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Evaluation of different jumping tests in defining position-specific and performance-level differences in high level basketball players

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ABSTRACT: The importance of jumping ability in basketball is well known, but there is an evident lack of studies that have examined different jumping testing protocols in basketball players at advanced levels. The aim of this study was to assess the applicability of different tests of jumping capacity in identifying differences between (i) playing position and (ii) competitive levels of professional players. Participants were 110 male professional basketball players (height: 194.92±8.09 cm; body mass: 89.33±10.91 kg; 21.58±3.92 years of age; Guards, 49; Forwards, 22; Centres, 39) who competed in the first (n = 58) and second division (n = 52). The variables included anthropometrics and jumping test performance. Jumping performances were evaluated by the standing broad jump (SBJ), countermovement jump (CMJ), reactive strength index (RSI), repeated reactive strength ability (RRSA) and four running vertical jumps: maximal jump with (i) take-off from the dominant leg and (ii) non-dominant leg, lay-up shot jump with take-off from the (iii) dominant leg and (iv) non-dominant leg. First-division players were taller (ES: 0.76, 95%CI: 0.35-1.16, moderate differences), heavier (0.69, 0.29-1.10), had higher maximal reach height (0.67, 0.26-1.07, moderate differences), and had lower body fat % (-0.87, -1.27-0.45, moderate differences) than second-division players. The playing positions differed significantly in three of four running jump achievements, RSI and RRSA, with Centres being least successful. The first-division players were superior to second-division players in SBJ (0.63, 0.23-1.03; 0.87, 0.26-1.43; 0.76, 0.11-1.63, all moderate differences, for total sample, Guards, and Forwards, respectively). Running vertical jumps and repeated jumping capacity can be used as valid measures of position-specific jumping ability in basketball. The differences between playing levels in vertical jumping achievement can be observed by assessing vertical jump scores together with differences in anthropometric indices between levels.

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INTRODUCTION

In addition to technical and tactical knowledge, appropriate anthropometric and body build features, precision and agility, jumping ability is a key element of success in basketball [1-5]. The importance of vertical jumping is particularly emphasized because the game is oriented around a basket that is set at a top height of 3.05 m. Players who have superior jumping capabilities are able to outperform their opponents in numerous situations requiring offensive and defensive responsibilities, such as blocking, jump shooting, and rebounding [6, 7]. Consequently, athletes and coaches in this sport are highly interested in testing and developing vertical jumping ability [8-10].

There are several different types of jumps that occur in basketball. In general, jumps can be divided into those performed from a standing position (standing jumps) and those performed after a running action (running jumps) [6, 7]. Specifically, in some situations, players perform standing jumps (e.g., rebounding by Centres, mostly when blocking an opponent's shot, performing jump shots), while in other situations, jumps are performed after running (e.g., rebounding by backcourt players, dunking, lay-ups). Namely, although different standing jumps are known to be highly inter-correlated, the association between running jumps and standing jumps is lower (i.e. less than 50% of the common variance), indicating that these standing and running jump performances should not necessarily be observed as a unique quality [11].

Previous studies have examined jumping performance in basketball while comparing playing levels (performance levels) [12, 13]. Koklu and his colleagues reported first-division Turkish players as being superior in CMJ performance than their second-division peers (40.6±4.7 and 36.0±5.0 cm, respectively), with no significant differences in squat-jump performance (37.8±5.7 and 34.7±5.7 cm, respectively) [13]. When compared three Tunisian national teams (under 18, under 20, and senior team) Ben Abdelkrim et al. evidenced better CMJ achievement in older players (41.4±4.6, 49.1±5.9, and 49.7±5.8 cm, respectively), while Castagna et al. reported similar CMJ for Italian regional level juniors and seniors, with better stiff leg jump (SLJ) in younger players (CMJ: 48.11±10.53 and 47.04±5.77 cm, SLJ: 39.92±5.04 and 42.66±4.29 cm, for seniors and juniors, respectively) [14, 15]. However, all of these studies investigated standing vertical jumps, while running jumps are rarely examined although known to be highly specific and important in basketball [7].

Three main playing positions within basketball (i.e., Guards, Forwards and Centres) have strictly defined position-related duties during the game. Such position-specific duties resulted in specific body types [16]. Centres are the tallest and heaviest, followed by Forwards, while the Guards are the shortest but most mesomorphic of all [17-19]. It is reasonable to expect that positional specifics in physical attributes and playing duties will be reflected in position-specific differences in jumping performance. Pojskic et al. reported CMJ of 40.40±5.04, 37.62±6.80, and 36.04±3.80 cm for Guards, Forwards and Centres, respectively, with significant ANOVA differences between Centres and the other two positions [20]. Similarly, Ben Abdelkrim et al. found the lowest CMJ for players involved in frontcourt duties (41.6±4.2 and 40.9±3.7 cm for Centres and Power Forwards) in comparison to backcourt players (50.2±5.9, 48.4±5.1, 52.5±5.0 for Point guards, Shooting guards and Small forwards, respectively) [15]. However, Koklu et al. and Ostojic et al. reported no significant differences in different types of vertical jump among three positions in basketball [1, 13]. Again, no study has examined position-related jumping performances for running vertical jumps.

From this brief literature overview it is clear that practically all studies that compared jumping performances between different levels of basketball players observed all players at once, without dividing them according to their playing position [13, 14]. Also, despite the clear specificity of jumps that occur in basketball, practically all studies investigated standard jumps (i.e. standing jumps). Evidently, little is known about the validity of other jumping performances (i.e. running jumps, reactive jumps) and their applicability in differentiating between playing levels and between playing positions [7, 8, 13-15].

Therefore, the aims of this study were to determine the reliability and discriminative validity of jumping tests in defining position-specific jumping ability in professional basketball players. Additionally, we examined the validity of jumping tests in identifying differences between professional basketball players involved at two playing levels (performance levels), separately for each playing position (i.e. separately for Guards, Forwards, and Centres).

MATERIALS AND METHODS

Participants

To obtain the sample size estimate, we used data obtained in a pilot test of 20 players (10 first-division and 10 second-division players). An analysis using the G*Power software (version 3.1.9.2; Heinrich Heine University Düsseldorf, Düsseldorf, Germany) for an independent two-way ANOVA (performance level x playing position; p-value of 0.05, power of 0.90 and effect size of 0.5) recommended 62 participants as an appropriate sample size. The study included 110 professional-level male basketball players from Bosnia and Herzegovina (height: 194.92±8.09 cm; body mass: 89.33±10.91 kg; 21.58±3.92 years of age). At the time of testing (competitive season 2014-2015), the players were involved in the highest national competitive ranks (i.e. first (N = 58) and second division (N = 52)). Testing was performed at the beginning of the season, and all of the subjects underwent a preseason preparation period before the testing. Only subjects who had no injuries and/or illnesses for 30 days before the experiment were included in this investigation (based on a health history questionnaire completed prior to testing). The players were categorized as Guards, Forwards and Centres (49, 22 and 39 players, respectively). Playing positions were self-reported by the athletes and additionally checked by the team manager (coach). The Ethical Board of the University of Split, Faculty of Kinesiology, provided approval of the research experiment (No: 2181-205-02-05-14-001). All subjects were informed of the purpose, benefits and risks of the investigation. All participants were older than 18 years and voluntarily participated in the testing after obtaining informed consent.

Procedure

The variables in this study included the participants' playing position, playing level (first division vs. second division), anthropometrics and jumping capacities.

The anthropometric variables were measured with stadiometers and scales (Seca, Birmingham, UK), and skinfold caliper (Holtain, London, UK) and included body height, maximal reach height, body mass, and percentage of body fat (BF%). Body height (cm) was measured barefoot to the nearest 0.1 cm. For standing reach height (maximal reach height), the subjects were encouraged to fully extend their dominant arm to reach as high as possible while a scale was fixed to the wall. The BF% was calculated using body density (BD) according to the following formula: $BD = 1.162 - 0.063 * \log \Sigma 4KN$ (where Σ4KN = sum of the biceps, triceps, subscapular and suprailiac skinfolds). Body density was converted to body fat percentage: $BF\% = (4.95 / BD - 4.5) * 100$. [19].

Jumping capacities were evaluated by the (i) standing broad jump (SBJ), (ii) countermovement jump (CMJ), (iii) maximal running vertical jump with take-off from the dominant leg (MVJ_D), (iv) maximal running vertical jump with take-off from the non-dominant leg (MVJ_ND), (v) 2-step approach vertical jump (lay-up shot jump) with take-off from the non-dominant leg (LU_D), (vi) lay-up shot jump with take-off from the non-dominant leg (LU_ND), (vii) reactive strength index (RSI), and (viii) repeated reactive strength ability (RRSA). The SBJ was tested using a standardized measuring mat (ELAN, Begunje, Slovenia), CMJ, RSI and RRSA were tested by Optojump equipment with 3-cm resolution (Microgate Bolzano, Italy), and modified VERTEC equipment (Vertec, Sports Imports, Hilliard, OH) was used to test the running vertical jumps.

The SBJ was performed from a standing position using a standardized measuring mat. Standardized instructions were given to the participants and allowed them to begin the jump with bent knees and to swing their arms to assist in the jump [21].

The CMJ test began with the participant standing in an upright position. A fast downward movement to about a 90° knee flexion was immediately followed by a quick upward vertical movement as high as possible, all in one sequence. The test was performed without an arm swing, as the hands remained on the hips [11].

The MVJ_D and MVJ_ND were tested as the maximal vertical jump after a self-determined running approach with take-off from the left or right leg. The subjects used an individually determined running approach (maximum 5 m distance from start to take-off) and performed a bounce jump with an arm swing. This task was followed by a quick upward vertical jump, accompanied with one-arm maximal reach height. The subjects were instructed to perform the jumping procedure in the way that they found most convenient, similar to their personal technique during a basketball game or practice. Originally, the participants were asked to use a right- or left-leg take-off. Later, the performances from the left and right leg were compared, and the better one was considered the jump that was performed by the dominant leg. The final achievement was calculated as the difference between the standing reach height and the test results as recorded on the measuring apparatus.

The LU_ND and LU_D were measured throughout the same procedures as MVJ_D and MVJ_ND, but participants executed a 2-step approach before the vertical jump.

The RSI was derived from the height achieved in a depth jump and the time spent on the ground developing the force required for that jump. The starting position for the depth jump involved the participant standing upright on a 40-cm box [22]. The participants were instructed to step off the box and to jump up as high as they could, attempting to minimize the contact time [23].

To evaluate repeated reactive strength ability (RRSA), the subjects performed 6 consecutive straight-leg vertical jumps. Each jump was assessed for the height jumped and the time spent on the ground developing the force required for each jump (contact time). The ratio of each jump height to its corresponding contact time was calculated. The average of all ratios was used as the final value of the RRSA for each participant.

The jumping tests were completed in three trials, with a pause of 1-2 minutes between trials and 5-7 minutes between tests. Before testing, the participants completed a 15-minute warm-up, including jogging, lateral displacements, dynamic stretching, and light jumping. Prior to each jumping test, 2-3 familiarization trials were completed. The best of the three trials was used as the final achievement of each athlete. On the first day, athletes were tested on anthropometrics, CMJ, RSI and RRSA. The remaining tests were conducted in a random order on the second day. Testing was performed indoors on a wooden floor in a gymnasium.

Statistical analysis

After assessing the normality (by the Kolmogorov-Smirnov test), the means and standard deviations were reported for all variables. The intra-session reliability was calculated on the basis of results of all athletes (n = 110). Additionally, a subsample consisting of 22 athletes was tested by testing (1st and 2nd day) and retesting (3rd and 4th day) to establish the inter-session reliability of the jumping tests. The relative reliability was analysed using the intraclass correlation coefficient (ICC), and the absolute reliability was analysed using the coefficient of variation (CV). The calculations were performed using the freely available Microsoft Excel 2010 software program [24, 25]. The homoscedasticity of all variables was proven by Levene's test.

To establish the factorial validity of the jumping tests, factor analysis with the Gutman-Kaiser criterion of extraction was used. Additionally, the relationships between the applied variables were established by Pearson's correlation coefficients [11, 26].

The discriminative validity of the applied tests was evaluated with regard to (i) playing position differences and (ii) performance level differences. For anthropometric and jumping variables, a 2-way-univariate ANOVA (performance level x playing-position) was performed, and differences between three playing positions were further evaluated by a Scheffe post-hoc test when appropriate. Additionally, differences between performance levels (first-division vs. second-division players) were evaluated by the magnitude-based Cohen's effect size (ES) statistic with modified qualitative descriptors. The effect size was assessed using the following criteria: <0.02 = trivial; 0.2–0.6 = small; >0.6–1.2 = moderate; >1.2–2.0 = large; and >2.0 very large differences [27]. To define the differences between performance levels, within each playing position, Student's t-test for independent samples was performed, with further analysis for ES differences.

The type I error rate of 5% ($p < 0.05$) was set a priori and considered statistically significant. StatSoft's Statistica ver. 12.0 (Tulsa, OK, USA) was used for all analyses.

RESULTS

With an ICC of 0.78-0.88 and CV of 3.0%-4.1% for intra-session reliability and an ICC of 0.74-0.85 and CV of 3.9-6.2% for inter-session reliability, the overall reliability of the tests was appropriate (Table 1).

In general, due to the large sample of tested subjects, all correlation coefficients indicating correlations among jumping tests were statistically significant (at $p < 0.05$). Also factor analysis results extracted one significant component. However, when observing the univariate associations between variables as indicated by Pearson's R, the correlations between the standing jumping performances and

TABLE 1. Intra- and inter-session reliability of jumping tests.

	Intra-session (n = 110)		Inter-session (n = 22)	
	ICC (95%CL)	**CV (95%CL)**	**ICC (95%CL)**	**CV (95% CL)**
CMJ	0.87 (0.82-0.90)	3.1 (2.5-3.7)	0.81 (0.64-0.90)	4.2 (2.8-5.9)
SBJ	0.86 (0.81-0.89)	4.0 (3.4-4.8)	0.81 (0.64-0.90)	5.2 (3.7-6.9)
MVJ_ND	0.88 (0.83-0.89)	4.0 (3.3-4.7)	0.79 (0.59-0.89)	3.9 (2.3-5.6)
MVJ_D	0.88 (0.83-0.89)	4.1 (3.4-4.7)	0.80 (0.63-0.91)	6.1 (4.6-7.8)
LU_ND	0.87 (0.82-0.90)	2.9 (2.3-3.7)	0.80 (0.63-0.91)	5.1 (3.7-7.0)
LU_D	0.87 (0.82-0.90)	3.0 (2.4-3.6)	0.85 (0.73-0.93)	6.2 (4.4-8.6)
RSI (index)	0.81(0.76-0.85)	3.2 (2.6-4.0)	0.81 (0.64-0.90)	3.9 (2.3-5.7)
RRSA (index)	0.78 (0.73-0.84)	4.1 (2.5-4.8)	0.74 (0.60-0.93)	4.9 (3.2-6.9)

ICC - intraclass coefficient; CV - coefficient of variation; CL – confidence limit; CMJ – countermovement jump; SBJ – standing broad jump; MVJ_D - maximal running vertical jump with the take-off from dominant leg; MVJ_ND - maximal running jump with the take-off from non-dominant leg, LU_D - lay-up shot jump with the take-off from dominant leg, LU_ND - lay-up shot jump with the take-off from non-dominant leg, RSI - reactive-strength-index, RRSA - repeated reactive strength ability.

TABLE 2. Intercorrelation matrix and factor analysis results.

	CMJ	SBJ	MVJ_D	MVJ_ND	LU_ND	LU_D	RSI	F
	r (95%CI)	r (95%CI)	r (95%CI)	r (95%CI)	r (95%CI)	r (95%CI)	r (95%CI)	
CMJ (cm)	-							0.73
SBJ (cm)	0.62 (0.49-0.72)†	-						0.68
MVJ_ND (cm)	0.49 (0.33-0.62)†	0.44 (0.27-0.58)†	-					0.86
MVJ_D (cm)	0.57 (0.43-0.68)†	0.43 (0.26-0.57)†	0.74 (0.64-0.81)†	-				0.88
LU_ND (cm)	0.56 (0.42-0.67)†	0.52 (0.36-0.65)†	0.88 (0.83-0.92)†	0.88 (0.83-0.92)†	-			0.89
LU_D (cm)	0.51 (0.35-0.64)†	0.52 (0.36-0.65)†	0.71 (0.60-0.79)†	0.75 (0.65-0.82)†	0.74 (0.64-0.81)†	-		0.89
RSI (index)	0.47 (0.31-0.59)†	0.31 (0.13-0.47)†	0.40 (0.23-0.55)†	0.56 (0.42-0.67)†	0.54 (0.38-0.67)†	0.45 (0.29-0.57)†	-	
RRSA (index)	0.37 (0.20-0.52)†	0.31 (0.13-0.47)†	0.40 (0.23-0.55)†	0.48 (0.32-0.61)†	0.47 (0.31-0.59)†	0.45 (0.29-0.57)†	0.56 (0.42-0.67)†	
ExplVar								4.16
PrpTotl								0.69

CMJ – countermovement jump; SBJ – standing broad jump; MVJ_D - maximal running vertical jump with the take-off from dominant leg; MVJ_ND - maximal running jump with the take-off from non-dominant leg, LU_D - lay-up shot jump with the take-off from dominant leg, LU_ND - lay-up shot jump with the take-off from non-dominant leg, RSI - reactive-strength-index, RRSA - repeated reactive strength ability, † denotes significant Pearson's product moment correlation coefficients at $p < 0.05$, F – correlations of the variables with principal component of the factor analysis, ExplVar – explained variance, PrpTotl – proportion of the total variance explained, note that RSI and RRSA (i.e. indexes) were not included in factor analysis calculation.

running vertical jumps were between 0.43 and 0.57 ($R^2 = 0.18$ to 0.33), indicating that standing jumps and running vertical jumps should not have been treated as a unique capacity (Table 2).

Significant main effects for positions were evidenced for body height (F: 56.51, $p < 0.01$, moderate ES), maximal reach height (35.34, 0.01, moderate ES), body mass (18.72, 0.01, moderate ES), and BF% (19.04, 0.01, moderate ES). First-division players were taller, heavier and had lower BF% than second division players.

Main effects for playing positions identified Centres as being the tallest, heaviest, and with the highest reach height. Playing positions differed significantly in MVJ_D (3.20, 0.04), LU_ND (3.21, 0.04), LU_D (4.48, 0.02), RSI (5.32, 0.01) and RRSA (3.98, 0.02). In general, Centres had the lowest values.

First-division Guards were heavier (t-value: 4.10, $p < 0.05$; large ES), had a lower BF% (t-value: 2.88, $p < 0.05$; moderate ES), and achieved significantly better results in the SBJ (t-value: 3.00, $p < 0.05$; moderate ES) than second-division Guards (Table 4).

Forwards involved in the first division were taller (t-value: 3.56, $p < 0.05$; large ES) and had a higher reach height (t-value: 2.84, $p < 0.05$; moderate ES) than second-division Forwards (Table 5).

First-division Centres were taller (t-value: 4.22, $p < 0.05$; large ES) and heavier (t-value: 2.56, $p < 0.05$; moderate ES) and had a higher standing reach height (t-value: 3.26, $p < 0.05$; large ES), and lower BF% (t-value: 3.08, $p < 0.05$; moderate ES) than their peers who competed in the second division (Table 6).

TABLE 3. Descriptive statistics and 2-way ANOVA effects.

	Playing position			Division		ANOVA			Effect size (Division)	
	Guards	Forwards	Centers	1st	2nd	Main effect Position	Main effect Division	Interaction Position x Division		
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	F (p)	F (p)	F (p)	d	95%CI
BH (cm)	188.23 ±5.52¥¶	197.10 ±5.09¶	201.72 ±5.26	197.38 ±7.65	191.59 ±7.53	7.85 (0.01)	56.51 (0.01)	0.10 (0.90)	0.76 (M)	0.35 /1.16
MRH (cm)	243.82 ±8.72¥¶	256.57 ±7.47¶	262.31 ±7.84	256.25 ±11.21	248.82 ±11.04	5.45 (0.02)	35.34 (0.01)	0.01 (0.99)	0.67 (M)	0.26 /1.07
BM (kg)	81.69 ±6.33¥¶	90.81 ±6.10¶	97.78 ±10.94	92.56 ±10.79	85.33 ±9.75	9.98 (0.01)	18.72 (0.01)	0.23 (0.79)	0.69 (M)	0.29 /1.10
BF% (%)	8.21 ±2.82	9.17 ±4.12	9.79 ±3.53	7.76 ±2.72	10.52 ±3.58	6.20 (0.02)	19.04 (0.01)	1.44 (0.24)	-0.87 (M)	-1.27 /-0.45
SBJ (cm)	246.9 ±19.93	248.10 ±22.37	240.58 ±23.69	251.09 ±21.4	237.9 ±20.19	1.02 (0.37)	1.76 (0.19)	0.15 (0.86)	0.63 (M)	0.23 /1.03
CMJ (cm)	46.44 ±6.00	45.53 ±5.54	43.99 ±5.52	45.51 ±5.55	45.29 ±6.13	0.26 (0.77)	3.13 (0.08)	0.52 (0.59)	0.04 (T)	-0.35 /0.43
MVJ_ND (cm)	71.04 ±8.65	71.58 ±8.68	68.03 ±8.31	68.86 ±9.67	70.38 ±7.39	1.71 (0.18)	1.64 (0.21)	0.70 (0.49)	-0.18 (S)	-0.57 /0.22
MVJ_D (cm)	78.73 ±9.61¶	75.68 ±6.08	72.53 ±8.78	75.05 ±10.1	77.44 ±7.25	3.20 (0.04)	1.66 (0.19)	0.32 (0.72)	-0.27 (S)	-0.66 /0.12
LU_ND (cm)	69.04 ±8.26¶	68.84 ±7.72	63.81 ±7.44	65.96 ±8.21	69.15 ±7.87	3.21 (0.04)	1.61 (0.20)	0.25 (0.77)	-0.39 (S)	-0.79 /0.00
LU_D (cm)	73.36 ±7.93	72.89 ±5.59	70.38 ±7.46	71.41 ±8.31	73.49 ±5.78	4.48 (0.02)	1.88 (0.17)	0.65 (0.52)	-0.28 (S)	-0.67 /0.12
RSI (index)	1.69 ±0.32¶	1.61 ±0.42	1.41 ±0.32	1.53 ±0.35	1.63 ±0.37	5.32 (0.01)	2.52 (0.12)	2.39 (0.09)	-0.28 (S)	-0.67 /0.12
RRSA (index)	1.59 ±0.41	1.72 ±0.33¶	1.43 ±0.35	1.55 ±0.39	1.61 ±0.39	3.98 (0.02)	4.45 (0.04)	0.92 (0.40)	-0.15 (T)	-0.55 /0.24

BH – body height; MRH – maximal reach height; BM – body mass; BF% - body fat percentage, SBJ – standing broad jump; CMJ – countermovement jump; MVJ_ND – maximal vertical jump non dominant leg; MVJ_D – maximal vertical jump dominant leg; LU_ND – lay-up shot jump non dominant leg; LU_D – lay-up jump dominant leg; † denotes significant ANOVA effects at $p < 0.05$, ¥ values significantly different from those observed in Forwards, ¶ values significantly different from those observed in Centers; d - magnitude-based Cohen's effect size; CI – confidence interval; (T) – trivial differences; (S) – small differences; (M) – moderate differences.

TABLE 4. Descriptive statistics and differences between first-division and second-division Guard players.

	First division Guards (n = 25)	Second division Guards (n = 24)	T test	Effect Size	
	Mean±SD	**Mean±SD**	**t value**	**d**	**95%CI**
BH (cm)	189.73±4	186.59±6.51	1.99	0.59 (S)	0.01/1.16
MRH (cm)	246.04±7.4	241.29±9.57	1.88	0.57 (S)	0.04/1.15
BM (kg)	84.79±4.89	78.14±5.99	4.10†	1.24 (L)	0.64/1.86
BF% (%)	7.14±2.58	9.44±2.63	-2.88†	-0.77 (M)	-1.35/-0.19
SBJ (cm)	254.96±16.95	239.16±19.79	3.00†	0.87 (M)	0.26/1.43
CMJ (cm)	46.87±5.37	46.02±6.63	0.49	0.14 (T)	-0.38/0.74
MVJ_ND (cm)	70.79±10.47	71.33±6.21	-0.21	-0.00 (T)	-0.56/0.56
MVJ_D (cm)	77.91±11.43	79.62±7.30	-0.58	-0.11 (T)	-0.67/0.45
LU_ND (cm)	67.67±9.12	70.62±7.03	-1.20	-0.24 (S)	-0.81/0.32
LU_D (cm)	72.61±9.46	74.19±5.95	-0.66	-0.12 (T)	-0.68/0.44
RSI (index)	1.64±0.31	1.73±0.33	-0.93	-0.28 (S)	-0.84/0.29
RRSA (index)	1.57±0.40	1.60±0.43	-0.24	-0.07 (T)	-0.63/0.49

BH – body height; MRH – maximal reach height; BM – body mass; BF% - body fat percentage; SBJ – standing broad jump; CMJ – countermovement jump; MVJ_ND – maximal vertical jump non dominant leg; MVJ_D – maximal vertical jump dominant leg; LU_ND – lay-up shot jump non dominant leg; LU_D – lay-up jump dominant leg; † denotes significant t-values at $p < 0.05$; d - magnitude-based Cohen's effect size; CI – confidence interval; (T) – trivial differences; (S) – small differences; (M) – moderate differences; (L) – large differences.

TABLE 5. Descriptive statistics and differences between first-division and second-division Forward players.

	First division Forwards (n = 11)	Second division Forwards (n = 11)	T test	Effect Size	
	Mean±SD	**Mean±SD**	**t value**	**d**	**95%CI**
BH (cm)	200.09±2.80	193.80±5.07	3.56†	1.45 (L)	0.52/2.39
MRH (cm)	260.36±6.12	252.40±6.75	2.84†	1.19 (M)	0.28/2.09
BM (kg)	92.00±3.82	89.50±7.92	0.94	0.40 (S)	-0.46/1.23
BF% (%)	7.61±3.55	10.90±4.19	-1.85	-0.81 (M)	-1.68/0.05
SBJ (cm)	256.09±20.81	239.3±21.61	1.81	0.76 (M)	-0.11/1.63
CMJ (cm)	46.45±5.33	44.52±5.88	0.79	0.33 (S)	-0.51/1.17
MVJ_ND (cm)	70.73±8.56	72.75±9.30	-0.49	-0.24 (S)	-1.06/0.62
MVJ_D (cm)	74.36±6.86	77.50±4.63	-1.12	-0.56 (S)	-1.37/0.33
LU_ND (cm)	67.45±7.09	70.75±8.61	-0.91	-0.40 (S)	-1.25/0.44
LU_D (cm)	71.36±6.39	75.00±3.63	-1.44	-0.67 (M)	-1.53/0.19
RSI (index)	1.47±0.46	1.76±0.32	-1.64	-0.70 (M)	-1.57/0.16
RRSA (index)	1.64±0.36	1.83±0.26	-1.27	-0.60 (S)	-1.44/0.27

BH – body height; MRH – maximal reach height; BM – body mass; BF% - body fat percentage, SBJ – standing broad jump; CMJ – countermovement jump; MVJ_ND – maximal vertical jump non dominant leg; MVJ_D – maximal vertical jump dominant leg; LU_ND – lay-up shot jump non dominant leg; LU_D – lay-up jump dominant leg; † denotes significant t-values at $p < 0.05$; d - magnitude-based Cohen's effect size; CI – confidence interval; (S) – small differences; (M) – moderate differences; (L) – large differences.

TABLE 6. Descriptive statistics and differences between first-division and second-division Centre players.

Centers	First division Centers (n = 22)	Second division Centers (n = 17)	T test	Effect Size	
	Mean±SD	Mean±SD	t value	d	95%CI
BH (cm)	204.07±4.13	197.86±4.67	4.22†	1.38 (L)	0.67/2.08
MRH (cm)	265.32±6.58	257.57±7.49	3.26†	1.13 (M)	0.44/1.80
BM (kg)	101.32±11.31	92.60±8.23	2.56†	0.85 (M)	0.19/1.51
BF% (%)	8.46±2.39	11.74±4.08	-3.08†	-1.04 (M)	-1.66/-0.32
SBJ (cm)	244.36±24.96	234.64±21.04	1.21	0.43 (S)	-0.23/1.05
CMJ (cm)	43.65±5.55	44.54±5.64	-0.47	-0.16 (T)	-0.79/0.48
MVJ_ND (cm)	65.82±8.87	66.50±7.35	-0.21	-0.09 (T)	-0.71/0.55
MVJ_D (cm)	72.41±9.57	72.80±7.19	-0.11	-0.05 (T)	-0.68/0.59
LU_ND (cm)	63.36±7.29	64.80±8.08	-0.50	-0.11 (T)	-0.74/0.53
LU_D (cm)	70.18±8.04	70.80±6.37	-0.21	-0.09 (T)	-0.72/0.55
RSI (index)	1.44±0.31	1.37±0.35	0.56	0.21 (S)	-0.43/0.84
RRSA (index)	1.47±0.40	1.36±0.23	0.82	0.32 (S)	-0.32/0.96

BH – body height; MRH – maximal reach height; BM – body mass; BF% - body fat percentage, SBJ – standing broad jump; CMJ – countermovement jump; MVJ_ND – maximal vertical jump non dominant leg; MVJ_D – maximal vertical jump dominant leg; LU_ND – lay-up shot jump non dominant leg; LU_D – lay-up jump dominant leg; † denotes significant t-values at $p < 0.05$; d - magnitude-based Cohen's effect size; CI – confidence interval; (T) – trivial differences; (S) – small differences; (M) – moderate differences; (L) – large differences.

DISCUSSION

The main aims of the study were to determine the reliability and discriminative validity of jumping tests in defining positional differences and performance level differences in high-level basketball. There are several important findings we will discuss in the following text. First, the jumping tests we studied were highly reliable. Moreover, playing positions did not differ in standing jumps, but running jump tests, RSI and RRSA were found to be valid measures of position-specific jumping tasks. Finally, we found small differences in the studied jumping capacities between playing levels.

Reliability and inter-correlations of jumping tests

Previous studies have already reported on the reliability of jumping tests in basketball players [28-30]. Generally, different methodological approaches have been applied, but the reliability of the tests have been reported to be very good to high, with a CV ranging from 3 to 4% [28], Cronbach's alpha of >0.90 [30], and test-retest correlation of 0.98 [29]. Therefore, our results on the adequate reliability of the CMJ and broad jump in basketball players are consistent with previous studies.

To the best of our knowledge, this is the first study analysing the reliability of running vertical jumps in basketball. Previous studies which examined similar tests in other sports (e.g. volleyball) documented similar reliability of sport-specific running vertical jumps (CV of 3-4% and 2.8% for basketball running vertical jumps and spike jump, respectively) [11, 31]. The appropriate reliability is particularly important as running jump tests are more complex than jumps performed from a standing position. As the complexity increases, the possibility of inappropriate technique, the occurrence of non-systematic error in test execution and altered reliability in running jumps is more probable [32].

The correlations between jumping tests indicated the relative independence of the standing and running jump tests. A previous study conducted in volleyball noted a correlation of 0.75 between spike jump (i.e., an attack jump) and CMJ in male players [11]. Because our results showed a lower association between running jumps and standing jumps than the study conducted in volleyball players, it seems that it is not only the "type of approach" (i.e., standing vs. running) that is a factor that distinguishes performance between different types of jumps. Most likely, the type of take-off (1-legged in basketball vs. 2-legged in volleyball) is also a factor that defines the specific jumping performance to some extent.

Playing position differences

Our results highlighted the discriminative validity of running jumps in differentiating playing positions in basketball. Surprisingly, there is a limited number of investigations that have focused on running jumps in basketball. In one of the few studies that have investigated this issue Miura et al. accentuated the importance of running jumps in basketball and reported determinants of such capacities in Japanese university-level players [7]. Therefore, the considerably better achievement of our players in lay-up shot jump (approximately < 60 and 70 cm in Japanese and our players, respectively) is a natural consequence of the difference in performance levels (i.e. university level players and professional players) [7]. Meanwhile, to the best of our knowledge no study has examined running jump performances for different playing levels in basketball.

Our results showing non-significant differences between playing positions in SBJ and CMJ support previous studies that reported no significant differences among playing positions in standing jumps in high-level basketball players [1, 13]. Meanwhile, we found significant differences among playing positions for almost all of the applied running jump tests. Altogether, (i) non-significant differences in standing jumps, and (ii) significant differences in running vertical jumps among playing positions supported our initial belief of position-specific jumping capacity in basketball. In explaining such differences among positions for running jumps (e.g. Guards are most successful, followed by Forwards), a short overview of jumping biomechanics is needed.

As with any other type of jump, including running vertical jumps, during the take-off phase, the athlete exerts a force that determines the maximum height that the centre of mass (COM) will reach after leaving the ground. During the take-off phase, the take-off leg pushes down on the ground, and in reaction, the ground pushes up on the body through the take-off leg. The run-up serves as a preparation for the take-off. The higher velocity of the run-up means a greater leg force and consequently a greater ground reaction force. Theoretically, a higher horizontal velocity (i.e., a fast approach run) should positively influence the maximal height of the COM (i.e., jump height), but this holds true only if the horizontal velocity is effectively transformed into vertical velocity (i.e., because of the necessity of the vertical displacement). However, this transformation is possible only if the leg extensor muscles provide sufficient force to resist the flexion of the leg due to the forward momentum of the athlete, and the momentum is also dependent on body mass ($p = m \times v$). [33, 34].

The heavier the body, the longer is the time (and/or greater force) needed to resist the forward momentum [34, 35]. Consequently, the superior running jump performance of the Guards and Forwards (lighter players) over Centres (heavier players) can be observed as a consequence of their lower body mass. This is naturally reflected even in RSI, where body mass is also a factor influencing performance.

The Forwards achieved the best results in RRSA, as a measure of repeated jumping ability. This study is one of the first to report such a finding, but it seems that of all of the playing positions, Forwards were the most capable of repeatedly shifting between eccentric and concentric contraction performance (i.e., they achieved numerically better results than even the Guards, with no significant post-hoc difference). This ability allowed them to maintain a high ratio between height reached and contact time throughout repeated bouts of eccentric-to-concentric contractions. The possible physiological and/or biomechanical bases of these findings exceeds the experimental design of this investigation but should be studied in detail in future investigations.

Playing-level differences

While practically all studies conducted so far have examined standing jumps and compared playing levels in the total sample (i.e., regardless of their playing position), this study extends previous knowledge by examining the possible differences in running jumps and comparing playing level with regard to position in basketball [12, 13]. As a result, significant differences between the first and second division players were found for Guards and only for SBJ performance. Therefore, we may conclude that the results of the previous studies when the authors evidenced significant differences between performance levels in standing jumps are probably a consequence of the significant differences between Guards of different playing levels [13].

The Centres of two performance levels did not differ significantly in jumping capacities. However, it must be noted that anthropometric indices (i.e., height and reach height) are also important with regard to their specific game duties [21]. In our study, the first-division Centres were 6.5 cm taller than their second-division peers, and this certainly assures them achieve superior real-game performance, including in jumping (regardless of the similar jumping performance, first-division Centres are able to reach the ball at a higher point). It is also important to note that the first-division Centres were almost 9 kg heavier and had 3% less body fat than their second-division peers. Because of the contact nature of their game, advanced lean body mass allows Centres superior positioning, which additionally improves real-game achievements in all duties where they have to perform jumps [19, 21].

Because of the numerous in-game situations such as jump-shooting, blocking opponents' shots, and rebounding efficacy, body length plays an important role in the real-game efficacy of Forwards [19, 21]. The first-division Forwards were on average 6 cm taller and reached 17.8 cm higher than their peers involved in the second division. Therefore, and as previously discussed for Centres, the higher maximal reach height almost certainly defines better real-game jumping performance regardless of the similar jumping performances for the two playing levels. Meanwhile, forwards are not as oriented towards physical contact as Centres, and therefore the non-significant differences in body mass and BF% between the Forwards involved at two performance levels were not surprising.

Limitations and strengths of the study

This study was performed in a country with a long tradition of basketball. Therefore, the generalizability of the results is somewhat limited, especially for those countries with different performance levels than those observed herein (i.e. first-division vs. second-division players) Another limitation of this study is related to the unequal number of subjects in each position (i.e., we reported on twice as many Centres and Guards as Forwards). However, this is a logical consequence of the number of players in each position in a basketball team, while we tried to reduce the influence of this limitation by observing not only the statistical significance of the calculated parameters (i.e., we also calculated effect size). Meanwhile, to the best of our knowledge, this is the first study that has reported performance level differences in jumping capacities for each of three playing positions in basketball while observing high-level seniors. Therefore, although we are aware that our findings are not the final results to be reported on this topic, we believe that they have contributed to the knowledge in the field.

Practical applications

Coaches working with basketball players should be informed of the applicability of evaluated testing protocols in defining jumping performances in basketball with regard to position-specific and performance-level differences.

Position-specific basketball jumping performance should be evaluated by running vertical jumps, reactive strength index, and tests consisting of repeated jumping performance. Running vertical jumps and the reactive strength index (i.e., the ratio between drop jump height and contact time) were valid in discriminating between backcourt players (i.e., Guards) and Centres. Meanwhile, tests of repeated jumping ability were found to be a valid measure to distinguish between Forwards and Centres.

The first-division Guards achieved better results in broad jump performance than the second-division Guards. Therefore, this test should be used to identify characteristic jumping performance (i.e., horizontal displacement performance) for this position in basketball.

Standing vertical jumps and running vertical jumps were relatively independent conditioning capacities. Professionals working in this sport should accordingly be informed of this finding. To objectively evaluate both capacities, separate testing of both is crucial.

CONCLUSIONS

To determine real-game basketball jumping performance, the maximal reach height achieved in vertical jumps should be recorded. Namely, the vertical displacement of the COM (i.e., jump height) was found to be similar across playing levels of basketball players (i.e., first division vs. second division), but differences in the anthropometrics between the players competing at the two levels were evident (i.e., first-division players were taller and had a higher maximal reach height). Naturally, it directly results in higher jumping reach height and consequent superior real-game jumping performance of the first-division players, regardless of the non-significant differences in measured jumping performances between playing levels.

Conflict of interest statement

The authors declare that they have no conflict of interest with reference to this paper.

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