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Anthropometric, Physiological, and Neuromuscular Profiles of Elite Female Basketball Players Across Court's Position

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Abstract

Purpose Basketball is a high-intensity team sport that requires speed and multidirectional movements, in addition to robustly training energy systems. Thus, this study aims to provide descriptive data on the physical, physiological, and neuromuscular characteristics in elite female basketball players according to athletes' positions on the court.

Methods Eighteen elite female athletes (25.7 ± 4.4 years old) from the elite Brazilian female basketball team participated in this study. On the first day, multiple laboratory and field tests were performed during a training camp, including body composition, vertical jumps, isokinetic strength, and running cardiopulmonary exercise testing (CPET). On the subsequent day, a repeated-sprint ability test was performed on an official basketball court. One-way ANOVA followed by post hoc tests was used for statistical analysis. The significance level was set for the $P < 0.05$ for all analyses.

Results There were significant differences in the physical and performance characteristics between positions. Centers, relative to guards and forwards, were significantly ($P \leq 0.03$ for all) heavier (17%–25%), taller (6%–12%), had greater fat percentage (22%–28%), lower VO_{2max} (21%–26%), higher quadriceps peak torque (17%–30%), lower jump height (27%–58%), less peak force (15%–48%), and lower speed (peak and acceleration) in the repeated sprints.

Conclusion Overall, physical capacities were able to discriminate athletes' court positions in elite female basketball, as many variables regarding body composition, cardiorespiratory fitness, neuromuscular and repeated-sprint performance displayed medium-to-large effects size. In general, Guards showed to be lighter, shorter, and fitter than their counterparts. Moreover, they presented better neuromuscular performance (isokinetic knee strength, jump, and repeated-sprint ability performance).

Keywords Body composition · Strength · Team sport · Athletic performance

Introduction

Basketball is a high-intensity team sport that requires alternate speed sprints or change of direction movements, occuring every 7 s and lasting approximately 10–30 s [18, 31]. Despite an athlete's role or team position, players may engage in significantly different intensities and movements throughout the match [24, 25]. Therefore, elite basketball players must develop multiple physical characteristics

to reach a high level of performance on the court and to endure neuromuscular fatigue throughout the season [19, 24]. Undoubtedly, players' body mass plays a role in their court performance. For example, Ferioli et al. [8] found that adverse changes in body weight throughout a 21-week collegiate women's basketball season significantly was associated with increased neuromuscular fatigue [8]. In the same study, the authors found that minimal changes in body mass led to increased preseason maximal oxygen consumption (VO_{2max}). Moreover, athletes with more power can better withstand fatigue than those experiencing large changes in weight and low VO_{2max} [24].

Jogging (551 ± 67 actions) is the most frequent action among elite female basketball players during the match, followed by stand/walk (436 ± 44 actions). Conversely, players spend a similar amount of time during the entire match in jogging (865 ± 40 s) and standing/walking (869 ± 48 s) [26]. Typically, basketball players keep the exercise intensity above 80% of

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their maximal heart rate and around 3–8 mmol/L of lactate concentration [17, 23, 26]. Additionally, the oxygen uptake (VO$_2$) achieved during a match was about 67% of their maximal aerobic power (VO$_{2max}$; 50.3 ± 5.9 mL/kg/min) [20].

Other important physical attributes of basketball players are strength, power, and change of direction ability [19]. Alterations in strength and power can indicate fatigue, assessed via countermovement jump (CMJ) tests, which is key in an intermittent sport like basketball [9, 31, 33]. Furthermore, previous research suggests that aerobic capacity is closely linked to CMJ performance throughout a full season in division I female basketball athletes [24]. Athletes with greater preseason VO$_{2max}$ exhibited minimal changes in CMJ power, and these minimal changes in power were associated with less fluctuations in body weight during the season [24]. While strength, power, and the ability to change direction quickly are of paramount importance, it is reasonable to suggest that athletes should also optimize body composition and aerobic capacity. These factors contribute to sustained power output during a long season, as an optimal aerobic capacity can improve power recovery or phosphocreatine replenishment, which are valuable for repeated-sprint ability [12].

Although many studies have expanded the knowledge of the fitness testing in basketball players [10, 21, 33], to our knowledge, there are no studies that provided a comprehensive evaluation of the physical and performance testing capacities of elite female basketball players. Furthermore, there is a dearth of information regarding reference values for such fitness variables, including body composition, aerobic capacity, change of direction, particularly among elite female athletes. Finally, it is essential for coaches and practitioners to have these data, especially for athletes who newly joined a team and lack previous follow-up regarding physical fitness.

Thus, this study aims to provide descriptive data about physical, physiological, and neuromuscular characteristics in elite female basketball players according to athletes' positions on the court.

Materials and Methods

Sample

Eighteen female athletes from the Brazilian female basketball squad (25.7 ± 4.4 years) participated in this study. This team is ranked 13th in the FIBA world ranking and has 9–15 years of training experience. All athletes were enrolled in an elite training regimen consisting of 2–4 weekly strength and conditioning sessions and 6–10 on-court sessions. Before the experiment, all participants were fully informed about the testing procedures and their related risks. All athletes provided their written informed consent. The study was approved by the local research ethics committee (number: 96949518.1.0000.5279) following the Declaration of Helsinki (revision of 2013).

Testing Procedures

The laboratory and field tests were performed during a training camp for the Women's pre-qualifying tournament Ameri-Cup (2019) for the Tokyo 2020 Olympic Games.

Body composition, vertical jumps, isokinetic, and running cardiopulmonary exercise testing (CPET) were performed on the first day. A minimal rest period of 10 minutes was provided between vertical jumps tests and isokinetic assessments, and a 30-min rest was implemented between isokinetic and CPET. On the second day, a repeated-sprint ability test was performed on an official basketball court.

Anthropometry and Body Composition

Body mass (Welmy W200, Santa Bárbara d'Oeste, SP, Brazil), height (Sanny 2020, São Bernardo do Campo, SP, Brazil), and subcutaneous skinfolds (Lange skinfold caliper, Cambridge Scientific Industries, Inc., Cambridge, USA) were obtained using standardized procedures [2]. Skinfold measurements (triceps, suprailiac, and thigh) were taken in duplicat, the measurements were retested if discrepancies exceeded 5%. Additional measurements were performed in such case, and the mean of the two closest values was used for analysis. Body density was estimated using the three-site skinfold Jackson & Pollock's equation for women [15]. The body-fat percentage was calculated using Siri's equation [28]. Fat-free mass (FFM) was calculated as the difference between total body weight and body fat (kg).

Vertical Jump Tests

Before the vertical jump assessment, athletes performed a free warm-up comprising light–moderate-intensity cycling and static and dynamic stretch. Next, they performed a specific warm-up and familiarization set of jumps consisting of several submaximal squats and countermovement jumps on the force plate. For the Squat Jump (SJ), athletes were instructed to begin around a 90° knee angle with hands held on hips. At the signal of the evaluator ("Ready, Go!"), the athlete was required tp perform the maximal force agains the ground without a downward movement and maintain their hands on their hips. For the Countermovement Jump (CMJ), athletes started in an upright standing position with hands placed on their hips. At the signal of the evaluator ("Ready, Go!"), athletes performed the fastest eccentric downward movement up to around 90° knee angle, followed by a maximal concentric upward movement. For Countermovement Jump with Arms (CMJa), athletes followed the same procedures as CMJ, except for arms, in which athletes were

instructed to start around 90° of shoulder flexion and move the arms simultaneously with the downward and upward movements of their legs.

Athletes performed three repetitions of each jump type (i.e., SJ, CMJ, and CMJa) with a 60 s rest between jumps, following the order SJ, CMJ, and CMJa, in an alternate way. The ground reaction force (GRF) signals were acquired from two force plates (model 9286B, Kistler™ Systems, Switzerland) and digitalized (Digital data Acquisition System 5691A, 24 bits, 1 kHz, Kistler Systems, Switzerland). Initially, a 2nd-order low-pass Butterworth filter (100 Hz) was applied to the GRF signals in direct and reverse directions to avoid phase distortions. Subsequently, the subject's body weight was substracted from the GRF signals. For all three types of jumps, peak force (PF) and impulse were normalized by the subject's weight (PF; N/BM, Impulse; N·s/BM). Impulse was calculated by numerical integration of GRF signal over time. Jump height was obtained using flight time, as follows: $JH = 9.80665 \cdot \left(\frac{\text{Flight Time}^2}{8} \right) \cdot 100$. It was chosen to estimate JH by flight time, since many sports centers use flight time-based instruments as contact mats. Finally, the Elastic Index (EI) was calculated in three ways as follows [4]:

$$EI = (CMJ \text{ height(cm)} - SJ \text{ height(cm)}/SJ \text{ height(cm)}) \times 100, \tag{1}$$

$$EI = (CMJa \text{ height(cm)} - CMJ \text{ height(cm)}/CMJ \text{ height(cm)}) \times 100, \tag{2}$$

$$EI = (CMJa \text{ height(cm)} - SJ \text{ height(cm)}/SJ \text{ height(cm)}) \times 100. \tag{3}$$

Isokinetic Assessment

Before isokinetic testing, the subjects cycled for a 5-min warm-up between 60 and 70 rpm (Wattbike Pro, Nottingham, UK). The knee extensor and flexor torque were measured using the Biodex System 4 PRO dynamometer (Biodex Medical Systems, New York, NY, USA). After the warm-up, the participants were seated on the chair and prepared for the test using straps on the upper body, hip, and thigh. Gravity correction was applied at 30° knee flexion after directly measuring the lower limb lever arm system's mass. The range of motion (ROM) varied from individual full flexion to full extension (considering 0° as a complete extension). The test protocol consisted of five submaximal concentric contractions of the tested muscles at the maximal angular speed of 60°/s to familiarize the participants with the procedures. Then, five maximal repetitions at 60°/s were performed in the concentric-concentric mode. The strength of knee extensors and flexors muscles was expressed as peak torque relative to body mass (N·m/kg). Afterward, the hamstring-to-quadriceps ratio (H/Q, expressed in percentage) was calculated for both limbs.

Running Maximal Cardiopulmonary Exercise Test

The Cardiopulmonary Exercise Test (CPET) was performed on a treadmill (Pulsar h/p/cosmos, Germany). The initial speed was fixed at 7 km/h, and the final speed was programmed to reach 15 km/h at 10 min of the test. However, the test was kept until the participant's volitional fatigue. The grade was set at 1% throughout the test. The metabolic cart Quark CPET (Cosmed, Rome, Italy) was used to continuously collect the cardiorespiratory variables [VO_2 (oxygen uptake), VCO_2 (carbon dioxide production), VE (minute ventilation), and heart rate (HR)]. Breath-by-breath data points were subjected to a smoothing process of 15 data points [22] and then averaged over 20-s intervals to avoid respiratory frequency bias for ventilatory thresholds (VTs) determination. Two experienced evaluators determined VT_1 and VT_2 by visual inspection following the ventilatory equivalent method [3]. If the two evaluators disagreed on the VT's determination in a blinded way, they reexamined the data together to provide a final decision. The equipment was calibrated per the manufacturer's instructions for the known gas mixture (16.00% O_2 and 5.00% CO_2) and flow before each test.

Repeated-Sprint Test

The repeated-sprint test was employed in 13 athletes to assess their anaerobic capacity. The test comprised 10×30-m sprints (15-m shuttle run) as quickly as possible, interspersed by 30 s of recovery. A timing system (Brower Timing System TC, Draper, USA) was used to record the time for each trial. The athletes assumed a standing position waiting for a sound signal from the evaluator ("Ready, Go!") before sprinting back to the "starting/finishing" photogate. Two additional photogates were placed 5 and 15 m from the starting line. The initial split time (5 m) and the overall time for each trial were recorded. Average acceleration (first 5 m), peak speed (m/s), total time (s), and decrement score (S_{dec}) were calculated, comprising all ten trials. S_{dec} was calculated as follows [11]:

$$S_{dec}(\%) = 1 - \left(\frac{\text{sum of trials time(s)}}{\text{best trial(s)} \times 10} \right).$$

The repeated-sprint test was performed 24 h after the laboratory tests (i.e., vertical jumps, isokinetic, and CPET).

Tables 1, 2, 3, 4 and 5 provide descriptive (mean ± standard deviation) and statistical (P posttest and effect size [Hedge-g]) comparisons between groups (players' position) for all tests performed.

Table 1 Anthropometric and body composition variables across courts' positions

Variable	Guards (n=4)	Forwards (n=11)	Centers (n=3)	ANOVA F	ANOVA P	ANOVA η²	G vs. F P	G vs. F g	F vs. C P	F vs. C g	G vs. C P	G vs. C g
Body mass (kg)	65.9±7.7 [60.2–78.2]	74.5±7.3 [66.2–82.4]	92.3±11.0 [78.1–99.8]	7.06	**0.01**	0.48	0.32	0.95	**0.02**	1.95	**0.01**	2.46
Height (cm)	166.0±3.7 [163.0–171.9]	178.5±4.7 [174.2–181.0]	190.0±1.8 [187.0–190.1]	24.7	**<0.01**	0.77	**<0.01**	2.58	**<0.01**	2.51	**<0.001**	7.19
Fat-free mass (kg)	54.3±4.9 [48.5–58.4]	57.0±3.6 [52.3–61.6]	60.3±3.6 [56.1–64.3]	2.27	0.14	0.23	0.58	0.80	0.68	0.88	0.15	1.40
Sum skinfold (mm)	43.5±15.1 [32.0–65.0]	50.0±10.7 [43.0–63.0]	73.0±14.6 [52.0–80.0]	3.22	0.07	0.30	0.99	0.38	0.12	1.56	0.09	1.50
%Fat (%)	18.2±5.2 [14.1–25.6]	20.9±3.7 [17.8–24.7]	28.7±4.7 [21.1–29.8]	3.14	0.07	0.30	0.99	0.40	0.13	1.53	0.09	1.51

The Bonferroni test and Hedge's g effect size columns comprise G vs. F, F vs. C, and G vs. C.

Data presented as median ± standard deviation and median 95% confidence interval. Bold denotes statistical significance ($P < 0.05$)

G Guards, F Forwards, C Centers, %Fat fat mass percentage, η^2 partial ETA squared

Table 2 Cardiopulmonary variables from incremental test across courts' positions

Variable	Guards (n=4)	Forwards (n=11)	Centers (n=2)	ANOVA F	ANOVA P	ANOVA η²	G vs. F P	G vs. F g	F vs. C P	F vs. C g	G vs. C P	G vs. C g
VO_{2max} (mL/kg/min)	47.4±3.4 [42.9–51.0]	45.3±3.7 [41.1–47.9]	37.4±1.9 [36.0–38.7]	5.33	**0.02**	0.45	0.97	0.95	**0.04**	1.95	**0.02**	2.46
HR_{max} (beats/min)	187±7 [181–194]	182±8 [173–189]	184±1 [183–184]	0.13	0.35	0.15	0.47	2.58	0.99	2.51	0.99	7.19
vVO_{2max} (km/h)	16.2±0.6 [15.7–16.7]	15.2±1.6 [13.0–16.3]	13.4±0.0 [13.4–13.4]	2.98	0.09	0.32	0.40	0.80	0.51	0.88	0.10	1.40
VO_2 at VT_1 (%)	59.7±6.2 [55.7–69.9]	65.2±6.2 [61.3–68.1]	76.8±3.4 [74.2–79.4]	4.39	**0.03**	0.40	0.57	0.38	0.13	1.56	**0.03**	1.50
HR at VT_1 (%)	75.1±7.2 [66.1–81.3]	74.9±5.8 [71.7–79.5]	83.1±5.5 [79.2–87.0]	1.51	0.26	0.18	0.99	0.40	0.40	1.53	0.37	1.51
Velocity at VT_1 (%)	51.9±4.7 [49.7–59.9]	58.9±5.2 [54.8–62.7]	63.8±1.6 [62.7–64.9]	3.31	0.07	0.34	0.27	0.65	0.59	1.44	0.08	2.54
VO_2 at VT_2 (%)	96.5±5.6 [85.5–97.7]	93.6±3.6 [86.7–96.4]	96.7±2.0 [95.3–98.1]	0.84	0.45	0.11	0.99	0.33	0.69	1.14	0.99	0.52
HR at VT_2 (%)	97.4±3.0 [91.7–97.9]	94.6±2.9 [92.6–97.4]	95.6±1.6 [94.5–96.7]	0.51	0.61	0.07	0.99	0.55	0.99	0.40	0.99	0.18
Velocity at VT_2 (%)	97.4±3.0 [91.7–97.9]	84.4±1.5 [82.8–92.3]	87.3±0.0 [87.3–87.3]	7.72	**0.01**	0.54	**0.01**	4.96	0.99	0.54	0.09	3.44

The Hedge's g effect size columns comprise G vs. F, F vs. C, and G vs. C.

Data presented as median ± standard deviation and median 95% confidence interval. Bold denotes statistical significance ($P < 0.05$)

G guards, F Forwards, C Centers, VO_{2max} maximal oxygen consumption, HR_{max} maximal heart rate, vVO_{2max} velocity attained at maximal oxygen consumption, VO_2 at VT_1 oxygen consumption at the first ventilatory threshold, HR at VT_1 heart rate at the first ventilatory threshold, VO_2 at VT_2 oxygen consumption at the second ventilatory threshold, HR at VT_2 heart rate at the second ventilatory threshold, η^2 partial ETA squared

Table 3 Knee isokinetic strength variables across courts' positions

Variable	Guards (n=3)	Forwards (n=10)	Centers (n=3)	ANOVA			Hedge's g effect size					
							G vs. F		F vs. C		G vs. C	
				F	P	η^2	P	g	P	g	P	g
Peak torque extension D (N·m/kg)	3.3±0.2 [3.2–3.6]	3.0±0.3 [2.8–3.5]	2.5±0.5 [2.3–3.3]	2.96	0.09	0.31	0.97	0.75	0.24	1.19	0.10	1.79
Peak torque extension ND (N·m/kg)	3.1±0.2 [3.0–3.4]	2.8±0.4 [2.3–3.1]	2.3±0.2 [2.2–2.6]	5.39	**0.02**	0.45	0.16	1.34	0.22	1.22	**0.02**	3.97
Peak torque flexion D (N·mkg)	1.8±0.1 [1.6–1.8]	1.6±0.2 [1.5–1.8]	1.5±0.2 [1.3–1.6]	2.32	0.14	0.26	0.99	0.63	0.36	1.03	0.17	2.05
Peak torque flexion ND (N·mkg)	1.8±0.1 [1.6–1.8]	1.5±0.3 [1.3–1.9]	1.5±0.2 [1.1–1.5]	1.79	0.21	0.22	0.97	0.66	0.65	0.80	0.25	2.27
H/Q D (%)	51.2±1.3 [50.2–52.8]	52.2±8.2 [52.8–60.8]	54.2±7.9 [47.4–63.2]	0.17	0.85	0.03	0.99	0.19	0.99	0.26	0.99	0.62
H/Q ND (%)	53.6±2.3 [52.1–56.5]	57.4±9.1 [45.2–68.6]	65.5±13.2 [44.0–68.1]	0.24	0.79	0.04	0.99	0.40	0.99	0.18	0.99	0.54

Data presented as median ± standard deviation and median 95% confidence interval. Bold denotes statistical significance ($P < 0.05$)

G Guards, F Forwards, C Centers, D dominant limb, ND non-dominant limb, H/Q hamstrings to quadriceps ratio, η^2 partial ETA squared

Statistical Analysis

Descriptive statistics (means and standard deviations) were calculated to summarize the test results for all athletes and then reported as different positions group (team position, e.g., guards, forwards, centers). Then, a one-way ANOVA was utilized for each test result to establish any main effects according players' positions. The Bonferroni post hoc analysis was utilized if a main effect of position was identified. Hedge's g (for comparison between groups) and partial ETA squared (for ANOVA) were utilized for interpretation of effect sizes, classified as 'Small (S)' (< 0.20), 'Medium (M)' (0.21–0.50), and 'Large (L)' (≥ 0.50). All statistical analyses and graphics were performed using the GraphPad Prism software (GraphPad Software, San Diego, CA, version 9.3.1).

Results

Table 1 depicts the body composition variables across each court position. Centers weighed significantly more ($F = 7.06$, $P = 0.01$, $\eta^2 = 0.48$ [M]) and were taller ($F = 24.7$ $P < 0.0001$, $\eta^2 = 0.77$ [L]) than the other groups. Fat-free mass was similar among players' positions ($F = 2.27$, $P = 0.14$, $\eta^2 = 0.23$ [M]).

Table 2 shows data regarding the running cardiopulmonary exercise testing. Centers had significantly lower VO_{2max} ($P = 0.02$), but similar HR_{max} ($F = 0.13$, $P = 0.35$, $\eta^2 = 0.15$ [S]) and vVO_{2max} ($F = 0.13$, $P = 0.35$, $\eta^2 = 0.32$ [M]) compared to the other groups. Also, Centers' ventilatory threshold 1 was achieved in a higher fraction of VO_{2max} (~80%) and was associated with VO_{2max} ($F = 4.39$, $P = 0.03$, $\eta^2 = 0.40$ [M]) compared to Guards. VO_2 at ventilatory threshold 2 was achieved in a higher fraction of VO_{2max} (~90%) for most players, regardless of position. Moreover, guards showed higher velocity at VT_2 (%max) compared to centers ($F = 7.72$, $P = 0.01$, $\eta^2 = 0.54$ [L]).

Table 3 presents the isokinetic strength results. Regarding normalized torque values in knee extensors, centres showed lower mean values than the other groups, regardless of leg dominance ($F = 5.39$, $P = 0.0.02$, $\eta^2 = 0.45$ [M]). Instead, knee flexors appeared similar among players' positions for dominant ($F = 2.32$, $P = 0.14$, $\eta^2 = 0.26$ [M]) and non-dominant ($F = 1.79$, $P = 0.21$, $\eta^2 = 0.22$ [M]) sides. Regarding the H/Q ratio, all groups presented similar values, regardless of limb side.

Table 4 illustrates the data for the three jumps performed (SJ, CMJ and CMJa). In general, centers presented lower jump high, take-off speed, peak force, and power for all jumps (see Table 4 for details), while guards and forwards presented similar results with low variability. The analysis of elastic indexes revealed high variability among player positions, centers seem to make better use of the muscle elasticity. However, these differences did not reach

Table 4 Vertical jump variables by courts' positions

Variable	Guards (n=4)	Forwards (n=10)	Centers (n=3)	ANOVA F	P	η²	G vs. F P	G vs. F g	F vs. C P	F vs. C g	G vs. C P	G vs. C g
Height SJ (cm)	29.2±4.9 [28.3–38.8]	28.1±2.1 [27.2–30.1]	19.4±1.1 [19.3–21.2]	7.06	**0.01**	0.67	0.22	1.06	**<0.01**	4.18	**<0.01**	2.93
Take-off SJ (m/s)	2.4±0.2 [2.4–2.8]	2.4±0.1 [2.4–2.5]	2.0±0.1 [2.0–2.1]	17.72	**<0.001**	0.70	0.25	1.05	**<0.01**	4.30	**<0.01**	3.29
Peak force SJ (N)	1.3±0.3 [1.3–1.8]	1.2±0.2 [1.0–1.4]	0.9±0.1 [0.9–1.1]	4.85	**0.03**	0.41	0.38	0.92	**0.02**	1.65	**0.02**	2.03
Peak power SJ (W)	2.7±0.7 [2.6–3.9]	2.6±0.3 [2.1–2.9]	1.7±0.2 [1.6–1.9]	8.34	**<0.001**	0.54	0.29	0.99	**0.02**	2.64	**<0.01**	2.49
Height CMJ (cm)	29.4±3.7 [27.9–36.1]	29.0±2.9 [26.2–31.9]	23.1±3.0 [19.0–24.8]	7.11	**0.01**	0.50	0.99	0.47	**0.01**	2.35	**0.01**	2.44
Take-off CMJ (m/s)	2.4±0.1 [2.4–2.7]	2.4±0.1 [2.3–2.6]	2.2±0.1 [2.0–2.3]	7.70	**0.01**	0.53	0.99	0.46	**0.01**	2.41	**0.01**	2.49
Peak force CMJ (N)	1.5±0.3 [1.2–1.8]	1.3±0.2 [1.1–1.7]	±0.2 [0.9–1.2]	2.18	0.15	0.24	0.99	0.57	0.45	1.05	0.17	1.57
Peak power CMJ (W)	2.5±0.5 [2.1–3.2]	2.3±0.4 [2.0–2.7]	1.7±0.1 [1.6–1.7]	5.49	**0.02**	0.44	0.99	048	**0.04**	2.10	**0.02**	2.34
Height CMJa (cm)	35.5±2.7 [33.2–39.7]	32.6±5.2 [30.1–37.0]	26.6±2.1 [25.0–29.1]	4.06	**0.04**	0.37	0.99	0.39	0.08	1.51	0.05	3.66
Take-off CMJa (m/s)	2.7±0.1 [2.6–2.8]	2.6±0.2 [2.5–2.8]	2.3±0.1 [2.3–2.4]	4.68	**0.03**	0.40	0.99	0.41	0.05	1.62	**0.04**	3.67
Peak force CMJa (N)	1.4±0.4 [1.2–2.2]	1.4±0.2 [1.1–1.5]	1.2±0.2 [1.0–1.4]	1.63	0.23	0.19	0.98	0.59	0.78	1.14	0.28	0.96
Peak power CMJa (W)	3.2±0.7 [2.7–4.3]	2.9±0.5 [2.5–3.5]	2.3±0.5 [2.0–2.9]	2.70	0.10	0.28	0.99	0.58	0.30	1.26	0.11	1.61
CMJ/SJ (%)	−3.1±5.4 [−6.8–5.8]	3.1±7.4 [−3.6–12.1]	16.8±11.8 [−2.2–19.3]	2.42	0.13	0.26	0.72	0.82	0.51	0.89	0.14	1.54
CMJa/CMJ (%)	18.6±5.8 [9.8–23.7]	17.9±9.0 [7.9–21.1]	26.0±12.7 [7.5–31.8]	1.18	0.20	0.21	0.99	0.15	0.99	0.54	0.99	0.45
CMJa/SJ (%)	17.6±9.9 [2.4–25.2]	15.4±14.5 [11.0–33.0]	28.8±13.5 [25.6–50.4]	0.38	0.69	0.06	0.99	0.42	0.45	0.95	0.25	1.68

Data presented as median ± standard deviation and median 95% confidence interval. Bold denotes statistical significance ($P < 0.05$)

G Guards, F Forwards, C Centers, SJ Squat Jump, CMJ Countermovement Jump, CMJa Countermovement Jump with arms, η^2 partial ETA squared

statistical significance, suggesting centers may show a greater capacity to exploit muscle elasticity, regardless of the involvement of arms.

Table 5 shows the results of the repeated-sprint test. Compared to guards and forwards, centers required more time to accomplish the task ($F = 7.17$, $P = 0.01$, $\eta^2 = 0.59$ [L]). It was noticed that centers showed lower average acceleration speed ($F = 6.31$, $P = 0.02$, $\eta^2 = 0.56$ [L]) and average peak speed ($F = 8.08$, $P < 0.01$, $\eta^2 = 0.62$ [L]) than guards and forwards. Nonetheless, the fatigue index was similar ($F = 0.77$, $P = 0.49$, $\eta^2 = 0.14$ [S]) and showed high data variability.

Discussion

This study aimed to provide descriptive data on physical, physiological, and neuromuscular parameters among elite female basketball players, according to athletes' positions on the court. Centers were heavier (17%–25%), taller (6%–12%), had greater fat percentage (22%–28%), lower VO_{2max} (21%–26%), higher quadriceps peak torque (17%–30%), and lower jump height (27%–58%) and peak force (15%–48%) than the other groups. H/Q ratio, knee flexors peak torque, fat-free mass, and fatigue index appeared similar among groups.

Some studies reported anthropometric and body composition differences among basketball players by positions. Carter et al. [5] compared body weight, height, and somatotype between the top and bottom teams in a championship, across different player positions. They found that guards were shorter and lighter than forwards and centers, while forwards were also shorter and lighter than centers. Our study aligns with these results, in which guards, forwards, and centers presented 65.9, 74.5, 92.3 kg for body weight, and 166, 178.5, and 190 cm for height (median values), respectively. In addition, Carter et al. [5] showed that guards presented the highest mesomorphic component compared to forwards and centers. Similarly, guards presented the highest relative fat-free mass compared to forwards and centers (82%, 79%, and 71%, respectively) in our samples. The guards are responsible for dribbling, passing, and defending actions (point guard) or shooting and dribbling (shooting guard). Given the demands of these actions, which require high agility and substantial court movement, the higher relative fat-free mass may offer a partial explaination.

Indeed, basketball is a team sport that demands all energy systems. The present study provides VO_{2max} values for a female elite team by positions. To the authors' knowledge, this is the first study to provide such data stratified by position since the literature yielded old (47.0 ± 1.7 and 54.3 ± 1.5 mL/kg/min) [29], estimated (43.3 ± 5.7 mL/kg/min) [26] or for the entire group VO_{2max} values (47.3 ± 4.4 mL/kg/min) [24]. Aerobic and anaerobic (slow and fast) sources [32] are highly required to

Table 5 Repeated sprint ability variables by courts' positions

Variable	Guards (n=4)	Forwards (n=7)	Centers (n=2)	ANOVA			Hedge's g effect size					
							G vs. F		F vs. C		G vs. C	
				F	P	η^2	P	g	P	g	P	g
Maximal speed (m/s)	6.7±0.2 [6.6–7.0]	6.4±0.2 [6.2–6.8]	5.9±0.4 [5.7–6.2]	7.17	**0.01**	0.59	0.41	0.63	**0.04**	3.32	**<0.01**	4.08
Mean speed 0–5 m (m/s)	4.4±0.2 [4.2–4.6]	4.3±0.2 [4.1–4.6]	4.0±0.1 [3.9–4.0]	6.31	**0.02**	0.56	0.96	1.00	**0.04**	5.00	**0.02**	6.00
Decrement score (%)	2.5±1.0 [1.8–4.0]	2.3±1.2 [1.0–4.2]	3.4±1.2 [2.6–4.2]	8.08	**<0.01**	0.62	0.99	0.35	0.75	0.93	0.99	0.68
Total time (s)	59±1.3 [57–60]	60±2.6 [54–62]	66±2.1 [64–67]	0.77	0.49	0.13	0.99	0.00	**0.02**	2.34	**0.02**	3.87

Data presented as median ± standard deviation and median 95% confidence interval. Bold denotes statistical significance ($P < 0.05$)

G Guards, F Forwards, C Centers, η^2 partial ETA squared

meet the metabolic demands of the sport competing at a high level. According to Narazaki et al. [18], a typical basketball match demands 67% of the maximal aerobic power (VO_{2max}; 50.3 ± 5.9 mL/kg/min) [20], whereas Abdelkrim et al. [1] stated that 9.3% of the game time is played above 95% of its maximum heart rate, whereas during 56% of the game, the heart rate ranges 85%–95% of the maximum heart rate. In addition, mean lactate levels during the four periods of a simulated match were 3.4 ± 0.9 mmol/L for female athletes [20] and ranged from 3.6 ± 0.7 to 4.6 ± 2.4 mmol/L over four game periods during a match [26]. Besides, Narazaki et al. [20] found a positive, strong ($r = 0.935$), and significant ($P < 0.05$) relationship between VO_{2max} and time spent in active movements (e.g., running and jumps). This result suggests that the athlete will need higher aerobic capacity (VO_{2max}) to cope with the intensity of the game. Beyond that, higher VO_{2max} may positively contribute to faster restoration of phosphocreatine during rest periods, supplying the energy needed for high-intensity efforts and reducing energy expenditure during light- to moderate-intensity efforts throughout the game [20, 25]. Although Narazaki et al. [18] yielded a great contribution to the understanding of basketball metabolism, some caution should be taken to extrapolate their results to athletes with different body composition and performance levels, since they did not provide data by court position. Moreover, it is possible that the match action could be impaired to a certain extent because of the use of the portable metabolic analyzer, which may introduce some bias to the obtained results.

In addition to the importance of developing a robust cardiorespiratory fitness level, basketball matches require adequate lower limb strength, since it is intimately related to most movements used in basketball (e.g., jogging, shuffling, and jumping) [26, 30, 31]. The present study revealed no differences in isokinetic strength variables across all court positions, despite centers presenting the lowest values compared to their peers. Notably, game-related lower limb injuries account for 58.7% of injuries in Women's National Basketball Association players [6], with knee injuries contribute to 17.8% of game-related lower limb injuries. Contrary to common belief and the focus of studies and media, anterior cruciate ligament injuries are relatively uncommon among female basketball players. However, when they do occur, they result in the longest-time loss during the season (almost one full year) and, and in some cases, can lead to early end of a young athlete's career [6, 13]. In this regard, the isokinetic strength test has been widely used in athletes to evaluate the side-to-side and agonist–antagonist balance of the knee in basketball players. Elite-level players have shown higher peak extension torque, offering valuable insights for practitioners and coaches when tailoring the training, since different playing positions may have different demands on quadriceps muscles [7]. For instance, Delextrat et al. [7] evaluated the isokinetic strength profiles (60°/s and 180°/s) of English National League Division II basketball players. They found

statistically significant differences between guards and forwards and between forwards and centers, in which guards showed the highest extension peak torque values at 60°/s.

Similarly, our results showed relatively higher extension peak torque values (N·m/kg) in the guards (at the same angular speed), followed by forwards and centers. On the other hand, the relative peak torque values for knee flexion and *H/Q* ratio were similar regardless of the positions. Discrepancies between the results found in the present study and the existing literature may be attributed variations in the sample, athletes' performance level, and sample size. While the differences observed in the present study were not statistically significant, Guards showed higher peak torque values than Forwards, who, in turn, displayed higher values than Centers, as found by Delextrat et al. [7]. It is hypothesized that Guards and Forwards, given their higher running and jump demands than Centers in the match, require higher strength levels to meet the match demands. Thus, the use of isokinetic strength evaluation could be valuable in monitoring athletes' strength levels througout the season.

Furthermore, vertical jump tests are routinely used in high-level sports to monitor oscillations in neuromuscular readiness, fatigue, and recovery status after training and to quantify adaptations to the training process [14]. Translating the results of the jumping ability tests into practical applications, however, can be more challenging than simply observing the oscillations in the jump heights obtained from the various jumping methods. It is prudent to consider that jumps account for as little as ~2.5% of the total actions in women's basketball matches [26]. Therefore, monitoring vertical jumps may not equate to monitoring a critical factor for performance [10], given the inconsistent nature of the relationship between jump ability and on-court performance in the existing literature [14]. In a study by Ferioli et al. [8] invoving Italian men's basketball players from Divisions I, II, and III, CMJ tests were conducted during the 1st week of preparation (T1), at the beginning of the competitive season (T2, 8 weeks after T1), and during the competitive phase (T3, 9 weeks after T2). The findings revealed no difference in JH between divisions and no changes in JH across time (T1, T2, and T3). Nevertheless, peak power output normalized by body weight was higher in T3 compared to T1 in Division I players. These findings suggest that jumping ability cannot be assessed only by how high the athletes jump but must also consider strategies to achieve their jump outputs. These findings in the literature highlight the importance of analyzing factors other than JH when assessing jump ability. The present study showed lower SJ results than those found by Sekulic et al. [27], and CMJ results lower than those reported by Laffaye et al. [16]. However, in the first case, the sample was composed of athletes from several sports beyond basketball, and in the second case, the results combined data from both male and female basketball players. Our results showed that centers exhibited a lower readiness

to jump overall than Guards and Forwards in both SJ and CMJ tests. However, these differences were observed only in take-off speed when the arm swing was included. The elastic improvement (CMJ/SJ) and the technical increment of arm swing (CMJa/CMJ and CMJa/SJ) showed no difference across different court positions.

Repeated-sprint ability (RSA) or the capacity for repeated-sprint exercise is one of the most common physical requirement in team sports, including basketball [11]. In our study, the athletes reached an average peak speed of ~7 m/s, which was classified as "Run" by Scanlan et al. [26] in a study that analyzed the physiological and activity demands in Australian female basketball players (i.e., the sprint was classified as efforts above 7 m/s). Although no differences in running frequency were found between backcourt (point and shooting guards) and frontcourt players (small and power forwards and centers) (295 vs. 297 times, respectively), differences emerged in the time spent running (390 vs. 419 s, respectively) and the distance covered (1744 vs. 1924 m, respectively). These data suggest that this speed range is essential for female basketball performance, and the player's position on the court plays an important role in the design of specific training. Given the increased running demand on frontcourt players, coaches must design an appropriate training program for improving and/or maintaining performance throughout the season.

While the current study yielded novel results and focused on elite-level athletes, several limitations should be acknowledged. First, the tests and measurements were completed only once, before the FIBA AmeriCup 2019 (competition phase), rather than being repeated upon completion of the season. It would be valuable to understand changes throughout a competitive season to better understand how physical performance can change throughout the season in elite athletes. Next, although not reported, it would be valuable to use the reported data and identify athletes who experienced non-contact injuries throughout the season. Conducting pre-season performance tests could help identify deficiencies that could put athletes at risk for soft tissue or non-contact injuries. Finally, the study sample was limited to a single, albeit elite-level, women's basketball team. This limited sample size and its imbalance (considering each group) may have affected the results. Acquiring physical performance data from multiple teams and hundreds of athletes worldwide can significantly improve the precision of training recommendations and performance thresholds in elite women's basketball athletes.

Conclusions

Overall, physical capacities differentiated between athletes' court positions on the basketball court in elite female basketball. Many variables regarding body composition,

cardiorespiratory fitness, and neuromuscular and repeated-sprint performance displayed *Medium* to *Large* effects size. In general, the Guards showed to be lighter, shorter, and fitter than their counterparts. Moreover, they presented better neuromuscular performance (isokinetic knee strength, jump, and repeated-sprint ability performance).

Practical Applications

The current study highlights performance variables of elite women's basketball athletes, and its findings can be utilized as additional reference values in the literature to further enhance the performance of professional women's athletes. It's worth noting that these data were collected shortly before a key competition (Tokyo 2020 pre-Olympic) in the season, indicating that the athletes were in good (maybe best) physical condition. The physical capacities evaluated in this study could discriminate athletes by court positions, which can also be used for monitoring athletes' performance throughout the season. Additionally, the insights from this study, combined with existing literature, emphasize the need for specific training programs catering to the specific demands of athletes in different court positions. These programs can contribute to enhancing the overall quality of elite women's basketball.

Declarations

Conflict of Interest The authors declare that there is no competing interest.

Ethics Approval This study was approved by the Research Ethics Committee of the Rio de Janeiro Municipal Health Secretariat (n° 96949518.1.0000.5279) and conducted following the Declaration of Helsinki (revision of 2013).

Informed Consent Informed consent was obtained from all individual participants included in the study.

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