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ORIGINAL RESEARCH

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A comparative study of vertical jump parameters in men's college basketball and volleyball players

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Abstract

This study aimed to compare lower limb strength disparities between male college volleyball and basketball players in four distinct vertical jump types. We recruited 100 second-level (above the national standard) male college athletes (50 basketball and 50 volleyball players) from Capital University of Physical Education and Sports who volunteered to participate. We assessed the performance of each athlete with regards to the squat jump (SJ), countermovement jump (CMJ), continuous jump with straight legs (CJs), and continuous jump with bent legs (CJb). Data analysis was performed by independent samples *t*-tests in SPSS version 25.0. software. In the CMJ test, volleyball players had a significantly higher vertical jump displacement (VJD; $p = 0.047$, $t = -2.018$), squat displacement (SD; $p = 0.005$, $t = -2.883$), peak force ($p = 0.023$, $t = -1.964$), and peak velocity ($p = 0.011$, $t = -1.687$) than basketball players. In the SJ test, volleyball players had a significantly higher VJD ($p = 0.041$, $t = -1.21$) and SD ($p = 0.008$, $t = -1.46$) than basketball players. In the CJs test, volleyball players had a significantly higher average vertical jump displacement (AVJD; $p = 0.042$, $t = -2.067$) than basketball players. In the CJb test, volleyball players had a significantly higher AVJD ($p = 0.001$, $t = -3.448$), average squat displacement ($p = 0.017$, $t = -2.44$), and average contact time ($p = 0.045$, $t = -2.038$) than basketball players. The overall vertical jump ability of college volleyball players was better than that of college basketball players. CMJ, SJ, CJs and CJb training should be included in daily training sessions and considered in the selection of basketball and volleyball players. In addition, coaches can use fast twitch Fibers, the effect of pre-stretch and k as the main evaluation indicators to assess daily training progress.

Keywords

Comparative study; Lower limb strength; Vertical jump; SJ; CMJ; CJs; CJb; Basketball; Volleyball

1. Introduction

The lower limb strength of athletes is important in every sport, but particularly in basketball and volleyball [1]. Scrambling for rebounds and jump shots in basketball [2] and blocking the net and jumping for hits in volleyball require significant lower limb strength [3]. According to previous research, each basketball game requires athletes to jump up 120–140 times [4], and a competitive volleyball match requires an attacker-athlete to jump up (including jumping up to hit and block) more than 200 times [5]. Muscular force and velocity produce power; this can be measured in an instant during movement. The latter parameter, also referred to as peak power, is frequently related to explosive actions such as sprinting, leaping and throwing, and may be a significant factor for success in a particular discipline [6].

In sports, competition, and training, basketball and volleyball athletes do not only need good explosive power in the lower limbs, they also need good lower limb muscular endurance to cope with the long hours of training and competition [7]. The vertical jump test is a popular and effective method for assessing an athlete's lower extremity endurance and explosive strength. In most sports, such as basketball and volleyball, vertical jumps are widely used as both a necessary activity and for functional evaluation [8–11]. Several protocols that support or validate suggested training systems have been reported in the literature.

There are several types of vertical jumps, including countermovement, squat, deep, single and continuous jumps [12]. In particular, countermovement, squat and drop jumps are often used to evaluate an athlete's explosive power in the lower limbs [13, 14], while continuous jumps are often used to evaluate an athlete's lower limb endurance [15, 16]. Compared with the drop jump, countermovement and squat jumps are similar to the jumping movements in basketball and volleyball games [17]. Basketball and volleyball competitions demonstrate how well an athlete's explosive strength and stamina work together

[18]. Therefore, it is important to assess the explosive power and endurance of the lower limbs of basketball and volleyball players.

Basketball and volleyball have certain similarities and differences. The major difference is that basketball is a contact sport, while volleyball is a non-contact sport; their main similarity is that they are both team sports [18]. Currently, research relating to the long jump in basketball and volleyball has focused on several areas. In comparing the vertical leap heights of female volleyball and basketball players, some researchers have discovered that the vertical jump height of female volleyball players is higher than that of female basketball players [1]. However, jump depth has been identified as the most effective index for evaluating the lower limb strength of basketball and volleyball players. Previous studies that assessed the link between lower extremity coordination during long jumps and injuries in both basketball and volleyball players found that athletes who prematurely specialize in one activity increase their risk of injury [19]. For many athletes, improving their jumping ability is a key training objective, and the drop jump is a well-known training technique that can be used to improve this ability. In contrast, a team participant should jump higher and perform leaps faster than their opponent during a game. To set a better personal record, each player must enhance their own jump performance. Previous studies predominantly used one or two types of vertical jumps to evaluate lower limb strength; however, in the present study, we used four types of vertical jumps to comprehensively assess the lower limb strength of male college basketball and volleyball players, including the squat jump (SJ), countermovement jump (CMJ), continuous jump with straight legs (CJs), and continuous jump with bent legs (CJb). In addition, we also included some new study metrics, including fast-twitch fibers (FT), the effect of pre-stretch (EP), average stiffness and average instantaneous force (AFi). Therefore, in this study, we aimed to compare the variations in lower limb strength between male basketball and volleyball players using various vertical jump techniques and to provide a theoretical basis for sports training and sports selection.

2. Methods

2.1 Participants

The sample size for this study was determined using G*Power (version 3.1.9.2; Franz Faul University Kiel, Kiel, Germany). Our analyses featured an α of 0.05, a power of 0.8, an effect size of 0.5, and statistical tests were performed to compare the difference between two independent averages. Based on these specifications, the estimated sample size was 50 participants per group, totaling 100 male athletes. For the basketball players, the average age was 20.75 $\pm$ 1.01 years, the average height was 186.18 $\pm$ 5.71 cm, and the average body weight was 85.70 $\pm$ 9.77 kg. For the volleyball players, the average age was 20.48 $\pm$ 0.93 years, the average height was 186.10 $\pm$ 6.46 cm, and the average body weight was 82.94 $\pm$ 8.33 kg. Age, height and weight did not differ significantly between the basketball and volleyball players. Players were selected randomly, regardless of the position they played in their respective games. All of the male athletes competed at the second level, above the national average, and had not sustained any lower limb injuries for more than three months prior to recruitment.

The participants had been actively engaged in consistent training (three times per week) for at least four years prior to the study. Each athlete practiced vertical jumps as part of their regular training regimen. None of the participants reported any illness or injuries that would have limited their ability to exercise or affected their ability to perform at their optimal level.

2.2 Testing protocol

Measurements were performed in the Laboratory of Sports Biomechanics at the Capital University of Physical Education and Sport, China. The participants were instructed to avoid further weight training on the day before the tests. In addition, the participants were instructed not to engage in any exercise or consume caffeine 24 hours prior to the test [17].

Participants wore comfortable clothes and athletic shoes and were assessed in a sports science laboratory under the supervision of laboratory staff. The participants were briefed on the vertical jump movements and testing criteria. The objectives of the study were explained to each participant prior to the tests. Following a 10-min warm-up, the participants performed three CMJs and three SJs in sequence on a force plate and subsequently performed one CJs and one CJb tests; a 10 min rest period was allowed between tests. All athletes were tested at the same time of the week (every day from 2 PM to 4 PM) in the laboratory with a 24 °C ambient temperature.

The SJ test was designed to assess leg performance rather than arm performance; thus, the participants were instructed to place their hands on their hips throughout the test [17]. The participants squatted (their favorite position), remained still for few seconds, and jumped as high as they could. At one-minute intervals, three leaps were completed, and the highest jump was selected for further analysis. The participants were not permitted to make any counter movements prior to takeoff, as shown in Fig. 1.

In the CMJ test, participants were instructed to place their hands on their hips because the test was designed to measure leg function rather than arm function [17]. To attempt an upward leap, the participants had to squat and jump up quickly. At one-minute intervals, three leaps were performed; the highest jump was selected for analysis, as shown in Fig. 2.

In the CJs test, participants stood straight for 1–2 s and then performed five continuous jumps. The participants were instructed to keep their knee joints straight throughout the contact period of each jump and were allowed to use their arms to support themselves during the jump. This jump replaced the drop jump used in other test methods. The participants achieved their maximum jump height within a few jumps. The CJs test is normally used to assess the flexibility of the lower limb extensor muscles [20]. This test is suitable for sporting events that require athletes to possess strength and stretch tolerance, as shown in Fig. 3.

The CJb test evaluates the mechanical power of the lower extremities. A series of 30-s jumps were performed with the knees bent. The participants were instructed to place their

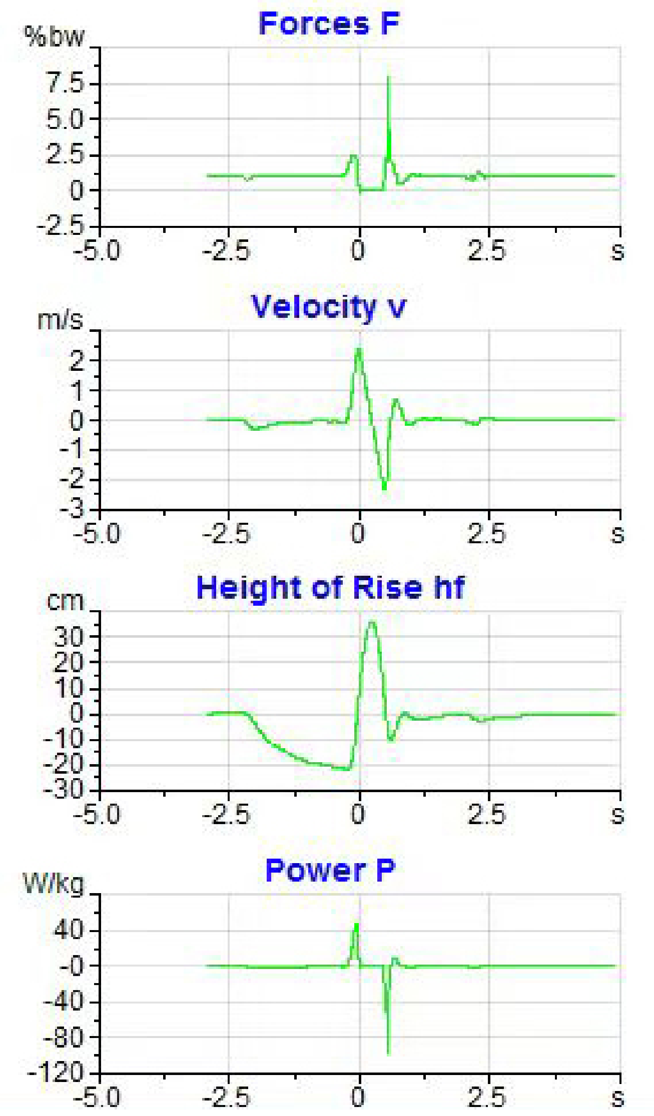

FIGURE 1. Schematic diagram of the SJ test index.

hands on their hips (to assess leg performance instead of arm performance), stood for 1–2 s and then jumped continuously for as long as they could. With each jump, the participants were required to bend their knees at 90 degrees during the contact phase [21]. The participants were not required to pause at the end of a jump, as shown in Fig. 4.

Vertical leaps were recorded at 500 Hz on a force platform (Quattro Jump, 9286AA, Kistler, Switzerland). Participants were told to keep their hands on their hips during the SJ, CMJ and CJb tests (to control arm contribution) and jump with their trunks as upright as possible during the SJ, CMJ, CJs and CJb test to restrict or eliminate energy benefits related with trunk activity.

2.3 Data analysis

All the data obtained from the SJ, CMJ, CJs and CJb tests were recorded and analyzed using Excel (2019) and the Statistical Package for the Social Sciences (SPSS 25.0; IBM, Chicago, IL, USA). Vertical jump displacement (VJD) was determined based on the anticipated flight time of the center of mass, using accepted techniques [14]. The lowest point of an athlete's

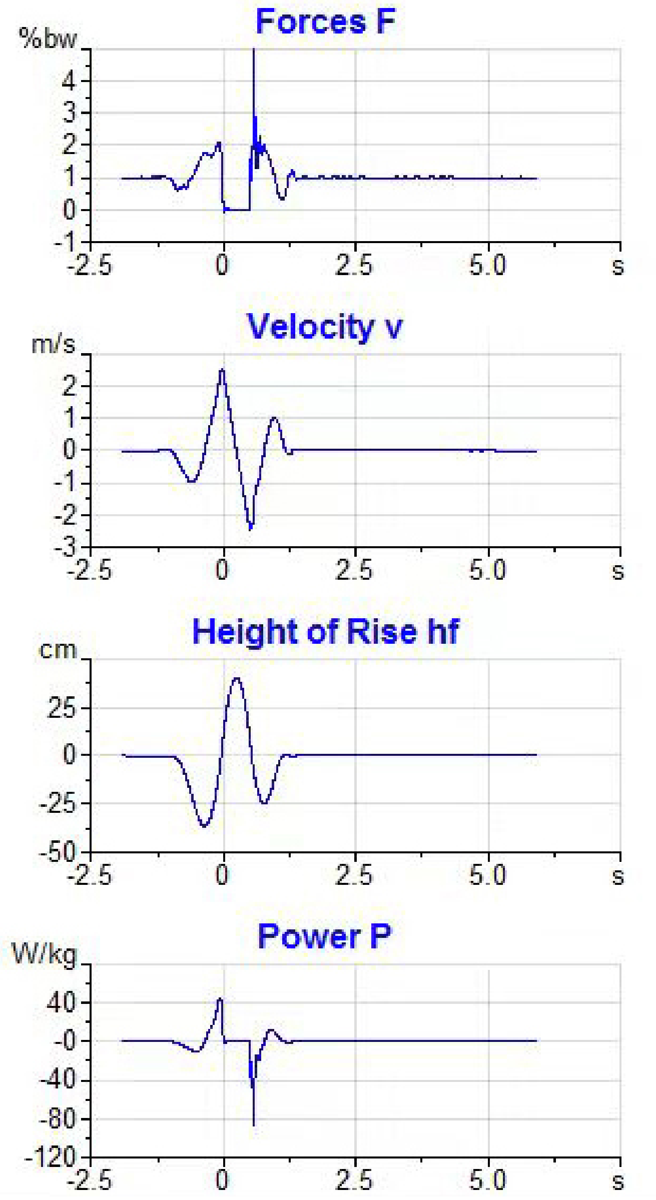

FIGURE 2. 1Schematic diagram of the CMJ test index.

squat was squat displacement (SD). The force plate directly recorded peak force (PF) and peak velocity (PV). Peak power was defined as the highest power value during the propelling phase (PP) of CMJ's and SJ's. From the point where velocity became positive until takeoff, the average power (AP) was equivalent to average concentric power. The term FT represents the fraction of swift muscle fibers responsible for explosive force; we estimated the percentage of FT. A special algorithm was built from many biopsies using age, sex and the training method for SJ's and CMJ's and jump height (the flight time technique). EP (%) was calculated as (hf (CMJ)/hf (SJ) × 100%) − 100% [17]. Analysis involved the average scores of the CJs and CJb test results. The selected indices for the CJs test were average vertical jump height, AP, average contact time (ACT), and average stiffness (k). Average stiffness (k) was calculated as abs ((Fi + body weight (BW))/Δh) [22]. The indicators selected in the CJb vertical jump test were average vertical jump height, average squat height, AP, AFi and ACT. Fi was defined as the force generated at the transition point

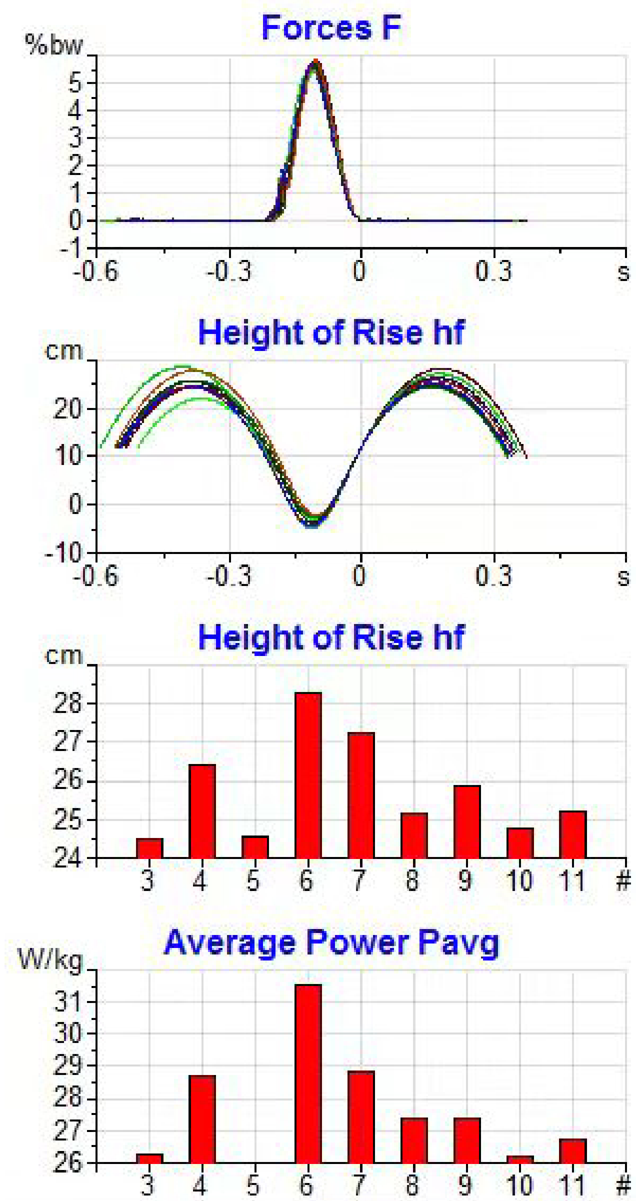

FIGURE 3. Schematic diagram of the CJs test index.

from eccentric to concentric contraction (when the power first became positive) minus the BW. Afi = F (ecc/con transition) − F_{bw}.

2.4 Statistical analysis

The data were summarized by descriptive statistics and are presented as average ± standard deviation (SD). To ensure that the residual data were normally distributed, the Shapiro-Wilk test was performed. The four different vertical jump types performed by basketball and volleyball players were compared by the independent samples *t*-test. The *t* and *d* values of the results are reported, where *t* represents the difference between two sample averages divided by the standard error of the difference between two averages and $d = t\sqrt{\frac{N_1+N_2}{N_1*N_2}}$ (N_1 and N_2 denote the number of basketball and volleyball samples). Cohen (1988) estimated d values in the behavioral sciences as 0.2, 0.5 and 0.8; these corresponded to small, medium and large effect sizes, respectively [23]. All analyses

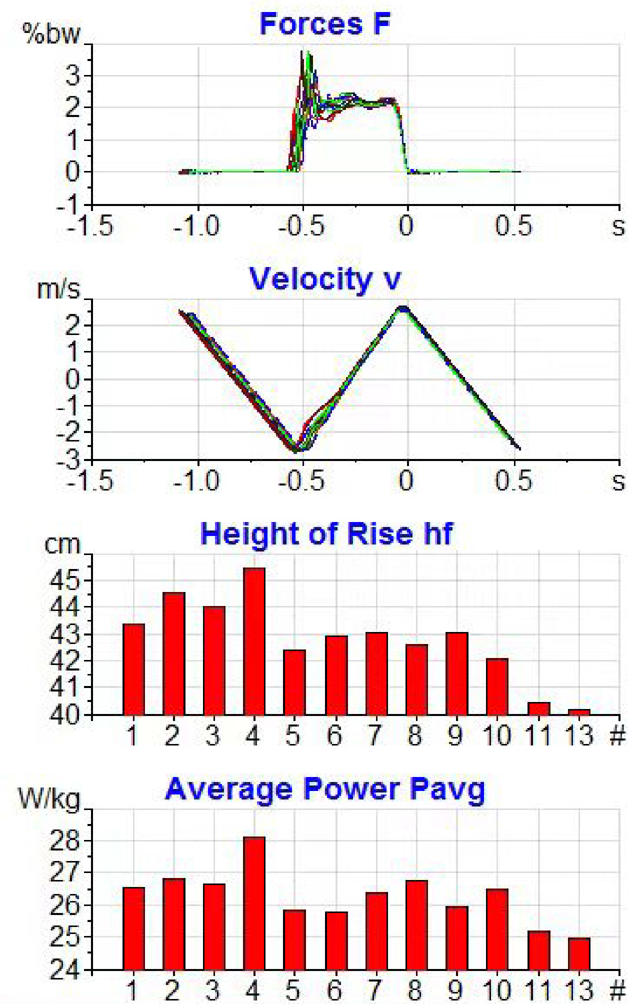

FIGURE 4. Schematic diagram of the CJb test index.

were performed using SPSS version 25.0 (Chicago, IL, USA).

3. Results

The data in this study were normally distributed and the variance of each data set was equal. Table 1 and Fig. 5 show the variability of the CMJ test indices when compared between the basketball and volleyball players. In the CMJ test, volleyball players had a significantly higher VJD ($p = 0.047$, $t = -2.018$), SD ($p = 0.005$, $t = -2.883$), PF ($p = 0.023$, $t = -1.964$), and PV ($p = 0.011$, $t = -1.687$) than the basketball players. PP, AP, FT and EP results did not differ significantly between the basketball and volleyball players.

Table 2 and Fig. 6 show the variability of the SJ test indices between the basketball and volleyball players. In the SJ test, volleyball players had a significantly higher VJD ($p = 0.041$, $t = -1.21$) and SD ($p = 0.008$, $t = -1.46$) than the basketball players. PF, PV, PP and AP did not differ significantly between the basketball and volleyball players.

Table 3 and Fig. 7 show the variability of the CJs test indices between the basketball and volleyball players. In the CJs test, volleyball players had a significantly higher AVJD ($p = 0.042$, $t = -2.067$) than the basketball players. However, volleyball players had a significantly lower k ($p = 0.002$, $t = 3.18$) than the basketball players. Average average power (AAP) and

TABLE 1. Comparative results of the CMJ test indices between the basketball and volleyball players (n = 100).

Variables	Basketball	Volleyball	*p*	*t*	*d*
VJD (cm)	48.41 ± 7.27*	52.51 ± 6.45	0.047	−2.018	−0.404
SD (cm)	26.31 ± 6.11**	29.11 ± 5.96	0.005	−2.883	−0.577
PF (%bw)	2.19 ± 0.27*	2.35 ± 0.31	0.023	−1.964	−0.393
PV (m/s)	2.51 ± 0.26*	2.79 ± 0.34	0.011	−1.687	−0.337
PP (W/kg)	50.21 ± 7.99	52.82 ± 9.64	0.056	−0.882	−0.176
AP(W/kg)	25.73 ± 3.62	27.19 ± 3.71	0.078	−1.784	−0.357
FT (%)	46.39 ± 12.64	48.26 ± 13.65	0.061	−0.667	−0.133
EP (%)	24.31 ± 13.67	25.83 ± 14.95	0.053	−0.394	−0.079

VJD: vertical jump displacement; SD: squat displacement; PF: peak force; PV: peak velocity; PP: peak power; AP: average power; FT: Fast-Twitch Fibers; EP: Effect of Pre-stretch.

*$p < 0.05$, **$p < 0.01$. $d\,(Effect\ size) = t\sqrt{\frac{N_1+N_2}{N_1 * N_2}}$ ($N_1 = N_2 = 50$).

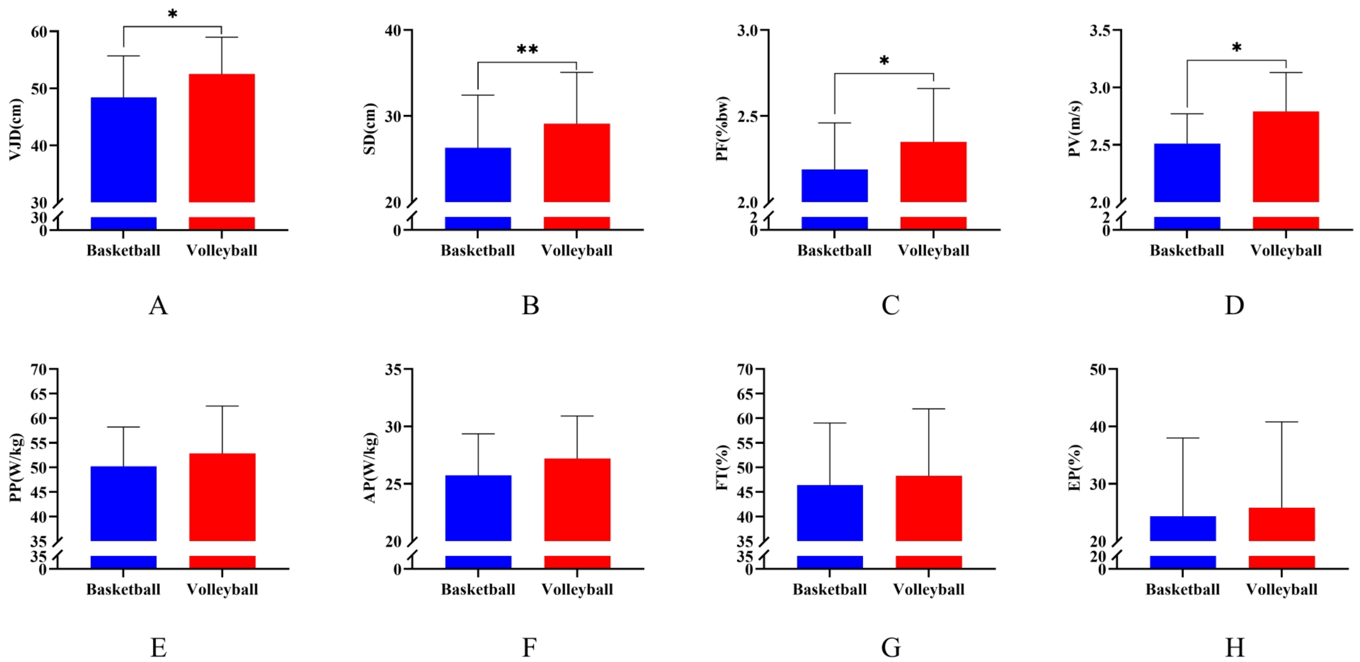

FIGURE 5. Comparative results of the CMJ test indices between basketball and volleyball players (n = 100). (A–H represent the differences in VJD, SD, PF, PV, PP, AP, FT and EP indicators between basketball and volleyball players, respectively. VJD: Vertical jump displacement; SD: squat displacement; PF: peak force; PV: peak velocity; PP: propelling phase; AP: average power; FT: fast-twitch fibers; EP: effect of pre-stretch. *$p < 0.05$, **$p < 0.01$.

TABLE 2. Comparative results of the SJ test indices between the basketball and volleyball players (n = 100).

Variables	Basketball	Volleyball	*p*	*t*	*d*
VJD (cm)	44.59 ± 5.87*	49.77 ± 5.53	0.041	−1.210	−0.242
SD (cm)	26.11 ± 5.50**	29.16 ± 6.98	0.008	−1.460	−0.292
PF (%bw)	2.42 ± 0.25	2.45 ± 0.23	0.163	−0.021	−0.004
PV (m/s)	2.33 ± 0.45	2.39 ± 0.32	0.258	−0.069	−0.014
PP (W/kg)	48.61 ± 6.42	49.22 ± 7.85	0.081	−0.061	−0.012
AP(W/kg)	20.11 ± 2.48	21.3 ± 3.12	0.067	−0.055	−0.011

VJD: vertical jump displacement; SD: squat displacement; PF: peak force; PV: peak velocity; PP: peak power; AP: average power.

*$p < 0.05$, **$p < 0.01$. $d\,(Effect\ size) = t\sqrt{\frac{N_1+N_2}{N_1 * N_2}}$ ($N_1 = N_2 = 50$).

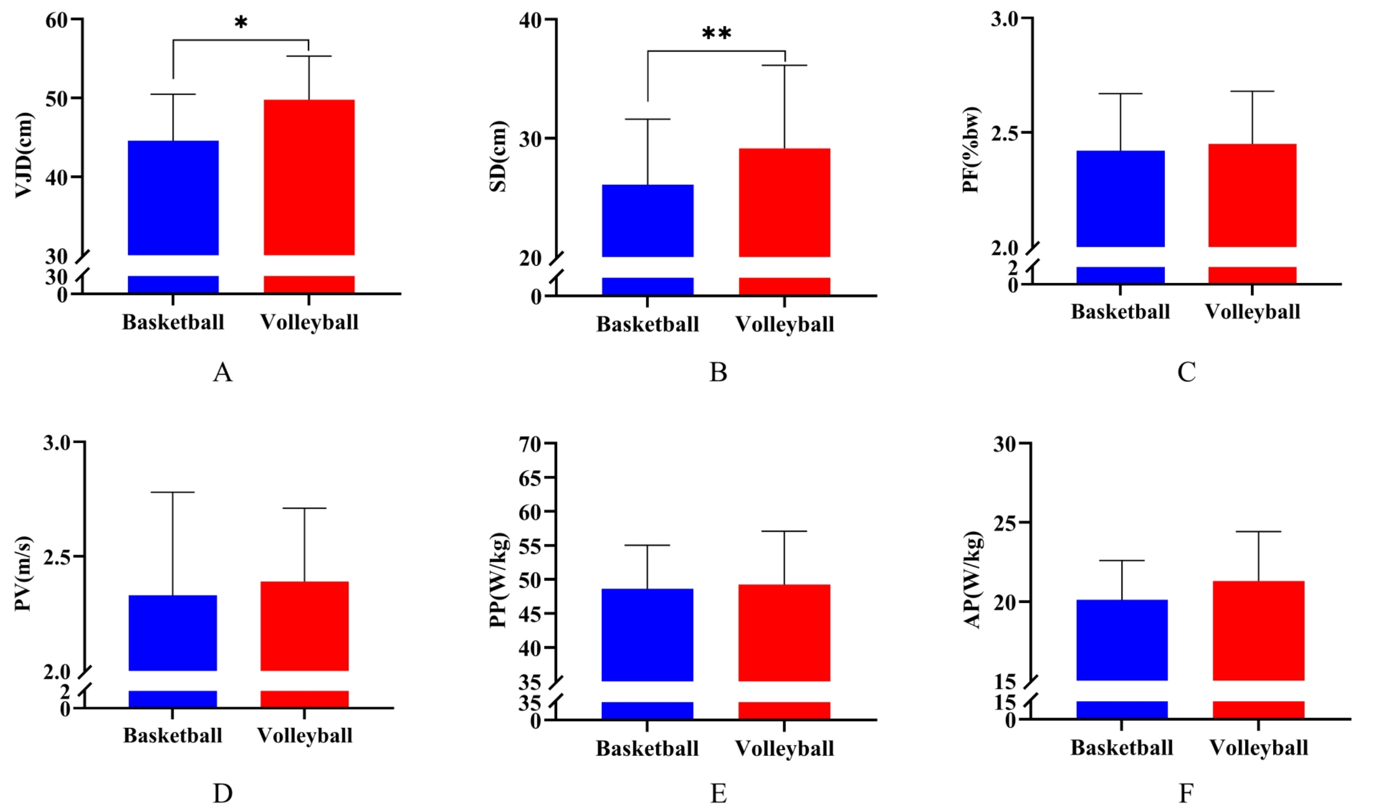

FIGURE 6. Comparative results of the SJ test indices between basketball and volleyball players (n = 100). (A–F) represent the differences in VJD, SD, PF, PV, PP and AP indicators between basketball and volleyball players, respectively. VJD: Vertical jump displacement; SD: squat displacement; PF: peak force; PV: peak velocity; PP: propelling phase; AP: average power. $*p < 0.05$, $**p < 0.01$.

TABLE 3. Comparative results of the CJs test indices between the basketball and volleyball players (n = 100).

Variables	Basketball	Volleyball	p	t	d
AVJD (cm)	36.20 ± 6.00*	38.53 ± 3.85	0.042	−2.067	−0.413
AAP (W/kg)	34.59 ± 8.12	35.59 ± 3.10	0.467	−0.731	−0.146
ACT (ms)	267.38 ± 62.37	277.60 ± 37.99	0.379	−0.886	−0.177
k	21.81 ± 8.87**	16.62 ± 5.28	0.002	3.180	0.636

AVJD: average vertical jump displacement; AAP: average average power; ACT: average contact time; k: average stiffness. $*p < 0.05$, $**p < 0.01$. $d\,(Effect\ size) = t\sqrt{\frac{N_1+N_2}{N_1*N_2}}$ $(N_1 = N_2 = 50)$.

ACT did not differ significantly between the basketball and volleyball players.

The differences in CJb test indices between the basketball and volleyball players is displayed in Table 4 and Fig. 8. In the CJb test, volleyball players had a significantly higher AVJD (p = 0.001, t = −3.448), ASD (p = 0.017, t = −2.44), and ACT (p = 0.045, t = −2.038) than the basketball players. However, volleyball players had a significantly lower AAP (p = 0.033, t = 2.177) than the basketball players. AFi did not differ significantly between the basketball and volleyball players.

4. Discussion

In the present study, we found that the VJD (or AVJD) of volleyball players was significantly higher than that of basketball players in all four types of vertical jump. This finding was consistent with previous studies [24–27]. However, a previous study that included female basketball and volleyball players [1] showed that the vertical jump heights of basketball and volleyball players were not related to gender but were closely related to the sport they engage in. It has been proposed that specific anthropometric measurements are necessary for successful athletic performance in various sports. According to Hunter *et al*. [28], height and leg length are reliable indicators for acceleration phase velocity. Longer lower limbs may enhance step length (by a longer stance distance) but may reduce step frequency because of the greater moment of inertia at the hip joint. However, it is still uncertain if longer lower limbs are beneficial with regards to acceleration performance [20]. Unfortunately, this study did not measure morphological indices such as the leg length of the athletes; this and other indices will be investigated in future studies.

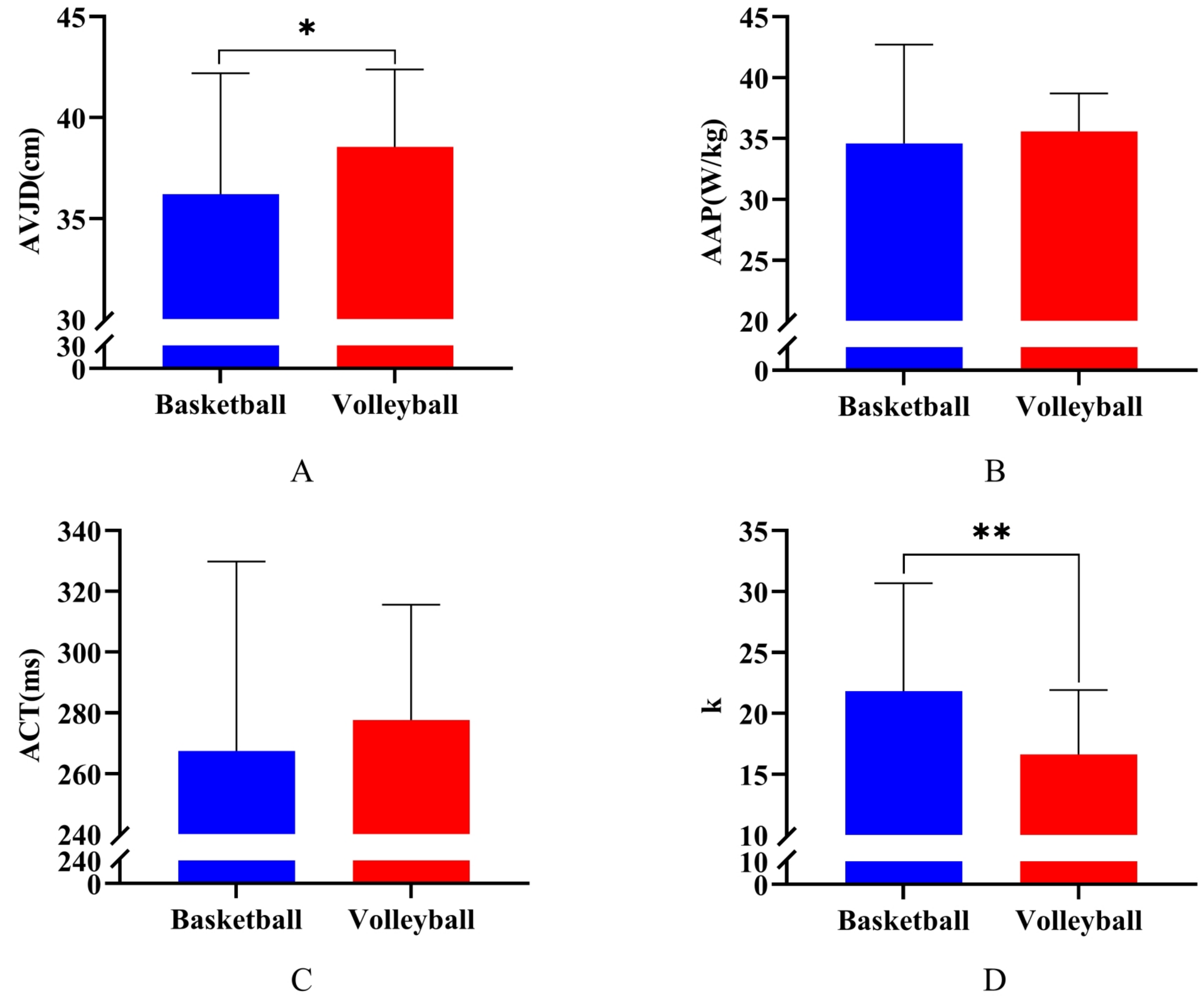

FIGURE 7. Comparative results of the CJs test indexes between basketball and volleyball players (n = 100). (A–D) represent the differences in AVJD, AAP, ACT and k indicators between basketball and volleyball players, respectively. AVJD: average vertical jump displacement; AAP: average average power; ACT: average contact time; k: average stiffness. *$p < 0.05$, **$p < 0.01$.

TABLE 4. Comparative results of the CJb test indices between basketball and volleyball players (n = 100).

Variables	Basketball	Volleyball	*p*	*t*	*d*
AVJD (cm)	38.35 ± 5.04**	42.17 ± 4.88	0.001	−3.448	−0.690
ASD (cm)	27.74 ± 7.69*	31.45 ± 5.74	0.017	−2.440	−0.490
AFi (%bw)	23.32 ± 3.63	24.43 ± 2.85	0.132	−1.524	−0.300
AAP(W/kg)	35.31 ± 2.46*	32.12 ± 2.89	0.033	2.177	0.435
ACT (ms)	571.70 ± 106.06*	618.78 ± 100.49	0.045	−2.038	−0.410

AVJD: average vertical jump displacement; ASD: average squat displacement; AFi: Average instantaneous force; AAP: average average power; ACT: average contact time.

*$p < 0.05$, **$p < 0.01$. $d\,(Effect\ size) = t\sqrt{\frac{N_1+N_2}{N_1*N_2}}$ ($N_1 = N_2 = 50$).

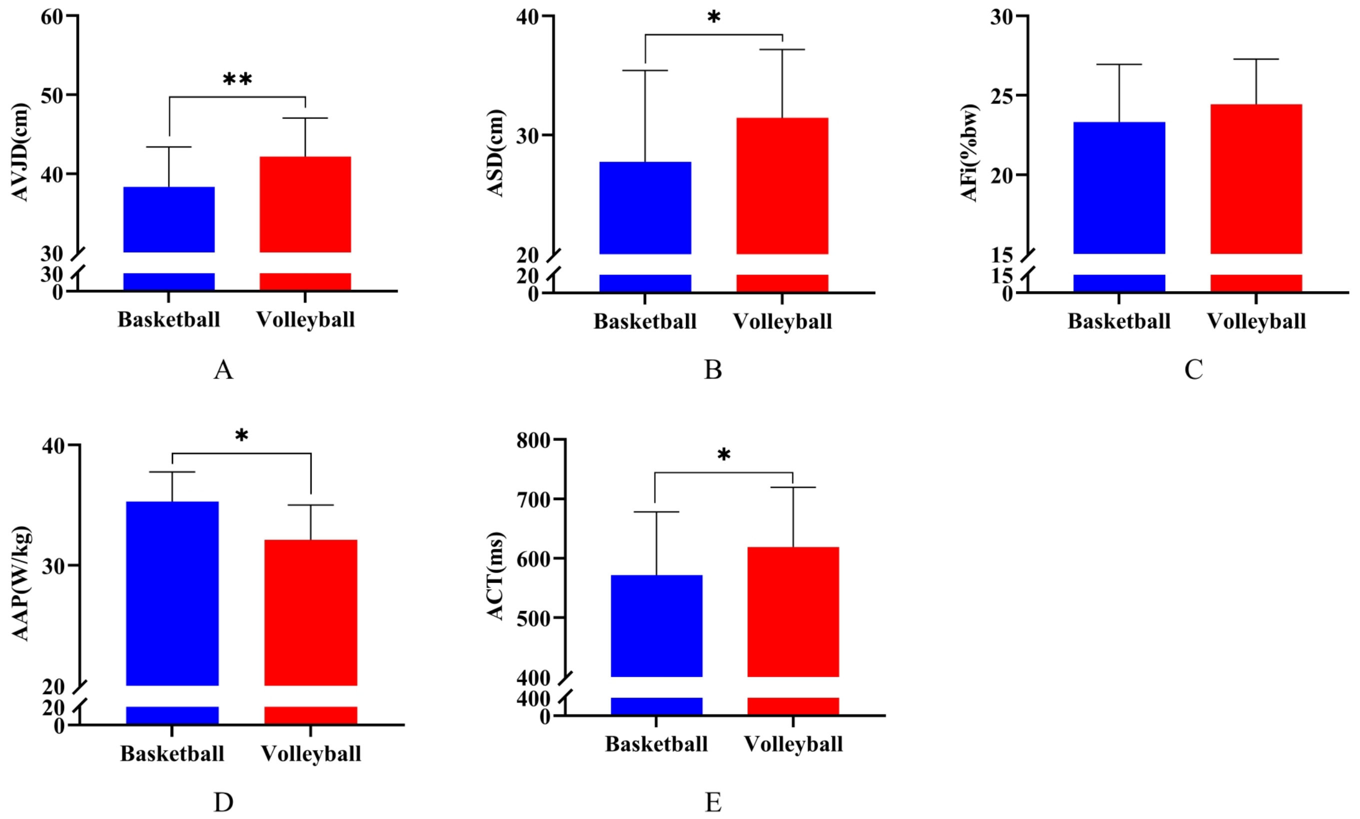

FIGURE 8. Comparative results of the CJb test indices between basketball and volleyball players (n = 100). (A–E) represent the differences in AVJD, ASD, AFi, AAP and ACT indicators between basketball and volleyball players, respectively. AVJD: average vertical jump displacement; ASD: average squat displacement; AFi: Average instantaneous force; AAP: average average power; ACT: average contact time. $*p < 0.05$, $**p < 0.01$.

According to previous studies, when an athlete jumps longitudinally, the vertical jump height is directly proportional to the squat height in the early phase of the jump [26]. That is, the lower the squat height, the higher the athlete's vertical jump height. Furthermore, our participants used a self-preferred knee flexion angle in the CMJ, SJ and CJb tests. Previous studies have compared jump height performance between CMJs performed with pre-determined and self-selected knee flexion angles [29]. Research has demonstrated an increase in jump height with larger countermovement depths due to the increased time available to apply force when compared with that observed with a self-selected countermovement depth [30]. However, other investigations did not difference between larger and self-selected countermovement depths [31].

In the CMJ test, the athlete's PF and PV are crucial measures of the explosive strength of the lower limbs. Volleyball players had significantly higher PF and PV values than when compared to basketball players. This suggests that when compared with male college basketball players, male college volleyball players have stronger explosive power in the lower limbs. This may be because volleyball players have higher bouncing ability than basketball players. This is consistent with the result of previous study [7]. A previous study compared the lower extremity strength indices of basketball, volleyball and soccer players using vertical jump tests and found that volleyball players had higher explosive strength in the lower extremities than basketball and soccer players [32–34]. This may be because volleyball players have better elastic potential energy reserves in the lower limb muscle [35]. Furthermore, the lack of a discernible difference in body size between volleyball players at each position in the game may help to explain this outcome, whereas significant body size differences are observed among basketball players in different game positions [5, 18]. With regards to PP, AP, FT and EP, there were no significant variations between the two sports. This contradicts the findings of earlier research [18]. The work performed by a muscle or muscle group per unit time is measured as its average power; this reflects the efficiency of the muscle or muscle group [36, 37]. Although no other research has attempted to verify this conclusion, PP and FT were closely related during the CMJ tests performed in the present study. One explanation for this is that FT enhances peak power by increasing the speed of muscular contraction [17].

In the SJ test, the VJD and SD of basketball players were significantly lower than those of volleyball players. PF, PV, PP and AP did not significantly differ between the two groups. This could be due to fact that the muscle fiber type of male college basketball players is the same as that of male college volleyball players. hence, there was no discernible difference [38].

In the CJs test, the AVJD of basketball players was significantly lower than that of volleyball players. However, volleyball players had significantly lower k values than basketball players. In a previous study, researchers used the oscillation technique to assess lower body stiffness and found that maximal stiffness was significantly correlated with both the isometric and concentric rate of force development [22]. Lower limb stiffness in basketball players is significantly greater than that in volleyball players; this may be due to both the isometric and concentric rate of force development [39]. AAP and ACT did not differ significantly between the volleyball and basketball players. The reason for the lack of a significant difference in ACT between basketball and volleyball players could be the use of a metronome during the test as this device provides strict control over the time taken for each vertical jump. Another possible reason is that the test process involved swinging of the arm; this may have caused surrogate compensation [40].

In the CJb test, AVJD, ASD and ACT was significantly greater in volleyball players than in basketball players. The reason for the significantly higher ACT in volleyball players than in basketball players may be that volleyball players have higher elastic potential energy in their lower limb muscles [15, 39, 41, 42]. Energy is saved by increasing the ground contact time, thus increasing the vertical jump height. This is consistent with previous research findings [16, 18]. However, volleyball players had a significantly lower AAP than basketball players.

This study has some limitations that need to be considered. For example, the results of this study are only applicable to male college basketball and volleyball players; thus, the applicability of these results for other athletes requires further investigation.

5. Conclusions

In the vertical jump test, the overall vertical jump ability of college volleyball players was better than that of college basketball players. Our data indicate that CMJ, SJ, CJs and CJb can be included in the daily training routine and criteria for the selection of basketball and volleyball players. In addition, coaches can use FT, EP and k as the main evaluation indicators for the daily training of athletes.

AVAILABILITY OF DATA AND MATERIALS

The data presented in this study are available on reasonable request from the corresponding author.

AUTHOR CONTRIBUTIONS

YL and MY—designed the research study; wrote the manuscript. MY, DTW and HFF—performed the research. PW—provided help and advice. MY and PW—analyzed the data. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was performed with the approval of the Institutional Review Board of Capital University of Physical Education and Sports (Approval number: 2020A76). All subjects signed an informed consent form.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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