

Original Research

Correlation analysis of vertical jump variables in male track and field athletes

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Submitted: 10 September 2021 Accepted: 29 November 2021 Published: 18 May 2022

Abstract

Background: The purpose of this study is threefold: (1) compare differences in countermovement jump (CMJ) variables and squat jump (SJ) variables in male track and field athletes; (2) explore the correlation of Fast Twitch Fibers (FT), Effect of Pre-stretch (EP) and other variables during the CMJ in male track and field athletes; (3) explore the correlation of SJ variables in male track and field athletes. **Methods:** 96 male university athletes (21.25 ± 1.04 years; 71.96 ± 8.58 kg; 180.05 ± 5.66 cm) in track and field volunteered to participate in this study. They are from Capital University of Physical Education and Sports, and all athletes are above the national standard at the second level. Subjects sequentially completed 3 CMJs and 3 SJs on the force plate. Throughout the entire range of motion, the CMJ and SJ were performed with both hands on the hips. In a laboratory, all of the individuals were assessed at the same time. SPSS 25.0 (Chicago, IL, USA) was used to run independent samples *t*-test and Pearson correlation analysis. **Results:** The vertical jump displacement (VJD) ($p < 0.01$), squat displacement (SD) ($p < 0.01$), peak velocity (PV) ($p < 0.01$), peak power (PP) ($p < 0.05$), average power (AP) ($p < 0.01$) were significantly higher during the CMJ than during the SJ. The peak force (PF) ($p < 0.01$) was significantly smaller during the CMJ than during the SJ. The FT and EP during the CMJ were associated with low test-retest reliability (coefficient of variation (CV): 9.73–8.86%). VJD, SD, PF, PP, and AP produced high test-retest reliability (CV: 2.29–4.48%) during both the CMJ and SJ movements. The correlation results were as follows, the VJD during the CMJ was significantly related to SD, PF, PP, AP ($r = 0.21$, $r = 0.42$, $r = 0.8$, $r = 0.69$, respectively). The PF during the CMJ was significantly related to PP and AP ($r = 0.87$, $r = 0.72$, respectively). The PV during the CMJ was significantly related to PP and AP ($r = 0.63$, $r = 0.79$, respectively). During the CMJ, there were significant connections between PP and AP ($r = 0.94$). Except for SD showed no significant relationships and the results for the correlation of other variables were the same as CMJ during the SJ. Furthermore, the Fast Twitch Fibers (FT) during the CMJ was significantly related to PP and AP ($r = 0.49$, $r = 0.46$, respectively). The Effect of Pre-stretch (EP) during the CMJ was significantly related to PV, PP, AP and FT ($r = 0.36$, $r = 0.24$, $r = 0.27$, $r = 0.22$, respectively). **Conclusions:** Our results indicate that both FT and EP were highly significantly correlated with PP in CMJ, and both FT and EP were significantly correlated with AP in CMJ. In addition, FT and EP data have good reliability. It means that FT and EP may be important indicators of lower limb strength in male track and field athletes under certain conditions. This will inform the training of male track and field athletes.

Keywords: Countermovement jump; Squat jump; Male; Fast Twitch Fibers; Effect of Pre-stretch; Track and field athletes

1. Introduction

Since ancient Greece, track and field have been one of the most important and fascinating of all Olympic Games competitions. With science and technology continue to advance, the level of athleticism increasing. Through continuous summaries and analysis of various athletics disciplines, it has been found that explosive power has a very important impact on the results that can be achieved by athletes in track and field. For example, in throwing, vertical jump, and sprinting events, strong explosive power is necessary to achieve excellent results [1]. The importance of impulsive ability in the lower limbs cannot be overstated.

Vertical jump is one of the important means to evaluate the impulsive ability of the lower limbs [2]. Vertical jumps are frequently used in sporting fields, not only as a necessary movement (e.g., basketball and volleyball), but also as a functional test [3–6]. Many protocols exist in the literature to prove or validate the proposed systems. Leaps with and

without countermovement [7–10], jumps with and without arm swing [11,12], drop jumps [13–15], single and double leg jumps [16], continuous jumps [17], squat jumps [7], and loaded squat jumps [18] are among the various types of jumps performed in those protocols. The height achieved by the user can be measured with any of these types of leaps, but the CMJ and SJ are the most widely utilized in all related work. The CMJ and SJ are intriguing since they are quick to complete, non-fatiguing, and need little familiarization. Moreover, they can provide useful information about an athlete's neuromuscular and stretch-shortening cycle (SSC) capacities [19–24].

The CMJ performance is determined by a complex interaction among several factors, including the maximal force developed by the musculature involved, the rate at which force can be developed, and the neuromuscular coordination [25]. The CMJ and SJ height have been widely used by sports performance professionals as an alternative



to direct assessment of maximal force and power [26,27]. Recently, as a simple task where maximum performance is clearly and objectively defined vertical jump has been applied to understanding human motor control of a multi-articular movement. One major practical question, however, remains the same: Which kinesiological factors are critical for vertical jump performance (VJP)? Coaches and trainers have tended to focus on lower limb muscular strength training as a means to improve VJP, but it seems that other factors can affect vertical jump performance as well [28]. Further, many researchers have investigated the correlation of variables in the lower limbs during CMJ and SJ. For instance, the researchers analyzed the long jump test and dynamic balance correlations on amateur rugby players [8], and Radhouane Haj Sassi *et al.* [29] examined the relationship to the free countermovement jump (FCMJ) and the 10-m straight sprint (10mSS). The main indicators involved are jump height, peak force, peak power, rate of force development, and reactive strength index [2–4,7,19,20]. However, the correlation between jump height, EP, and FT has not been well investigated. Therefore, the purposes of this study are (1) comparing differences in countermovement jump (CMJ) variables and squat jump (SJ) variables in male track and field athletes; (2) exploring the correlation of Fast Twitch Fibers (FT), Effect of Pre-stretch (EP) and other variables during the CMJ in male track and field athletes; (3) exploring the correlation of SJ variables in male track and field athletes. Thus, it provides a reference for the training of male track and field athletes.

2. Methods

2.1 Subjects

A total of 96 university male track and field athletes (21.25 ± 1.04 years; 71.96 ± 8.58 kg; 180.05 ± 5.66 cm) volunteered to participate in this study. The events of specialization were short-distance ($n = 27$), middle-distance ($n = 16$), hurdling ($n = 13$), jumping ($n = 26$), and throwing ($n = 14$). All of these male athletes are above the national standard at the second level, and they had not had a lower limb injury in nearly three months.

Participants had been training regularly (three times per week) for at least four years before the study. Vertical jumps were a part of every athlete's regular training routine. They did not disclose any injuries or other conditions that prevented them from training or influenced their maximum physical performance in any way.

2.2 Testing protocol

The measurements were taken at China's capital university of physical education and sports' Laboratory of Sports Biomechanics. All participants were instructed to refrain from rigorous exercise the day before the assessments, as well as any additional resistance training in the 72 hours leading up to the tests. Participants were also asked to refrain from exercising and drinking caffeinated beverages for 24 hours before the testing sessions.

Under the supervision of the personnel, subjects entered the Sports Science laboratory wearing comfortable apparel and athletic shoes and were familiarized with the vertical jumping movements and testing requirements. Before the tests, each participant was familiarized with the research goals. After a 10-minute warm-up, the participants performed three CMJs and three SJs on the force plate in order. In a laboratory with an ambient temperature of 24°C , all athletes were examined at the same time of the week.

In the SJ test, subjects were asked to rest their hands on their hips, as this test was designed to measure leg performance rather than arm performance. Subjects squatted (preferred position) and held stationary for 1–2 seconds (Fig. 1), then tried their hardest to jump up. Three jumps were conducted at one-minute intervals, with the highest leap being chosen for further investigation. Before take-off, subjects were not allowed to perform any countermovement.

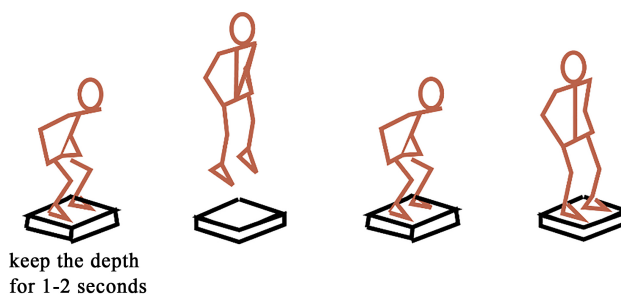


Fig. 1. Diagram of squat jump.

In the CMJ test, subjects were asked to rest their hands on their hips, and the exam was designed to measure leg performance rather than arm performance. Subjects began in a fully erect standing position and were asked to make a quick downward movement (preferred position) followed by a quick upward movement (Fig. 2) before attempting to jump up. Three jumps were conducted at one-minute intervals, with the highest leap being chosen for further investigation.

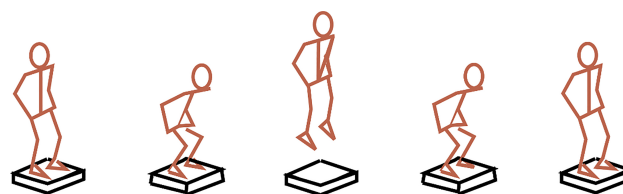


Fig. 2. Diagram of countermovement jump.

Vertical jumps were recorded at 500 Hz on a force platform (Quattro Jump, 9286AA, Kistler, Switzerland). Participants were required to keep their hands on their hips (to control arm contribution) and jump with their trunks as erect as possible in both SJ and CMJ to minimize or reduce energy gains related to trunk activity.

2.3 Data analysis

Excel (2019) and SPSS 25.0 (Chicago, IL, USA) were used to collect and analyze all SJ and CMJ data. The vertical jump displacement (VJD) was determined using previously established methods based on the projected flight duration of the center of mass [30]. Squat displacement (SD) was the lowest position of the athlete's squat. Peak force (PF) and peak velocity (PV) were measured directly by the force plate. The maximal value of power during the propulsive phase of the CMJ and SJ was determined as peak power (PP). Average power (AP) was average concentric power from the time when $v(t)$ becomes positive until takeoff. Fast Twitch Fibers (FT) 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. Uses jump height of SJ and CMJ (flight time method), sex, training type, and age. Effect of Pre-stretch (%) (EP) = $(hf(\text{CMJ})/hf(\text{SJ}) \times 100\%) - 100\%$.

Table 1. Characteristics of performance during the countermovement jump (CMJ) and squat jump (SJ) (n = 96).

Variable	CMJ	SJ	<i>p</i>	<i>t</i>
Vertical jump displacement (cm)	50.03 ± 6.84**	45.68 ± 8.07	0.000	4.03
Squat displacement (cm)	33.85 ± 6.5**	24.89 ± 7.53	0.000	8.82
Peak force (% bw)	2.24 ± 0.18**	2.34 ± 0.22	0.001	-3.32
Peak velocity (m/s)	2.65 ± 0.27**	2.47 ± 0.24	0.000	4.88
Peak power (W/kg)	50.46 ± 8.06*	48 ± 7.35	0.029	2.2
Average power (W/kg)	29.94 ± 4.37**	24.44 ± 3.53	0.000	9.6
Fast Twitch Fibers (%)	49.15 ± 19.49	-	-	-
Effect of Pre-stretch (%)	26.86 ± 19.02	-	-	-

* $p < 0.05$, ** $p < 0.01$. Values are expressed in Mean ± SD.

2.4 Statistical analysis

The data are shown in descriptive statistics for mean and standard deviation (SD). The Shapiro–Wilk test was performed to verify the normality of the residual data. The variables for the CMJ and SJ were analyzed using an independent samples t-test and Pearson correlation analysis. Pearson's product moment correlation coefficients were used to determine the relationship of CMJ variables. Within-subject variation and reliability for CMJ variables and SJ variables was determined by calculating the coefficient of variation (CV), confidence limits (95%), and intraclass correlation coefficients (ICC) as described by Hopkins [31]. Significant at $p < 0.05$ and $p < 0.01$ were recorded separately and considered as significant. The analyses were performed with the Statistical Package for Social Sciences (SPSS 25.0, Chicago, IL, USA).

3. Results

The data follows a normal distribution. Table 1 displays the mean (± SD) values for the CMJ and SJ. During the CMJ, the VJD ($p = 0.00$), SD ($p = 0.00$), PV ($p = 0.00$), PP ($p = 0.029$) and AP ($p = 0.00$) were significantly greater than during the SJ. The PF ($p = 0.001$) was significantly smaller during the CMJ than during the SJ.

Tables 2 and 3 show the calculated CV and ICC for each of the force-time variables measured during the CMJ and SJ, as well as the related 95% confidence limits. VJD, SD, PF, PV, PP, and AP all had strong test-retest reliability (CV range: 2.29–4.48%) and test-retest correlations (ICC range: 0.88–0.98) for CMJ and SJ movements. Low test-retest reliability (CV range: 9.73–8.86%) and high test-retest correlations (ICC range: 0.96–0.98) were seen in the FT and EP for the CMJ.

Table 2. During the CMJ, the coefficients of variation (CV), intraclass correlation coefficients (ICC), and related 95% confidence limits for variables (n = 96).

Variables	CV (%)	ICC (range)
VJD	2.93	0.97 (0.92–0.99)
SD	4.25	0.95 (0.89–0.98)
PF	3.52	0.88 (0.79–0.96)
PV	4.03	0.94 (0.86–0.98)
PP	2.29	0.90 (0.76–0.96)
AP	3.64	0.89 (0.77–0.98)
FT	9.73	0.96 (0.90–0.99)
EP	8.86	0.98 (0.86–0.99)

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.

Table 3. During the SJ, the coefficients of variation (CV), intraclass correlation coefficients (ICC), and related 95% confidence limits for variables (n = 96).

Variables	CV (%)	ICC (range)
VJD	2.43	0.98 (0.91–0.99)
SD	4.28	0.93 (0.90–0.95)
PF	4.09	0.89 (0.78–0.98)
PV	3.72	0.92 (0.85–0.99)
PP	2.93	0.94 (0.80–0.98)
AP	3.51	0.92 (0.81–0.99)

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

The interrelationship between variables for the CMJ and SJ are presented in Tables 4 and 5. SD, PF, PP, and AP were all significantly connected to VJD during the CMJ.

Table 4. Results of intercorrelation of variables during CMJ tests (n = 96).

	CMJ							
	VJD	SD	PF	PV	PP	AP	FT	EP
VJD	1.00							
SD	0.21*	1.00						
PF	0.42*	0.20	1.00					
PV	-0.02	0.01	-0.03	1.00				
PP	0.8**	-0.00	0.87**	0.63**	1.00			
AP	0.69**	0.02	0.72**	0.79**	0.94**	1.00		
FT	-0.00	-0.02	-0.03	0.19	0.49**	0.46**	1.00	
EP	0.02	-0.06	0.07	0.36*	0.24*	0.27*	0.22*	1.00

* $p < 0.05$, ** $p < 0.01$. CMJ, countermovement jump; 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.

The PF during the CMJ was tied to PP and AP in a significant way. PP and AP were both significantly connected to PV during the CMJ. During the CMJ, there were significant correlations between PP and AP (Table 4). With the exception of SD showed no significant relationships and the results for the correlation of other variables are the same as CMJ during the SJ (Tables 4 and 5). Furthermore, PP and AP were both significantly related to the FT during the CMJ. PV, PP AP, and FT were all significantly connected to EP during the CMJ.

Table 5. Results of intercorrelation of variables during SJ tests (n = 96).

	SJ					
	VJD	SD	PF	PV	PP	AP
VJD	1					
SD	-0.15	1.00				
PF	0.47*	-0.13	1.00			
PV	-0.07	-0.05	-0.13	1.00		
PP	0.75**	0.01	0.88**	0.31*	1.00	
AP	0.71**	-0.03	0.76**	0.67**	0.92**	1.00

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

4. Discussion

In the present study, there were significant relationships between VJD and SD ($r = 0.21$; $p = 0.046$) during the CMJ. The lower the squat position, the greater the vertical jump performance under a certain condition. The current findings are in line with previous findings. Rodrigo G. Gheller *et al.* [32] discovered that jumping from a more flexed knee posture seemed to be the greatest method for achieving the best results [33]. This outcome is contrary to that of Moran and Wallace *et al.* [34] who found that jumps performed with 90 degrees of knee flexion had higher CMJ height than jumps performed with 70 degrees of knee flex-

ion (0 indicates entire extension). Domire and Challis *et al.* [35] reported that a deeper squat depth did not result in larger jump heights, and they suggested that the results were due to non-optimal coordination during the jumps. In addition to VJD, there was no significant correlation between SD and others variables during the CMJ and SJ. The squat height of the vertical jump was used as the preferred squat height for the subjects in this study, and SD influenced the intersegmental coordination of vertical leaps [33]. However, longer force exertion and thus higher jump performance does not imply necessarily better impulsive ability [36].

This study found a significant correlation of VJD and PF during the CMJ ($r = 0.42$, $p = 0.031$) and SJ ($r = 0.47$, $p = 0.035$). In contrast to earlier findings, this represents a significant improvement. One hypothesis is that jump height is mostly determined by coordination rather than just by increased strength in triple extension [37,38]. Meanwhile, Maximum physical strength (as evaluated by a one-rep maximum back squat) was found to be strongly linked with VJD in college-aged athletes by Petersen *et al.* [39]. Changes in neural drive, which have a substantial influence on force development throughout the early (0–50 ms) and mid phase (50–200 ms) of rising muscular force, are most likely to blame for variation in TPF within an individual [40]. Moreover, despite having similar movement patterns, SJ and CMJ have different properties [41]. Therefore, it is suggested that the relevance of PF to VJD during the CMJ might be the coordination of the lower limb joints.

According to Rodrigo G. Gheller *et al.* [32], when the joints produced lower segmental angular velocity, the knee and hip were more in phase, implying that the movement pattern was more stable in this situation. However, in this study, there were no significant relationships between PV and VJD during the CMJ and SJ. The possible reasons are that the subjects selected for the study included field and track events in athletics, and they need more horizontal displacement in training and competition, so this may be the reason for the above results.

The current study's findings reveal a clear and significant link between PP and VJD during the SJ and CMJ. These findings are in line with others that have been published. It was previously observed that peak power in a 40 kg traditional jump squat and CMJ height in a group of Australian rules football players had a similar positive link ($r = 0.75$) [42,43]. Furthermore, 5JT performance was highly connected with vertical jump height and power factors, according to Chamari *et al.* [2]. Peak power ($r = 0.8$, $p < 0.05$ to $r = 0.83$, $p < 0.01$) was likewise determined to be the characteristic most associated with a vertical performance by Ashley *et al.* [44]. One of the greatest indicators of CMJ performance is the power reached during the concentric phase of the vertical leap. This should not be surprising, power is a physical quantity that reflects how fast or slow work is done. This outcome is contrary to that of Morin J B, Jiménez-Reyes P *et al.* [45] who found vertical jump height is a poor indicator of maximal power output. The researchers suggested that the reasons for this result were individual push-off distance, optimal loading and force-velocity profile. The relationship between SJ or CMI height is clearly confounded by individual anthropometrical and physiological factors inherent to each athlete tested. Not taking these factors into account may lead to bias when quantifying Pmax via single jump tests without additional load. In addition to that, there was a significant relationship between PP and FT during the CMJ, there is no literature on this result until now, Possible reasons are that Fast-Twitch Fibers increase peak power by increasing the velocity of muscle contraction.

The present study showed that the EP during the CMJ was significantly related to PV, PP, AP, and FT, respectively. Previous studies have employed pre-stretch augmentation percentage (PSAP) estimates to analyze an athlete's capacity to use the SSC to improve their vertical jump height (JH) and peak power (PP) [24,46]. However, there was no significant relationship between FT and VJD in the present study, and this is different from the previous studies. The possible reasons are that effect of pre-stretch is considered to be a measure of the ability to utilize the pre-stretch of the muscles during a CMJ. To a certain extent, it does not directly affect the vertical jump height, but the peak power and peak velocity of the vertical jump.

In summary, the present data indicate that there is a significant correlation between FT, EP, and PP during the CMJ movement in male track and field athletes. The significant correlation suggests that FT and EP can reflect the countermovement jump performance to a certain extent. Meanwhile, FT and EP data have good reliability, and EP and PP may be used as a measure of CMJ performance when testing male track and field athletes in lower limb explosive exercise techniques. However, there are some limitations to the article, as this study was conducted on track and field athletes, while the applicability to other athletes (basketball, volleyball, soccer, etc.) remains to be verified.

5. Conclusions

Our results indicate that both FT and EP were highly significantly correlated with PP in CMJ, and both FT and EP were significantly correlated with AP in CMJ. In addition, FT and EP data have good reliability. It means that FT and EP may be important indicators of lower limb strength in male track and field athletes under certain conditions. This will inform the training of men's track and field athletes.

Abbreviations

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

Author contributions

XK and YF designed the research study and performed the research. HW provided help and advice on the vertical jump experiments. XK 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

All examinations were performed before the commencement of the season, and this study was performed with the approval of the Institutional Review Board of Capital University of Physical Education and Sports (Approval number: 2018A06). In compliance with the Declaration of Helsinki on human testing, all participants were told about the procedures and completed an informed consent form.

Acknowledgment

Thank numerous individuals who participated in this study.

Funding

We gratefully acknowledge the financial support by State Key R&D Program (No. 2018YFF0300603).

Conflict of interest

The authors declare no conflict of interest.

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