

## Reliability and Differences of Jump Kinetics Related to Different Load in College Male Athletes

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*The purpose of this study was to explore reliability and differences of jump kinetics related to different training load in college male athletes. The subjects were required to perform countermovement jump (CMJ) and loaded countermovement jump (LCMJ-0%, LCMJ-20% and LCMJ-80% of one-repetition maximum squat) three times for each load which were recorded by a force plate. One-way repeated measures ANOVA and the LSD post hoc method were employed to evaluate the results. The results revealed that jump kinetics-related parameters increased/decreased by the load. Compared with the loading jumps, the CMJ incorporate with an arm swing directly led to an increase in eccentric contraction duration during jumping. Most of the jump mechanical parameters under substantially different load conditions fall within the good to excellent reliability. It appears that the CMJ and CMJ with extra load were reliable in explore the kinetics related parameters.*

**Keywords:** *countermovement jump, one-repetition maximum, arm swing, eccentric contraction*

### Introduction

In volleyball, basic movements such as blocking, spiking, scrambling, and fast shifting are linked with indicators of physical fitness. Lower limbs' explosive power, agility, and muscle strength play an important part. Players compete in the field for a long time and perform high-intensity intermittent exercise. Therefore, lower limb neuromuscular power output has a great influence on sports performance in this arena which related to muscle strength, power, and neural function. Through the relationship between the ground reaction force that players generate when they jump and the time series, different kinetics parameters related to the evaluation of the explosive power state can be calculated, such as the development of the maximum rate of force, impulse, hang time, and other force parameters. In the past, peak power output (PPO) was a common means of evaluating athletes' overall performance. However, in recent years, new research results have led to the suggestion that a single PPO index should not be used to evaluate the jumping state as far as possible because PPO may be affected by the final result due to the jumping mode and the muscle mechanism (Fàbrica et al. 2020, Ruddock and Winter

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2015). Gathercole et al. (2015b) used the countermovement jump (CMJ), which is the most common method of monitoring lower limb explosive power, to evaluate nerve adaptation. In their study, maximum power, impulse, concentric contraction time, eccentric contraction time, flight time, and other parameters were evaluated at different time series stages. The results revealed that many parameters showed recovery within 24 hours, indicating that fatigue evaluation using multiple indicators would be a feasible approach.

In volleyball, which is a high-intensity intermittent sport, muscles must produce strong contractions to power rapid explosive whole-body movements such as sprinting and jumping. Therefore, lower limb explosive power is a common indicator of athletic ability. There will be differences in muscle development morphology and ability among different athletes due to their positions. Previous research found differences in muscle thickness, fascicle length, and isokinetic muscle strength, identified correlations between squat jump (SJ) height and countermovement jump (CMJ) height, and sprint performance (Alegre et al. 2009, Nimphius et al. 2012, Spiteri et al. 2015). As a test to monitor athletes' neuromuscular status, the CMJ has also been widely used in different fields, and common CMJ test methods often take average peak, jump height, and maximum power as indicators (Cormack et al. 2008, Cormie et al. 2009). Previous studies have pointed out that information related to muscle fatigue may be overlooked when exclusively considering the above indicators, which can result in inaccurate judgement of the current status due to the lack of reproducibility and sensitivity (Knicker et al. 2011). Cormie et al. (2009) studied nerve and muscle adaptability and mechanisms during training using a time-domain analysis of strength parameters, based on CMJ strength signals and subsequent calculations; this method allowed for the effective observation of fatigue changes in muscles and nerves, so as to observe the states of and changes in external load stimulation and muscle eccentric contraction. Traditionally, muscle contraction state and ability are synoptically observed through CMJ analysis. Due to the combined eccentric and concentric contractility, this phenomenon is caused by the stretch shortening cycle (SSC), which involves material metabolism, mechanical energy, and nerve conduction factors (Nicol et al. 2006).

For many athletes, the ability to generate a lot of power in a short time is very important, and performing loaded jump training by applying an external load is an effective means of increasing muscle strength and power (Dugan et al. 2004, Zink et al. 2006). Vertical jumping is also commonly used to evaluate individuals' muscle strength and power (Carlock et al. 2004, Hori et al. 2006). Countermovement jumping (CMJ) is the most frequently used vertical jumping technique for evaluating muscle strength and power. Measuring athletes' jump height and monitoring the act of jumping (Cronin et al. 2004, Dugan et al. 2004, Garcia-Lopez et al. 2005) is an effective means of evaluating vertical jump power (Hori et al. 2009) and monitoring the neuromuscular state (Heishman et al. 2020, Legg et al. 2017). To improve the explosive power of lower limbs for volleyball player, the loaded squat jump is one of the most commonly used training method which provides positive benefits for jumping performances. However, the players usually used an arm swing CMJ in the field but not only squat jump without arm swing. Therefore, the

purpose of this study was to quantify the pattern of within-subject variability in kinetic variables in college male volleyball players. This study also sought to determine the changes in jump mechanical parameters with different training load. This investigation should provide valuable insight to coaches on basic physical training to establish effective training modes.

## Methods

### *Participants*

Sixteen elite male college volleyball players were used as the study participants (mean age =  $21.5 \pm 1.5$  years; mean height =  $185.5 \pm 3.5$  cm; mean weight =  $79.5 \pm 5.2$  kg). All the participants in the study had participated in professional volleyball training for over five years and were registered in the Division I men's University Volleyball League in Taiwan. The subjects were free of major musculoskeletal system disorders within the year preceding the study. During the experiments, verbal cues were used in the experiment, and the participants were required to make their best effort. Approval from the relevant local Institutional Review Board (Landseed International Hospital Institutional Review Board, NO.18-015-B1) and individual written informed consent from all participants were obtained beforehand. All experiments were performed in accordance with relevant local guidelines and regulations.

### *Research Tools and Test Methods*

In this study, the CMJ with an arm swing and the loaded countermovement jump (LCMJ) were used to measure the lower limbs' maximum explosive power, and the parameters (Table 1) were calculated based on the force exerted on the ground (Gathercole et al. 2015b). Each subject stood on a force plate (9260AA, Kistler Ltd., Switzerland) to perform the experiment in triplicate, the mean value was taken as the calculation parameter, and then the individual's bodyweight was taken as the benchmark for standardization. The weight plate's sampling frequency was set to 1,000 Hz for data collection. The weight-bearing devices used in the experiment were the Olympic standard men's barbell and weight plates. The barbell was 220 cm in length and 20 kg in weight. The bar body was 131 cm in length and 2.8 cm in diameter. The CMJ and LCMJ methods adopted in this study are as follows:

- I. CMJ with arm swing (Figure 1a): In this study, the CMJ entailed the subject standing upright on the force plate, with the chest and both legs straightened. After preparing, the subject quickly squatted to the optimal take-off point, and then jumped vertically as rapidly and as high as possible. The process must be continuous, without pause, and both arms must swing.
- II. LCMJ (Figure 1b): In this study, the LCMJ entailed that the subject stand on the force plate and perform a high-bar back squat. The barbell was fixed

on the upper back, with both the subject's hands holding the bar. The feet were separated at shoulder width, and the back was kept upright. After preparation, the subject squatted quickly to the optimal take-off point and jumped vertically as high as possible. The purpose of this jump movement was to observe the SSC response during load-bearing take-off. For LCM-0% load, plastic water pipes were used instead of barbells.

**Figure 1a.** CMJ with Arm Swing**Figure 1b.** LCMJ with Barbell**Table 1.** The Calculated Variables of Jump Performances

Variable	Abbreviation	Description
Peak force	PF	Greatest force achieved during the jump
Mean force	MF	Mean power generated during the concentric phase of the jump
30ms-Maximum rate of force development	30ms-mRFD	Largest force increase during a 30-ms epoch
50ms-Maximum rate of force development	50ms-mRFD	Largest force increase during a 50-ms epoch
Time to peak force	TTPE	Time from jump initiation to peak force
Flight time	FT	Time spent in the air from jump take-off to landing
Jump height	JH	The maximum jump height achieved
Eccentric duration	Ecc-Dur	Time required to perform the eccentric CMJ phase
Concentric duration	Con-Dur	Time required to perform the concentric CMJ phase
Total duration	Toltal-Dur	Time required to perform the entire CMJ

Source: Gathercole et al. 2015b.

### Experimental Procedures

First, the one-repetition maximum (1RM) was measured. Before the 1RM test, the subjects were given appropriate guidance, and the test procedures were explained to ensure that they understood how to correctly perform the experimental steps and movements. In accordance with the instructions, the subjects used appropriate

weights to practice squat weightlifting. While holding the opposite sides of the barbell with their hands, they extended from 90 degrees to 180 degrees, with the knee joints as the center, and then returned to the original position. For warm-up, six to ten repetitions were performed with an estimated load of about 50% to 1RM. The warm-up allowed the subjects to familiarize with the test devices and the squat weightlifting movements. After warm-up, the subjects rested for 3 minutes and then made up to three attempts to lift the 1RM weight, with intervals of at least 15 minutes. After a rest period of at least 15 minutes, the weight was increased by 5–10 kg until failure to perform a single complete movement. The mean 1RM measured in this study was  $99.34 \pm 8.14$  kg.

The interval between the formal experiment and 1RM measurement was 72 hours. During formal measurement, the CMJ test was performed first. The subjects were required to perform the CMJ test three times on the force plate, following the given instructions, and then perform LCMJ-0% three times, after taking a 10-minute break. After completion, the subjects took another 10-minute break, and then LCMJ-20% was performed three times. After completion, the subjects took another 10-minute break, and then LCMJ-80% was performed three times. A total of 12 jump measurements were taken.

### *Statistical Analysis*

Data from all the tests were processed using a custom-written MATLAB script (Version R2008a; MathWorks Inc., USA) including peak force (PF), mean force (MF), 30ms maximum rate of force development (30ms-mRFD), 50ms maximum rate of force development (50ms-mRFD), time to peak force (TTPF), flight time (FT), jump height, (JH), eccentric duration (Ecc-Dur), concentric duration (Con-Dur) and total duration (Total-Dur). The results of PF and MF were standardized according to the body weight (BW) of each participant. The Statistical Package for the Social Sciences (SPSS) 20.0 software (version 20.0; SPSS Inc., Chicago, IL, USA) was used for the statistics and data analysis. First, the reliability of the measured data was tested using the intra-class correlation coefficient (ICC) for each calculated variable. One-way repeated measures ANOVA and the LSD post hoc method were employed to evaluate the results of CMJ, LCMJ-0%, LCMJ-20% and LCMJ-80%. The level of significance was set at  $\alpha = 0.05$ .

### **Results**

The analyzed results for jump performances variables including CMJ, CMJ-0%, LCMJ-20% and LCMJ-80% are outlined in Table 2. Based on the distinction of ICC value, it can be divided into the following parts, medium reliability (0.5 to 0.75), good reliability (0.75 to 0.90), and excellent reliability (above 0.9). According to the analysis of the results, it is shown that most of the jump mechanical parameters under substantially different load conditions fall within the range of good (0.75-0.90) to excellent (above 0.90), and only five values fall into the medium reliability (0.50-0.75), which are 30ms-mRFD (LCMJ-80%), Ecc-Dur

(LCMJ-0%, LCMJ-20%, LCMJ-80%), Total-Dur (LCMJ-0%). This results demonstrated that the results of this study meet the reliability after repeated measurement. The results of descriptive statistics show that PF, MF, 30ms-mRFD, 50ms-mRFD, FT, JH, and Ecc-Dur decrease as the load increases. However, the parameter values of TTPF, Con-Dur and Total-Dur are increasing. After repeated measures ANOVA, PF, FT and JH showed the same significant difference results ( $p < 0.01$ ) (CMJ > LCMJ-0% > LCMJ-20% > LCMJ-80%). There are also significant differences in the MF ( $p < 0.01$ ) (CMJ > LCMJ-0% > LCMJ-80%; CMJ > LCMJ-20% > LCMJ-80%). A significant difference was reached in the Ecc-Dur ( $p < 0.01$ ) (CMJ > LCMJ-0%; CMJ > LCMJ-20%; CMJ > LCMJ-80%). Significant difference was reached in the part of TTPF ( $p < 0.01$ ) (LCMJ-80% > LCMJ-20% > CMJ; LCMJ-80% > LCMJ-0%). A significant difference was reached in the Con-Dur part ( $p < 0.01$ ) (LCMJ-80% > LCMJ-20% > CMJ; LCMJ-80% > LCMJ-20 > LCMJ-0%). There is a significant difference in Total-Dur ( $p < .01$ ) (LCMJ-80% > LCMJ-20%; LCMJ-80% > LCMJ-0%; LCMJ-80% > CMJ).

**Table 2.** The Intraclass Correlation Coefficient (ICC) and Comparison of Different Loaded Countermovement Jump

	CMJ (ICC)	LCMJ-0% (ICC)	LCMJ-20% (ICC)	LCMJ-80% (ICC)	F
PF	2.69±0.25 (0.963)	2.36±0.20 (0.933)	2.12±0.20 (0.973)	1.79±0.10 (0.919)	183.826**
MF	1.52±0.13 (0.869)	1.35±0.11 (0.820)	1.31±0.11 (0.855)	1.23±0.05 (0.856)	22.336**
30ms-mRFD	17.81±10.59 (0.828)	15.96±12.88 (0.942)	15.52±7.21 (0.814)	14.82±8.17 (0.689)	0.326
50ms-mRFD	20.36±11.32 (0.860)	15.84±12.80 (0.932)	14.76±6.89 (0.756)	13.37±6.39 (0.785)	0.123
TTPF	0.56±0.16 (0.885)	0.59±0.18 (0.871)	0.65±0.16 (0.911)	0.78±0.16 (0.942)	20.505**
FT	0.60±0.05 (0.971)	0.55±0.04 (0.930)	0.46±0.04 (0.947)	0.31±0.05 (0.928)	470.409**
JH	44.23±6.65 (0.970)	37.37±6.00 (0.938)	26.38±4.98 (0.950)	12.22±3.56 (0.938)	379.990**
Ecc-Dur	0.41±0.09 (0.838)	0.34±0.08 (0.746)	0.32±0.06 (0.503)	0.29±0.08 (0.668)	7.664**
Con-Dur	0.52±0.12 (0.948)	0.57±0.17 (0.930)	0.66±0.17 (0.949)	0.80±0.15 (0.955)	29.919**
Total-Dur	0.93±0.13 (0.842)	0.91±0.17 (0.669)	0.98±0.18 (0.836)	1.09±0.15 (0.840)	8.816**

## Discussion

According to analysis of variance with repeated measures, data such as PF, MF, TTPF, FT, JH, Ecc-Dur, Con-Dur, and Total-Dur all research the level of significant difference. The results for PF, MF, FT, JH, and Ecc-Dur showed that these parameters' values decreased with a load increase, while TTPF, Con-Dur, and Total-Dur increased. Although 30ms-mRFD and 50ms-mRFD did not show significant differences, their values also decreased with an increased load.

The vertical jump adopted in this experiment was an SJ with an arm swing. We found that PF, MF, FT, JH, and Ecc-Dur showed similar phenomena, and that the parameter values obtained under CMJ were the highest. Previous research

pointed out that when CMJ tests are performed with an arm swing, the results will be affected by specific sports' particularities and that skilled jumpers' familiarity with the relevant sport would increase, thus improving the reliability of the results (McMahon et al. 2018, Slinde et al. 2008, Vaverka et al. 2016). Since the participants in this study were excellent volleyball players for whom jumping is a fundamental physical performance factor, the parameters' credibility increased. In sports science, because the main goal is to improve athletes' performance through sports training, accurate performance tests are very important. Furthermore, sports testing results must be reliable and precise in order to detect minimal but meaningful changes caused by exercise training. Furthermore, exceptional athletes' sports training outcomes need to be tested regularly. Therefore, the test methods must be reproducible and allow for the identification of subtle differences within the subject. Measurement errors can occur in all types of tests, so it is important to analyze retest reliability, since retests demonstrate repeated measurements' reproducibility. Confidence level analysis of this study's results demonstrated the feasibility of good reliability in volleyball players' CMJ test results.

Previous studies pointed out that changing the movement involved in CMJ may influence each jump's strength relative to its time signal curve (Feltner et al. 2004, Gathercole et al. 2015a, Gathercole et al. 2015b, Laffaye et al. 2014). The LCMJ mode adopted in this study eliminated the arm swing, but retained the movement characteristics of the squat, i.e., the dynamic muscle movement (SSC) was used to retain the functions that require concentric and eccentric muscle contractions during jumping. Therefore, the results of comparing CMJ and LCMJ-0% show that higher PF, FT, JH, and Ecc-Dur values were obtained for CMJ, mainly due to the influence of the arm swing movement. When performing a CMJ, swinging the arms in the countermovement direction increased squat amplitude, which directly led to an increase in Ecc-Dur (17.07%). The subsequent upward arm swing increased the kinetic energy and directly affected PF, FT, and JH. Hence, it is speculated that omitting the arm swing during CMJ changed the movement and thus the test's reproducibility, especially in sports that require a lot of jumping (Heishman et al. 2020, Klavora 2000). Similar phenomena were observed for TTPF, Con-Dur, and Total-Dur. Although the same verbal prompts, i.e., "jump as high as you can" and "jump naturally," were given to the experiment subjects before they performed each test, the parameter values obtained for LCMJ-80% were the highest. This was mainly due to the increase in the magnitude of the load. That is, when external resistance increased, it took more time to complete the muscle contraction movement. From the perspective of training, shortening the movement's duration is the most important means of improving muscle contractibility and strength output. The results of this study showed that LCMJ-80% training could improve muscle contractibility, as well as TTPF, Con-Dur, and Total-Dur.

## Conclusion

In this study, a CMJ with different loads was used to test the lower limbs' neuromuscular status. This method allowed for an understanding of the current status of the subject's body quickly and practically, with relatively low physiological pressure and a relatively light load. It is therefore considered to be an effective method of evaluating neuromuscular fatigue during jumping. In volleyball competitions, jumping is performed repeatedly, as it is needed to complete many of the sport's required movements. Evidently, performing jump-related movements as tests can correspond well to athletes' abilities. Previous assessment methods using CMJ have been proven to be methods for monitoring lower limb performance and fatigue factors. In this study, different intensities were continuously added as a reference. The results showed significant differences in movement mode and sports performance due to load status. In the future, daily training modes in the high load process could be evaluated, thereby preventing injuries and improving training efficiency.

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