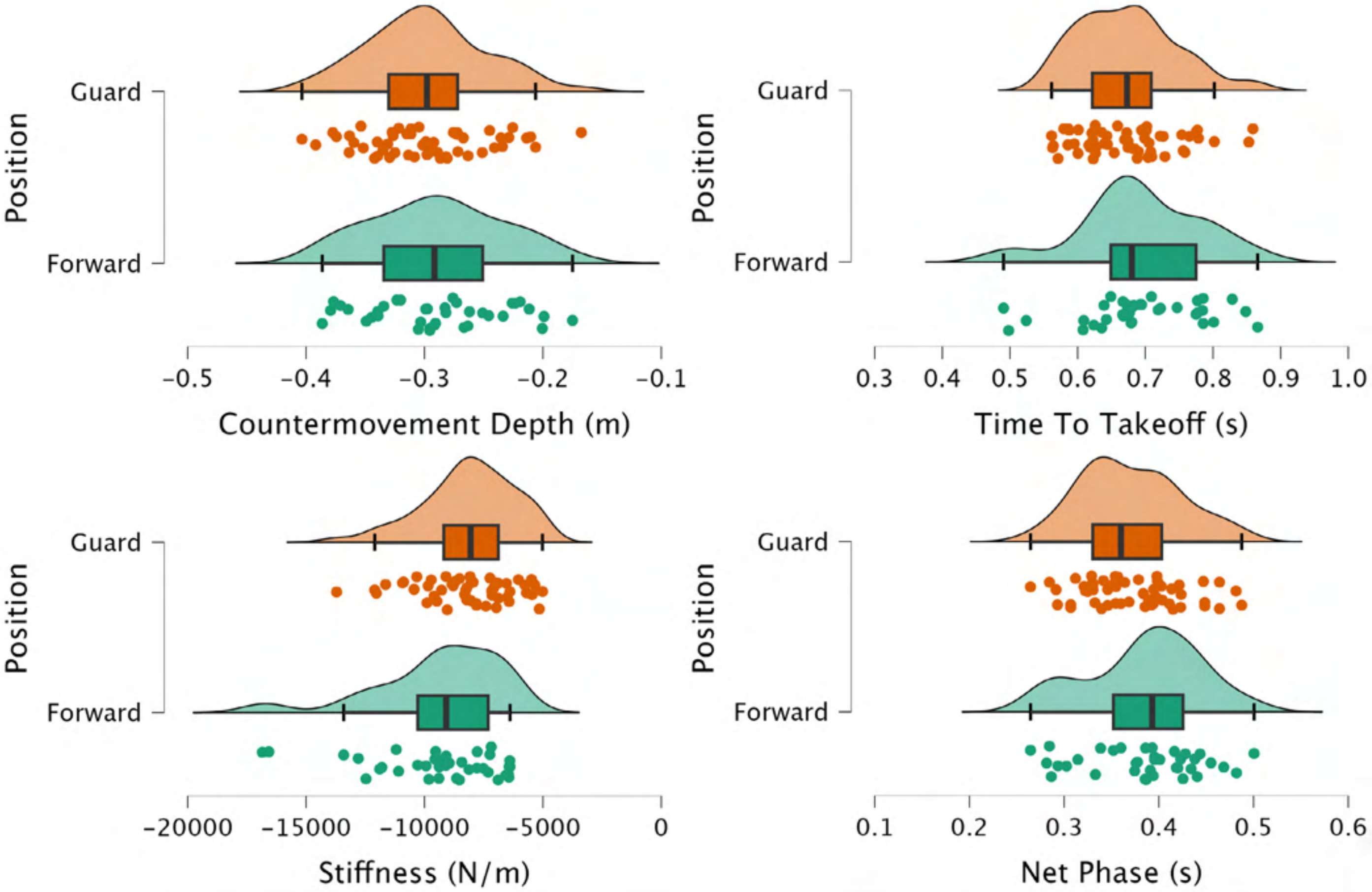


Figure 11. Rain cloud plots for strategy metrics by position. Net phase (NP) is braking phase time plus propulsive phase time; an alternative metric to TTT. Generally individuals are not graded on these metrics as poor or excellent, as there is an optimal strategy for each individual that produces an optimum output.

DISCUSSION

To the best of our knowledge, this study is the first to present force plate-derived CMJ normative percentile data and positional comparisons across a multi-team NCAA DI MCBB Power Five cohort. Between forwards and guards, 45% (18 of 40) of the reported metric showed significance ($p >$ 0.05) and 35% (14 of 40) yielded moderate-large effect sizes. Considering the degrees of variance in anthropometrics (*noted in Table 1*) between positions, differences in temporal-based metrics and absolute value metrics may be influenced by body mass, limb length, and torso length. Of the 18 significant metrics, only three non-output (i.e. braking, propulsive, transfer) metrics favoured guards. The first being ARPP ($d = 0.46$) and the only significant guard-favouring propulsive metric. RFMD and PRBF also showed a moderate effect ($d = 0.57$), possibly showing the importance of generating high braking (i.e. decelerative) forces relative to body mass for the guard position - a position that demands large volumes of short accelerations and decelerations in close quarters (36, 37). The aforementioned differences in positional game demands was also recently found in a NCAA DI MCBB study using accelerometer/GPS embedded smart compression showing that the number of high speed accelerations and decelerations (> 3.5 m/s^2) for guards is slightly higher than forwards in both practice and game situations (4). In contrast to findings from a systematic review of elite, sub-elite, and youth basketball, which revealed that forwards exhibited higher volumes of high-speed decelerations (5), Heisman et al. (2020) found no significant differences between positions in NCAA D1 MCBB athletes (19). The conflicting results might stem from variations in the experience levels of the analyzed populations, as well as differences in the technology and bandwidth utilized to measure the number of high-threshold accelerations and decelerations across the aforementioned literature. The importance of high speed decelerations in basketball was echoed recently in the works of Phillip et al. (2023), where the researchers found that CMJ braking qualities separate high vs. low minute MCBB players. In that study, ABV (0.93 ± 0.07 m/s) and BRFD (19,819 ± 4460 N/m) were significant separating metrics (8). In the present paper, there was no significant positional difference for ABV (forwards: -0.86 ± 0.11 vs. guards: -0.90 ± 0.11 m/s) or BRFD (forwards: 11406.24 ± 4566.18 vs. guards: 11376.12 ± 4384.59 N/s), although BRFD was highly correlated to PRBF ($r = 0.90$) a metric that favored guards. In this study, ABV was not highly correlated to any significant metrics ($r >$ ± 0.85), although ABV was highly correlated to non-significant metrics PBV ($r = 0.98$), PRBP ($r = 0.87$), and ARBP ($r = 0.91$). Harper et al. (2020), found higher eccentric (braking) peak power (i.e. PBP) and eccentric (braking) peak velocity (i.e. PBV) in soccer & rugby athlete's that possess the ability to quickly decelerate their horizontal momentum better after a 20m sprint (9) - a common sprint distance in elite basketball (i.e. ¾ court sprint test used at the NBA Combine). This further supports the need for the development of the braking phase in guards and hybrid guards/forwards (i.e. small forwards), especially those who expect to have high on-court contributions. In contrast to the BRFD abilities observed in Heisman et al.'s study (2020), the average forward in this study generated 4854.84 more N/s, while guards produced 4824.72 more N/s. These results suggest a potential evolution in the NCAA DI MCBB athlete over a four-year period.

Moderate-large between group comparisons were found for PBF ($d = 0.68$) and ABF ($d = 0.86$), and FMD ($d = 0.68$) all favouring forwards. Considering that FMD is the end force point of braking and starting force point of propulsion, it seems that relative braking forces favor guards, whereas absolute braking forces favor forwards. Although non-significant, ARBF ($d = 0.36$) also favoured guards by an average of 8.98 N/kg. It is also worth noting that FMD (i.e. force at zero velocity) is often considered the point at which amortization occurs, or rather the "transfer point" as outlined in this study. This is a critical point along the CMJ, especially in sports that require usage of the stretch-shortening cycle, because a jumper must efficiently transfer the momentum generated in unweighting and braking to propulsion in order to maximize propulsive momentum (i.e. net impulse) in order to jump high. This is further justified by a study from McHugh et al. (2020), where they found that an "optimal" jump is one where peak force occurs at the low position (i.e. FMD) (38). An additional metric to consider at the transfer point is IR. IR is a ratio metric calculated by dividing PNI/BNI; conceptually it answers "how much braking net impulse was used in propulsion"? For forwards, the average IR value was 2.16 (95% CI = 2.07, 2.24) meaning that the acceptable range with 95% confidence for forwards is between 2.07-2.24. In layperson's terms, propulsive net impulse is 2.07-2.24x larger than braking net impulse. Similarly, guards average IR value was 2.14 (95% CI = 2.07, 2.22).

Six metrics displayed an effect size value >1 (JM, POSNI, PNI, PPF, APF, PPP) and all favoured forwards; three of which are output metrics and are closely correlated to body mass (JM: *r* = 0.84, PNI: *r* = 0.84, POSNI: *r* = 0.80). The remaining three large effect metrics in addition to APP (*d* = 0.84) are propulsive metrics and considered drivers of performance, none of which are relative metrics. Therefore, it seem presumptive that these differences could be explained by the heavier body masses found in forwards in this study - on average 16.63 kg heavier. Comparatively, APF, PPF, APP, and PPP in this study were all larger compared to those found by Heisman et. al (2020) in a cohort of one NCAA DI MCBB team (19). These findings further justify positional separation for scoring and reporting of output metrics JM, PNI, POSNI and driver metrics PPF, APF, PPP, APP.

The remaining three significant output metrics are JH, mRSI (JH/TTT), and NPI all guard-favouring, yet with only a small effect size (*d* = 0.43-0.47). This is consistent with previous NCAA DI MCBB findings from Heisman et al. (2020), showing a statistical significance (*p* < 0.001) between JH for forwards/center combined group (34.6 ± .40 m, *n* = 7) and guards (42.6 ± .40 m, *n* = 7); no significance was found for mRSI (19). In comparison, forwards and guards in this study jumped higher on average by 6.4 and 1 cm, and yielded larger mRSI values by 0.15 and 0.13, respectively. The median mRSI values in this study ($\tilde{x}$ = 0.62) are more in line with those reported by Krzyszkowski et al. (2022) in a paper investigating phase-specific jump indicators, with median mRSI values of 0.55 (23). More recently, Murr et al. (2023), monitored four CMJ metrics over the course of a NCAA DI MCBB season for nine athletes and found pre-season JH values of 0.45 ± 0.03 m and mRSI values of 0.585 ± 0.05, however there was no split by positional group (20). Most recently, Philipp et al. (2023), compared CMJ metrics of high vs. low minute MCBB (*n* = 15) athletes and found that high-minute MCBB athletes showed a JH of 53.4 ± 6.61 cm; findings were not split by position. These findings are important to consider as the reported JH values by Philipp et. al (2023) (8), on-average are 9.8 cm higher than guards in this study and 12.4 cm higher than forwards in this study. In the current study, there was no split between high and low-minute MCBB players and all players were used for comparison regardless of playing time. The small differences in JH, mRSI, and NPI in this study may warrant inter-group comparison, especially for a hybrid position such as a small forward. Lastly, the JHs reported in this study on average are 2.3 cm higher for forwards and 4.9 cm higher for guards compared to baseline (no-position split) values recently found in National Association of Intercollegiate Athletics (NAIA) MCBB (22). NAIA is a subdivision of basketball that is athletically comparable to NCAA Division-II (D2). This supports the claim that JHs increase as leagues advance (7). Similarly, Cabarkapa et. al (2023), looked at previous MCBB athletes (*n* =10) now participating in pro leagues in Germany and France and found JH averages of 42.7 cm (no-position split) (39), suggesting that JH does not increase much post college. This potentially shows that JH may max out at college for the majority of basketball athletes, or that JHs increase with exceeding levels up to college, but not professional.

It is also important to note that NPI is a novel ratio metric in this study and calculated by adding together braking phase time and propulsive phase time (i.e. Net Phase), then dividing JH (using the take-off velocity calculation method) by Net Phase. This metric has potential as a measure of rapid force production and is used in place of CMJ-derived mRSI; as a limitation for mRSI on force plates is the potential for an early initiation in the unweighting phase (NPI eliminates the unweighting phase). In this study, all early initiations were removed prior to data analysis and mRSI (forward CV% = 20, guards CV% = 16) and NPI (forward CV% = 23, guards CV% = 19) exhibited similar positional group CV%. NPI may be preferred in large group settings where data quality measures may be logistically unfeasible due to time and volume-constraints. In this study, TTT showed no between-group significance and was also highly correlated to NP (*r* = 0.86). STIFF is another ratio metric that showed forward-favouring significance (*d* = 0.55). This metric is derived from the change in force to low position (i.e. ABF) and CMD. As mentioned earlier, CMD is often considered a "range of motion" metrics by practitioners, and showed no significant difference between groups (forwards: CMD = -0.29 ± 0.06; guards: CMD = -0.30 ± 0.05). Considering that ABF showed a large effect size favouring forwards, it seems speculative that ABF accounts for the significance of STIFF, however STIFF and ABF exhibit a relationship of *r* = -0.48 whereas STIFF and CMD correlate with *r* = -0.80. Meaning that 64% of STIFF can be explained by changes in CMD, whereas ABF can only explain 23%.

Asymmetry (BFAA, PFAA) and landing (RPLF) metrics were analyzed in this study and showed no significance, however these are worth mentioning for practitioner insights because they are heavily used in applied-settings. BFAA is a novel metric, and was calculated by subtracting the absolute value of right average braking force by the absolute value of left average braking force for each individual jump trial. PFAA was calculated using the same formula, but using left/right propulsive forces. This calculation of asymmetry is novel, and may serve best for monitoring asymmetry as it is a Newton value as opposed to a percentage. Percentages are a common way of reporting asymmetry, however it is challenging to derive standard scores from positive and negative percentage values for large cohorts of athletes (scores often average out around zero). In this study, the forward average difference in force asymmetry for BFAA was 136.31 ± 86.62 N and guard average was 111.73 ± 86.81 N. It is important to note that both asymmetry metrics displayed the highest CV% out of all 40 metrics analyzed, further confirming findings from previous works that asymmetry variables are extremely variable and should be approached with caution (40). Landing was analyzed by comparing RPLF, represented as the percentage of bodyweight an athlete land's with upon impact after flight. Similar to IR, there is typically an accepted range for RPLF. For forwards the average was 519.54% (95% CI = 407.6, 527.2) and the average for guards was 571.70% (95% CI = 459.7, 579.4).

The last remaining significant CMJ metric is BNI. BNI is an interesting metric because it is the impulse that sets up the impulse that directly dictates jump height. It is also equal to braking momentum, or rather PBV times body mass. Conceptually, BNI may be thought of as the capacity of the braking phase as it is the all-encompassing braking area. In this study, BNI favoured forwards (d = 0.78) on average 17.26 N.s more than guards. Further splitting the metric into its components, we see that forwards produce less PBV than guards, yet weigh more. Thus, the significantly higher BNI for forwards is due to a heavier body mass.

Time of day and day of week testing effects were analyzed to gauge the impact on data collected at various time points throughout the week using mRSI as a freshness indicator. There were no significant effects between AM and PM collected tests, however there was a significant difference on mRSI values collected on Wednesday's compared to mRSI values collected on Mondays, Thursdays, or Fridays. These effects were moderate-large, potentially indicating that Wednesdays during the pre-season period is the time of the week that MCBB athletes may be the freshest. Therefore, higher demanding stretch-shortening cycle activities (i.e. drop jumps) may be programmed on this day. These results should be approached with caution as only 13.5% of the sample size was tested on Wednesday, and only one team. The effects could be due to the increased athleticism for this respective team.

CONCLUSION

Practitioners may use this information periodically throughout the competitive MCBB season. The first and most obvious is to compare the percentiles found in this paper to current athlete values, and again when new athletes enter a program. Knowing these benchmark standards will help practitioners understand what metrics should be improved upon with training (i.e. making metrics trainable). When using this information in applied-settings, practitioners should also be aware of the variability in certain CMJ metrics (i.e. BRFD). Secondly, these findings may be used during the screening process for not only strength and conditioning personnel, but also basketball scouts/recruiters looking to filter recruits by physiological performance before evaluating technical skills. This is possible for current MCBB recruiters, and also NBA scouts looking to evaluate the physical performance of a possible draft pick - as current scouting operations involve an NBA representative contacting the MCBB strength and conditioning coach for performance data and insights. The value in force plate data to scouting and screening is further supported by long-lasting evidence from Hoare (1999), who found that junior elite basketball athletes who rank higher in physical performance tests also rank high in sport-coach reported best player rankings with 60% alignment (41). Similarly, physical performance tests have been linked to on-court contribution (42). Thirdly, this information has an impact for MCBB sports medicine personnel to serve as benchmarks for healthy force plate-derived CMJ positional reference values during the RTP process.

The strengths of this study include a relatively large cohort (n =96) of NCAA DI MCBB players among seven teams and four Power Five conferences. Additionally, all MCBB athletes were well-trained and had at least three months in the respective team's strength and conditioning program regularly using the Hawkin Dynamics force plate system. Lastly, CMJ data was reported for output, driver, and strategy metrics, and all data collected in this study was pre-season testing data gathered in each team's respective weight room; meaning that all data points can be uniformly compared considering time of year and environmental comfort. The main limitations of this study were that the data collection occurred on different days of the week, different times of the day, and over a span of 26 days; whereas the demands of pre-season training load from each team are relatively unknown, potentially affecting the acute neuromuscular readiness of the athletes. Finally, there were only four centers who participated in this study. While true centers are rare and hard to find, a larger sample size is needed to ultimately create more robust benchmarking standards for this outlier group.

In summary, the new era of basketball may be moving towards positionless gameplay, however positional differences still exist between forwards and guards when analyzing force plate-derived CMJ metrics. While the overarching aim of this study was to compare positions and propose percentile benchmarks for key metrics answering the question…what is good? It should be noted that it is not likely for the best basketball player of each position to rank within the top percentile for all metrics. However, there is a high likelihood that the best player of each position will have an optimal configuration of CMJ metrics that are important for excelling at their respective position, team's style of play, and athletic conference. Future research should look to identify force plate-derived CMJ metrics that matter most for on-court production, and develop a Total Score of Athleticism (43) score by position to determine optimal configuration.

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INFORMED CONSENT STATEMENT

Informed consent was obtained from all participants involved in the study.

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AFFILIATIONS

Drake Berberet is a full-time employee of Hawkin Dynamics.

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.

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APPENDIX

Appendix A

1. Walking Knee to Chest 3ea followed by a Back Pedal back to where there started
2. Walking Quad Pull 3ea followed by a Back Pedal back to where there started
3. Walking Big Kicks 3ea followed by a Back Pedal back to where there started
4. Walking SL RDL 3ea followed by a Back Pedal back to where there started
5. Alternating Side Lunge 3 out 3 back
6. World's Greatest Stretch 3ea
7. Reverse Lunge with Overhead Reach 3ea
8. Forward Lunge with Rotation 3ea
9. Reverse Lunge with Overhead Reach 3ea
10. Skip 10yds down & back
11. Karaoke 10yds down & back
12. A Skip 10yds down & back
13. Power Skips 10yds down & back
14. Skips for Distance 10yds down & back
15. Pogo Hops x10
16. Single Leg Pogo Hops x10ea