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ORIGINAL RESEARCH

A comparative study of lower limb strength during vertical jump of male college students in table tennis, badminton and tennis

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Abstract

The objectives of this paper are to explore the correlation of kinetic indices of SJ (squat jump) and CMJ (counter-movement jump) and the differences of lower limb strength mechanics indexes of table tennis, badminton and tennis players under SJ and CMJ. This study included 60 male collegiate athletes, 20 each from table tennis, badminton, and tennis. Subjects performed SJ and CMJ tests on a force platform and the vertical jump data were analyzed. Table tennis, badminton and tennis players demonstrated significant differences in the SJ and CMJ assessments. Badminton players outperformed table tennis players in terms of peak power (PP) ($p = 0.005$) and peak velocity (PV) ($p = 0.017$). Badminton players beat table tennis players in PV ($p = 0.028$), PP ($p = 0.022$), fast twitch fibers (FTF) ($p = 0.033$) and pre-stretch effect (EP) ($p = 0.0004$). Tennis players exhibited lower peak force (PF) ($p = 0.006$) indicators than badminton players. For athletes in all three sports, the SJ test markers (vertical jump displacement, PF, PP and PV) demonstrated a strong positive correlation. There was a highly significant positive correlation between VJD and PF, PP, PV and FTF among badminton players. Significant positive connections were discovered between PF, PP, PV, FTF and EP, as well as between PP and PV and FTF and EP. PV and FTF had a very strong positive correlation, as did EP, PV and FTF. College badminton players had higher vertical jumps than table tennis and tennis players. In addition to vertical jump height, PP (power production), PV (power velocity) and FTF (force-time factors) are important markers for assessing the success of vertical jumps in athletes' daily training. These findings can assist coaches and athletes develop better vertical jump training programs.

Keywords

Table tennis; Badminton; Tennis; Lower limb strength; Vertical jump; SJ; CMJ

1. Introduction

Table tennis, badminton and tennis are all part of the racket sports group. These sports are characterized by constant rhythmic and intensity variations, as well as quick, repetitive activities of short duration [1–3]. Players are required to utilize a wide range of physical abilities, including speed, strength, cardiovascular endurance, agility, perceptiveness and decision-making abilities during competition [4]. What these sports have in common is that they all rely on the feet, waist and hands to generate power, enabling explosive power and strength to be generated [5]. Footwork is a crucial aspect of table tennis, badminton and tennis technique and the key to improving footwork lies in the athlete's lower limb strength [6]. Lower limb strength is essential for athletes to move, jump and perform sports techniques [7]. Athletes' physical fitness, particularly their lower body strength, has a direct impact on their motor qualities and, in turn, their sporting performance. The development of fundamental motor abilities in sports directly influences performance [8–10]. The vertical jump is one of the most important methods used to assess an athlete's lower body strength. The CMJ and SJ are fascinating because they require minimal familiarization, are simple to perform and are not exhausting. They can also provide valuable insights into an athlete's neuromuscular and stretch-shortening cycle (SSC) capabilities [11–15].

Tennis players need to coordinate several body parts when serving for power to generate the ideal racquet position, trajectory and velocity when they make contact with the ball. Individuals were divided into three groups (beginner, intermediate, elite) to gauge leg power (Pmax) by doing counter-movement leaps [16]. One researcher analyzed the physical fitness of high-level table tennis athletes across different genders. The focus was on how their lower body strength was reflected through their vertical jump performance [17]. Certain clinical experimental investigations have gathered kinematic and dynamic information regarding players playing forehand topspin using 3D motion capture devices, including infrared cameras and high-speed cameras [18]. In table tennis, whole-body synchronization is crucial, and the level of performance of the upper limbs is heavily influenced by the performance levels of the lower limbs. The crucial function of the lower limbs in table tennis has been extensively explored and documented in recent years [19–24]. Optimal lower limb movement performance will increase the racket and ball's velocity since it is the start of the kinetic chain [19, 25, 26]. A study has also evaluated changes in lower limb strength among badminton players before and after different training interventions using the longitudinal jump test [1].

Recent studies on the lower limb strength of table tennis, badminton and tennis players have primarily focused on analyzing the technical movements of the upper limb stroke, as well as the strength and coordination of the upper limb [27–29]. However, no studies have been conducted to compare the lower limb strength among athletes in these three sports. Despite the similarities in the use of rackets and similar movement patterns, each sport places distinct demands on the lower limb musculature due to variations in court size, playing surface and game-specific techniques. Therefore, it is important to investigate the differences in lower limb strength profiles among these sports to identify the physical attributes necessary for optimal performance. This study aims to explore the variability of longitudinal jump indices among table tennis, badminton and tennis players, as well as to identify the most relevant indices for lower limb strength in these athletes. The findings of this study will provide scientific guidance for athletes' training and can serve as a reference for athlete selection.

2. Materials and methods

2.1 Participants

The study's sample size was determined using G*Power (version 3.1.9.7; Franz Faul University Kiel, Kiel, Germany). Our analyses featured an α of 0.05, a power of 0.8, an effect size of 0.45 to compare the difference between three independent averages. Based on these specifications, the estimated sample size was 17 participants per group, totaling 51 male athletes. However, we recruited 60 male athletes (52 at the National 2 level and 8 at the National 1 level), with 20 each from table tennis, badminton, and tennis. All participants (as shown in Table 1) were right-handed and were recruited from Capital University of Physical Education and Sports. Before the experiment, participants underwent a rigorous physical examination to ensure they were physically fit and free of muscle and joint disease in the past 6 months. All 60 subjects completed all tests of this experiment successfully.

2.2 Experimental procedures

The Laboratory of Sports Biomechanics at Capital University of Physical Education and Sport in China conducted the measurements. All participants were in good health. Before the assessments, the participants were informed to avoid weight training for 72 hours and physical activity and caffeine consumption for 24 hours.

They were also instructed on the testing criteria and the vertical jumping motions before entering the Sports Science laboratory. The staff observed the participants, who wore casual clothing and sports shoes. After a 10-minute warm-up, the athletes performed three CMJs and three SJs on the force plate alternately. All athletes underwent testing at the same time each week in a lab with a 24 °C ambient temperature.

During the SJ test, participants were asked to place their hands on their hips to assess leg performance rather than arm performance. The subjects squatted in the preferred posture and remained still for one and a half seconds (Fig. 1) before jumping up. Three leaps were performed at one-minute intervals, and the highest jump was selected for further analysis. Subjects were not allowed to make any counter movements before takeoff.

The CMJ test was designed to evaluate leg performance and not arm performance. During the test, participants were instructed to rest their hands on their hips. To perform the test, subjects were asked to execute a quick downward movement followed by a rapid upward movement (as shown in Fig. 2) before attempting to leap up. Three jumps were made at one-minute intervals, and the highest jump was selected for further analysis.

The vertical leaps were recorded at 500 Hz using a force platform (Quattro Jump, 9286AA, Kistler, Switzerland). To eliminate energy gains resulting from trunk activity, participants were instructed to keep their hands on their hips to control arm contribution. Additionally, they were required to jump with their trunks as upright as possible in both SJ and CMJ.

TABLE 1. Participants characteristics and anthropometric measures (Mean ± SD) (n = 60).

Variable	Age (yr)	Height (cm)	Weight (kg)	BMI (kg/m^2)	Training Experience (yr)	Quadriceps muscle strength (rectus femoris, vastus medialis, vastus lateralis; %MVC)
Table Tennis	21.04 ± 1.37	171.26 ± 7.80	60.14 ± 7.31	20.22 ± 2.16	9.06 ± 3.61	35.9 ± 6.5, 48.3 ± 5.0, 41.8 ± 11.2
Badminton	20.86 ± 1.46	178.37 ± 6.29	70.24 ± 9.82	20.89 ± 1.64	8.44 ± 3.93	34.6 ± 6.1, 47.2 ± 5.6, 43.2 ± 10.9
Tennis	21.18 ± 1.30	179.19 ± 7.08	71.03 ± 9.75	21.64 ± 2.01	9.23 ± 2.89	35.7 ± 7.0, 48.5 ± 6.3, 41.6 ± 10.5

BMI, Body Mass Index; MVC, Maximum Voluntary Contraction.

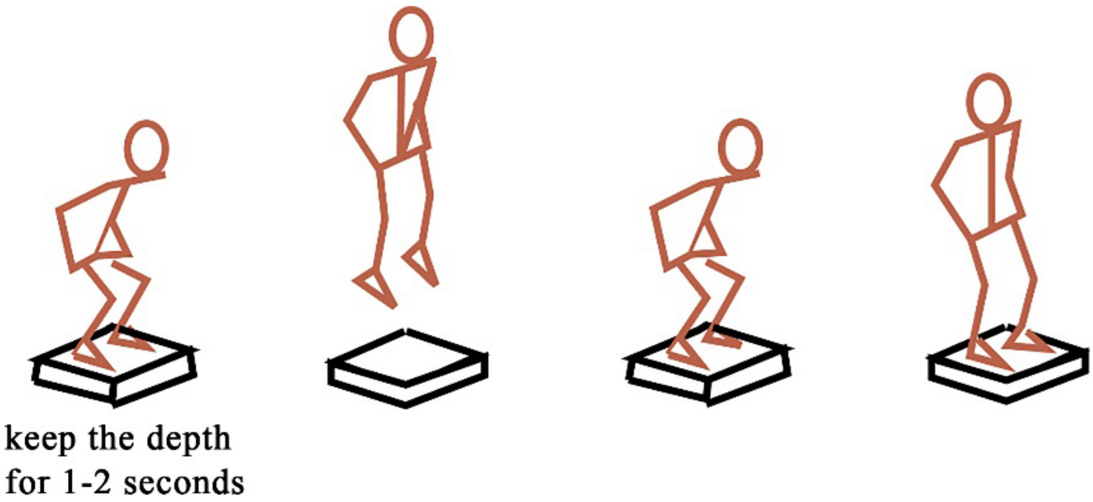

FIGURE 1. Diagram of squat jump.

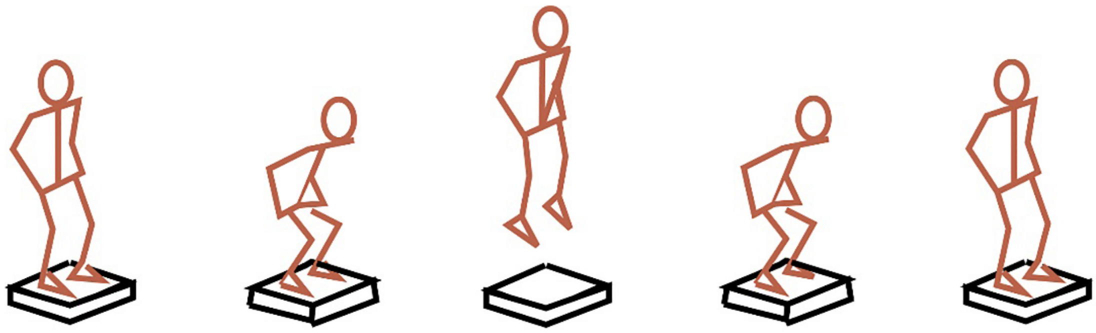

FIGURE 2. Diagram of countermovement jump.

2.3 Data analysis

The SJ and CMJ data were collected and analyzed using SPSS 25.0 (IBM, Chicago, IL, USA) and Excel (Microsoft Office 2019, USA). The vertical jump displacement (VJD) was calculated using standard methods based on the expected flight time of the center of mass [30]. The force plate directly recorded peak force (PF) and peak velocity (PV). The highest value of power during the propelling phase of the CMJ and SJ was identified as peak power. Fast Twitch Fibers (FTF) was the percentage of fast-twitch fibers (estimate), indicating the percentage of fast muscle fibers responsible for explosive force. A proprietary algorithm based on hundreds of biopsies was used to calculate this. The algorithm uses the jump height of SJ and CMJ (flight time method), sex, training type and age. The effect of Pre-stretch (%) (EP) was calculated using the formula (hf (CMJ)/hf (SJ) $\times$ 100%) $-$ 100% [31].

2.4 Statistical analysis

We analyzed data using descriptive statistics for the mean and standard deviation. We tested the residual data for normality using the Shapiro-Wilk test. To assess the variables for CMJ and SJ, we used one-way analysis of variance (ANOVA), and for *post hoc* multiple testing, we used Bonferroni. We looked at the correlation between the longitudinal jump indicators for tennis, badminton and table tennis individually using Pearson's correlation. We examined the CMJ variables' correlation using Pearson's product-moment correlation coefficients. We considered significant values as those with $p < 0.05$ and $p < 0.01$, and we conducted all analyses using the Statistical Package for the Social Sciences (SPSS 25.0, IBM, Chicago, IL, USA).

3. Results

The collected data was tested for normality, and the results indicated that the data followed a normal distribution. Furthermore, there were no significant differences in height, weight, BMI (Body mass index), quadriceps muscle strength among the three groups of subjects ($p > 0.05$).

3.1 Differences between table tennis, badminton and tennis players in SJ and CMJ tests

Fig. 3 illustrates that there were significant differences in PP (table tennis: 45.36 $\pm$ 5.76, badminton: 52.57 $\pm$ 7.77; p = 0.005) and PV (table tennis: 2.41 $\pm$ 0.22, badminton: 2.62 $\pm$ 0.22; p = 0.017) indicators between table tennis and badminton players in the SJ test. The results showed that the badminton players had significantly higher scores than table tennis players.

As shown in Fig. 4, there were significant differences in PV (table tennis: 2.57 $\pm$ 0.25, badminton: 2.76 $\pm$ 0.23; p = 0.028), PP (table tennis: 48.09 $\pm$ 7.71, badminton: 54.63 $\pm$ 7.09; p = 0.022), FTF (table tennis: 31.68 $\pm$ 5.85, badminton:

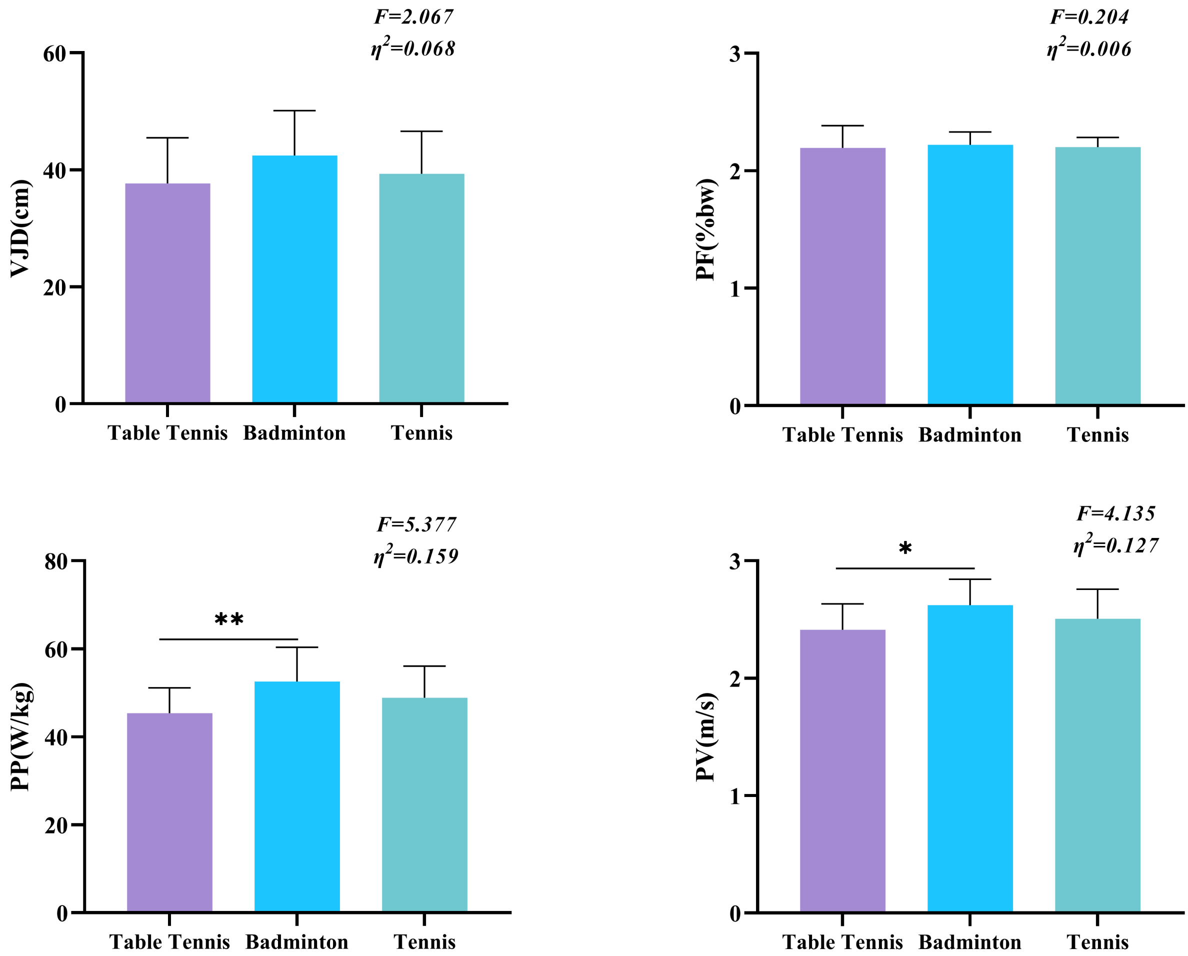

FIGURE 3. Results of the variance analysis of SJ index in table tennis, badminton and tennis players (n = 60). *$p < 0.05$, **$p < 0.01$. SJ, squat jump; VJD, vertical jump displacement; PF, peak force; PP, peak power; PV, peak velocity.

38.96 ± 10.46; $p = 0.033$) and EP (table tennis: 21.61 ± 4.53, badminton: 29.62 ± 2.62; $p = 0.0004$) indicators between table tennis and badminton players in the CMJ test, and the results of badminton players were significantly higher than table tennis players. There was a significant difference in PF indicators between badminton and tennis players (badminton: 2.27 ± 0.08, tennis: 2.17 ± 0.10; $p = 0.006$). Badminton players had significantly higher results.

3.2 Correlation of indicators for table tennis, badminton and tennis players in SJ and CMJ tests

3.2.1 Correlation of SJ test indicators in table tennis, badminton and tennis players

According to Table 2, there was a significant positive correlation between the indicators measured in the SJ test (VJD, PF, PP and PV) for athletes in all three sports: table tennis, badminton and tennis.

3.2.2 Correlation of CMJ test indicators in table tennis, badminton, and tennis players

Table 3 presents the results of the CMJ test conducted on players of table tennis, badminton and tennis. The study found a highly significant positive correlation between the VJD and

TABLE 2. Correlation of SJ test indexes in table tennis players.

Variable	VJD	PF	PP
Table tennis			
PF	0.51*		
PP	0.70**	0.53*	
PV	0.59*	0.56*	0.86**
Badminton			
PF	0.68**		
PP	0.71**	0.95**	
PV	0.79**	0.67**	0.73**
Tennis			
PF	0.80**		
PP	0.83**	0.89**	
PV	0.91**	0.74**	0.83**

**$p < 0.05$, **$p < 0.01$. SJ, squat jump; VJD, vertical jump displacement; PF, peak force; PP, peak power; PV, peak velocity.*

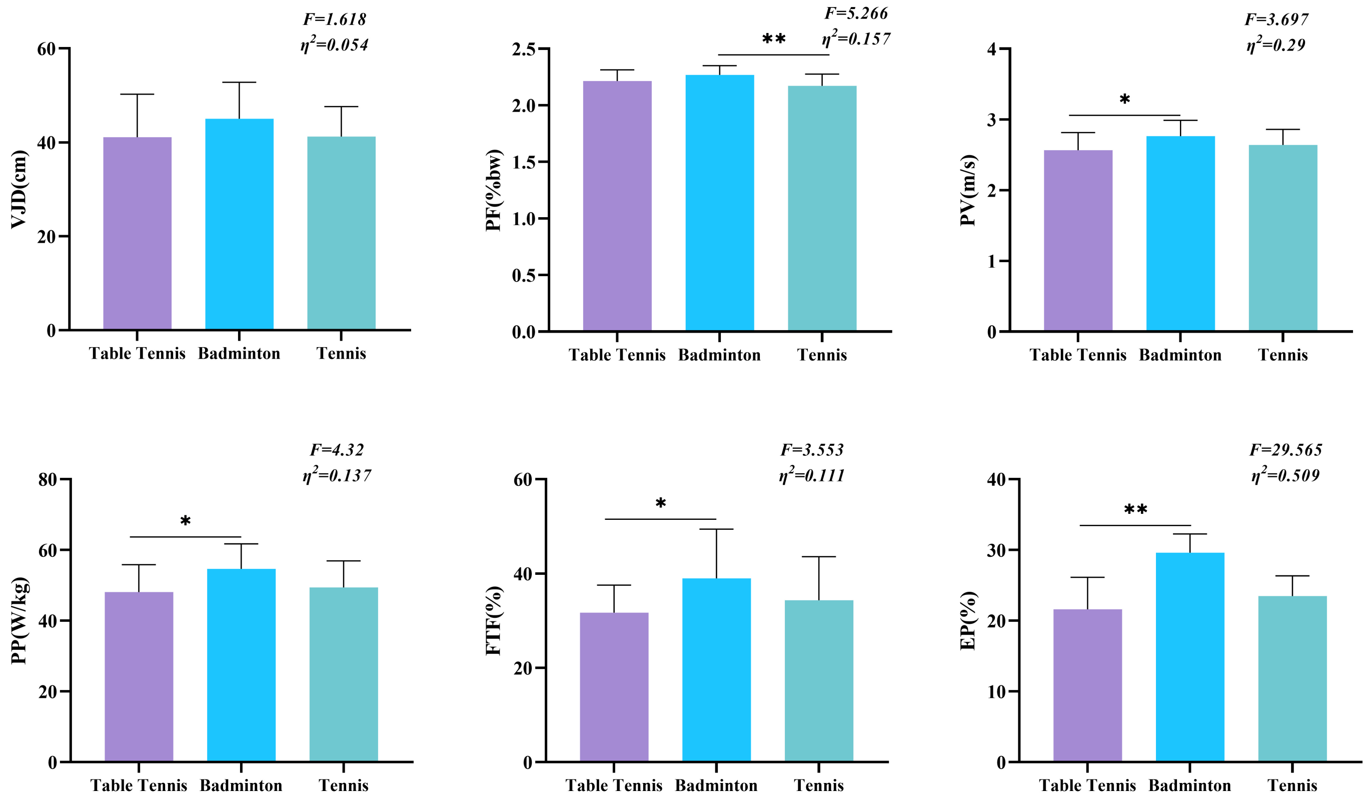

FIGURE 4. Results of the variance analysis of CMJ index in table tennis, badminton, and tennis players (n = 60). $*p < 0.05$, $**p < 0.01$. CMJ, countermovement jump; VJD, vertical jump displacement; PF, peak force; PV, peak velocity; PP, peak power; FTF, Fast Twitch Fibers; EP, Effect of Pre-stretch.

TABLE 3. Correlation of CMJ test indexes in table tennis players.

Sports		VJD	PF	PP	PV	FTF
Table tennis						
	PF	0.14				
	PP	0.78**	0.17			
	PV	0.87**	0.21	0.94**		
	FTF	0.83**	0.29	0.83**	0.86**	
	EP	0.03	0.50*	0.21	0.16	0.25
Badminton						
	PF	0.74**				
	PP	0.78**	0.80**			
	PV	0.95**	0.71**	0.82**		
	FTF	0.87**	0.71**	0.75**	0.90**	
	EP	0.39	0.70**	0.58**	0.49*	0.46*
Tennis						
	PF	−0.20				
	PP	0.76**	0.28			
	PV	0.90**	0.12	0.93**		
	FTF	0.88**	0.13	0.85**	0.94**	
	EP	−0.45**	0.27	−0.32	−0.33	−0.20

$*p < 0.05$, $**p < 0.01$. CMJ, countermovement jump; VJD, vertical jump displacement; PF, peak force; PV, peak velocity; PP, peak power; FTF, Fast Twitch Fibers; EP, Effect of Pre-stretch.

PP, PV and FTF of table tennis players. Similarly, there was a highly significant positive correlation between PV and PP and between FTF, PP and PV in table tennis players. In addition, a significant positive correlation between PF and EP was observed for table tennis players. For badminton players, the study revealed a highly significant positive correlation between the VJD and PF, PP, PV and FTF. Moreover, a highly significant positive correlation was observed between PF and PP, PV, FTF and EP. Moreover, a highly significant positive correlation was observed between PP and PV, FTF and EP. Additionally, there was a highly significant positive correlation between PV and FTF. A significant positive correlation between EP, PV and FTF was also observed. Lastly, for tennis players, the study found a highly significant positive correlation between VJD and PP, PV, FTF in the CMJ test, and a highly significant negative correlation with EP. Furthermore, the study found a highly significant positive correlation between PP and PV, FTF and between PV and FTF in tennis players.

4. Discussion

We conducted a study to analyze the strength mechanics indices of table tennis, badminton and tennis players in SJ and CMJ tests. We also examined the correlation of longitudinal jump indices in athletes from each of these sports. A major finding was that there were no significant differences in VJD for table tennis, badminton and tennis in SJ and CMJ test. The literature has established that the way a jump is executed affects the leaping height, which is consistent with our results [32, 33]. The badminton players had significantly higher in PP and PV than table tennis players in SJ and CMJ test. Power is a physical quantity that reflects how fast or slow work is done. This result is different from what researcher found [34] who discovered that the height of a vertical jump is a poor predictor of maximum power. The researchers hypothesized that individual push-off distance, ideal loading, and force-velocity profile were to blame for this outcome [35]. PP and PV in both vertical jump forms occur at the moment the athlete leaves the ground. The badminton players may have used the lower-body stretch-shortening cycle (SSC) more effectively compared to the table tennis players examined, which could be the reason for this discrepancy. We also found that synchronizing the function of each muscle participating in a multi-joint movement is necessary to get the best bodywork. When all motor units are recruited synchronously and fire at their fastest rate, the muscles may create the largest tension in the shortest amount of time. This coordinated movement is called intra-muscular coordination [33]. Finally, we found that badminton players have significantly better foot reaction time and eye-hand coordination than table tennis players, according to a previous study [36].

During the CMJ test, it was observed that badminton players had significantly higher FTF and EP than table tennis players. It is a known fact that stretching a muscle before shortening causes the muscle's tension to rise above the maximal isometric tension, increasing the possibility of an increase in work production during shortening. There is substantial evidence that passive elastic components in muscles store elastic energy, which can be reused during muscle shortening and contribute to increased positive work. This, combined with the muscle stretch, which causes an increase in muscle activation, commonly referred to as potentiation, leads to an increase in work production [33, 37]. There is no significant difference in the relative assistance lines compared to tennis players. However, it should be noted that tennis matches have a restricted vertical component, which might ultimately result in a lower vertical SSC performance compared to other sports [38, 39].

In the SJ test, it was found that two out of the four indicators—VJD, PF, PP and PV—showed a significant positive correlation for table tennis, badminton and tennis players. This suggests that multiple indicators can be used to fully evaluate an athlete's vertical jump during the SJ test. Under certain circumstances, the value of PP increases as the values of PP and PV increase. This is in line with previous studies which have shown that even though individual muscles may function perfectly during multi-joint movements, the overall mechanical work of the body may not be as high if their actions are not properly coordinated. Inter-muscular coordination, or the coordinated contraction of the muscles, refers to the way the muscles contract in a task-dependent order [40]. These findings support previous reports that have shown a positive correlation between peak power in a 40-kg conventional jump squat and CMJ height in Australian rules football players [41, 42].

During the CMJ test, there was a significant positive correlation between VJD and PP, PV, FTF in table tennis, badminton and tennis. This result suggests that the athlete's FTF increases the athlete's initial velocity during the long jump, thus positively impacting the athlete's VJD. It was also observed that there is a strong correlation between PP and FTF during the CMI, but there is no research available on this finding yet. One possible explanation for this correlation is that Fast-Twitch Fibers accelerate muscular contractions, thus boosting peak power [35]. In anaerobic activities, strong correlations were found between the percent of IIA fibers and 1 repetition maximum (RM) snatch performance ($r = 0.94$), static vertical jump height ($r = 0.79$) and power ($r = 0.75$) and countermovement vertical jump power ($r = 0.83$) in national caliber Olympic weightlifters [43].

The study shows a significant correlation between FTF and EP during the CMJ movement in badminton players, indicating that both FTF and EP can represent the counter-movement jump performance to some extent. As studies have shown the high reliability of FTF and EP data, FTF can be used to measure CMJ performance while assessing male badminton players in lower limb explosive exercise techniques [35].

This study is different from previous studies that examined the correlation of longitudinal jump indicators in track and field athletes. It aims to investigate the variability in different longitudinal jump forms and the correlation between vertical jumps in table tennis, badminton and tennis players. Although both studies used similar indexes, there were differences in the results. However, this study has some limitations such as sample size, demographic limitations and generalization of the findings. The sample in this study is limited to college athletes and the findings are only applicable to them. Future research should focus on a more in-depth and multifaceted study of athletes' lower extremity strength using the vertical jump as a testing method for coaches and athletes.

5. Conclusions

According to this study, college badminton players outperformed table tennis and tennis players in vertical jumps. The study also found that in addition to measuring vertical jump height, it is important to use indicators such as PP, PV and FTF to evaluate the effect of vertical jump in athletes' daily training.

ABBREVIATIONS

CMJ, countermovement jump; SJ, squat jump; VJD, vertical jump displacement; PF, peak force; PV, peak velocity; PP, peak power; FTF, Fast Twitch Fibers; EP, Effect of Pre-stretch; CV, coefficient of variation; ICC, intraclass correlation coefficients.

AVAILABILITY OF DATA AND MATERIALS

The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

AUTHOR CONTRIBUTIONS

DTW and LXW—designed the research study and performed the research. HFF—provided help and advice on the vertical jump experiments. XRL—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

The Institutional Review Board of Capital University of Physical Education and Sports approved this study, and all tests were completed prior to the start of the season (Approval number: 2020A76). All participants completed an informed permission form after being briefed about the procedures, in accordance with the Declaration of Helsinki on human experimentation.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found, in the online version, at https://oss.jomh.org/files/article/1792794525181067264/attachment/Supplementary%20material.docx.

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