**Title**

**A comparison of biomechanical parameters between two methods in countermovement jump**

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**A comparison of biomechanical parameters between two methods in countermovement jump**

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**Abstract:**

The purpose of the present study was to compare biomechanical parameters between countermovement jump with and without arm swing, and to investigate the effect of arm swing on enhancing the performance in countermovement jump. Five male elite volleyball players participated in this study. The two methods of countermovement jumps were performed on a force platform, high-speed motion capture system at a frequency of 250 Hz, video point 2D motion analysis for kinematic parameters, and the integration was calculated by OriginPro. Some biomechanical parameters were analyzed, to examine the importance of biomechanical parameters in countermovement jump. A comparison between the two methods of countermovement and correlations between arms swing and biomechanical parameters were used. Results showed that the performance was better on countermovement with arm swing than countermovement without arm swing for the parameters (Maximum height, Maximum force, Velocity at takeoff, Kinetic Energy at takeoff). Arm swing was strongly correlated with Maximum force and Velocity at takeoff. Maximum height was strongly correlated with Height at takeoff, Maximum force, Velocity at takeoff, Kinetic Energy at takeoff and Impulse at takeoff. Finally, the relative contribution of arm swing in improving jump height was noted as arm swing led to significant improvements in the countermovement with arm swing by 27.08%.

**Key words:**

Biomechanics, vertical jump, arm swing, force platform

**Introduction**

Many of studies investigated vertical jump and compared countermovement jump to squat jump, but this study compares two methods of countermovement jump with arm swing (CMJ with arm swing) and without arm swing (CMJ no arm swing) and the relationships between biomechanical parameters and arm swing.

In the vertical jump, as well as in many sports skills, the arms are swung vigorously upwards during take-off to enhance performance (Lees et al., 2004).

Vertical jump is very important in sports. A high vertical jump contributes to successful athletic performance, particularly in sports such as basketball, volleyball, and football. It is a crucial motor task for all human beings and requires coordination and synchronization among multiple joints and muscles. Previous studies have emphasized the importance of the coordination of segmental actions and the function of particular muscles for enhanced jump performance (Bobbert and van Ingen Schenau, 1988; Pandy and Zajac, 1991; Van Soest et al., 1993).

In vertical jump, there are two ways to propel the body’s center of mass (CM) upwards: a countermovement jump (CMJ) and a so-called squat jump (SJ). In a CMJ, people start from an upright position and initiate downward movement before starting to move upwards, while in a SJ they start from a squatted (or semi squatted) position without a preparatory countermovement. It is well known that CMJs are generally 2- 4 cm higher than SJs as a result of the stored elastic energy, stretch reflexes, and the active states of the muscles (Komi and Bosco, 1978; Viitasalo and Bosco, 1982; Bobbert and Casius, 2005).

 Vertical jumps are commonly used in sport practice. Especially counter movement jumps (CMJ) are performed to diagnose muscular strength or ‘explosive power’.

The counter-movement jump (CMJ) is a commonly used method in performance diagnostics to measure leg power and explosiveness (Richteret al., 2010).

The time history of the vertical ground reaction force (GRF) of a CMJ decreases below body weight during eccentric phase in the counter movement and rises to a few times body weight in the concentric phase (Fukashiro and Komi, 1987; Hubley and Wells, 1983; Vanezis and Lees, 2005).

Arms have been widely reported as enhancing take-off velocity by 6–10% or more when using an arm swing. Despite this marked effect on performance, the mechanisms by which arm swing leads to an increase in take-off velocity have not been fully established (Lees et al., 2004; Harman et al., 1990; Luhtanen and Komi, 1979; Shetty and Etnyre, 1989).

The purpose of the present study was to compare of biomechanical parameters between countermovement jump with and without arm swing and to investigate the effects of arm swing on enhancing the performance of countermovement jump.

**Material and Methods:**

**Participants:**

Five male elite volleyball players participated in this study (age: 20.2 ± 1.06 years; body mass: 82.77 ± 19.3 kg; height: 189.6 ± 9.34 cm). They were from Alexandria, Egypt, and participated in regional and national competitions; and they are members of a professional team that plays in the Egyptian Volleyball Super League.

**Measures:**

To perform CMJ arm swing, athlete started at a static standing position with free hands, and the jump was preceded by a countermovement of acceleration below the center of gravity, achieved by flexing their knees at about 90 degrees, an angle that was observed and visually controlled by the examiner. During the jump, the trunk was kept vertical, and the athlete was instructed to jump at the highest possible speed and to the highest point that he could reach. In this protocol, the agonist muscles were stretched during descent, when the elastic structures were stretched, and there was an accumulation of elastic energy that could be used when going up (concentric phase). In CMJ without arm swing, athlete did the same previous performance but started at a static standing position with hands kept on the hip.

**Procedures:**

Before data collection, athletes stretched and warmed up for a short time and then received technical instructions and trained specifically for CMJ to ensure that the protocol was standardized. This stage included about 5-6 CMJs arm swing and CMJs without arm swing at intervals of about 1 min. The number of jumps depended on the movement technique that each individual presented. After that, athletes performed three CMJs arm swing and three CMJs without arm swing, with recovery interval of 2 min. The two methods of countermovement jumps were performed on a strain gage force platform (MP4060®, Bertec Corporation, Columbus, OH,USA), which measured the vertical component of ground reaction force (GRF) at a sampling rate of 1000 Hz. In addition, two-dimensional analysis, marker position data were obtained by a high-speed motion capture system (Fastec In Line Network-Ready High-Speed Camera, MaxTRAQ Motion Analysis System to capture) at a frequency of 250 Hz, video point v 2.5 2D motion analysis for kinematic parameters, and the integration was calculated by OriginPro 8.5 SR1 Data Analysis and Graphing Software. The following instants and biomechanical parameters were measured for this study: Firstly the instants; Point (a) is the lowest point of the countermovement jump, where the jumper’s center of mass is momentarily at rest ~velocity is zero! The leg muscles are now strongly activated and the ground reaction force is close to maximum (Low point), Point (b) is the maximum ground reaction force point of the countermovement jump (Maximum force), Point (c) is the takeoff instant (TO), Point (d) marks the peak of the jump (Maximum height). Secondly the biomechanical parameters; Maximum height, Height at low point, Height at TO, Maximum force, Velocity at TO, Kinetic Energy at TO, Potential Energy at TO, Impulse at TO, Hip angle at low point, Knee angle at Low point, Ankle angle at low point, Hip angle at TO, Knee angle at TO, Ankle angle at TO.

**Figure 1:**

**The acceleration, force, velocity and distance curves of countermovement jump.**

***a****: (Low point instant),* ***b****: (Maximum force instant),* ***c*** *(TO instant),* ***d****: (Maximum height instant).*

**Statistical analysis:**

For the statistical analysis of the data the IBM SPSS Statistics 21 was used. Descriptive statistics, Kolmogorov-Smirnov and Shapiro-Wilk tests were used to check data normality, and results showed that all parameters had a normal distribution. After that, the Student t-test for independent samples was used to compare results for CMJ with and without arm swing, and the Pearson correlation was used to evaluate the relationships between CMJ parameters and arm swing.

**Results:**

Table (1) shows the results of biomechanical parameters comparisons for CMJ arm with and without swing.

According to Table (1), the performance (countermovement) was better CMJ with arm swing compared with CMJ without arm swing, on the parameters (Maximum height, Maximum force, Velocity at TO, Kinetic Energy at TO, Potential Energy at TO).

**Table 1**

**Table (1): Descriptive values (mean ± SD), and Comparison (variance percentage %), (t-test) for parameters measured in CMJ with arm swing and CMJ without arm swing**

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| . |
| **parameters** | **CMJ arm swing** | **CMJ no arm swing** | **Variance percentage** | **t** | **Significance** |
| **Mean** | **S.D** | **Mean** | **S.D** | **%** | **P-value** |
| Maximum height (m) | 0.61 | 0.03 |  0.48 | 0.03 |  27.08 | 10.28 | P˂ 0.001 |
| Height at low point (m) | -0.36 | 0.06 |  -0.44 | 0.05 | -18.18 | 4.10 | P˂ 0.001 |
| Height at TO (m) | 0.22 | 0.02 |  0.16 | 0.02 |  37.50 | 8.21 | P˂ 0.001 |
| Maximum force (N) | 1235.62 | 86.37 |  955.53 | 81.41 |  29.31 | 8.83 | P˂ 0.001 |
| Velocity at TO (m/sec) | 2.84 | 0.09 |  2.65 | 0.10 | 7.17 | 5.29 | P˂ 0.001 |
| Kinetic Energy at TO (J) | 331.78 | 30.56 |  289.88 | 24.79 | 14.45 | 4.01 | P˂ 0.001 |
| Potential Energy at TO (J) | 176.45 | 26.15 |  131.23 | 24.24 | 34.46 | 4.75 | P˂ 0.001 |
| Impulse at TO (N.sec)  | 233.61 | 21.35 |  218.95 | 19.02 | 6.70 | 1.92 | NS |
| Hip angle at Low point (deg) | 66.18 | 8.67 |  54.96 | 17.40 | 20.41 | 2.11 | P˂ 0.05 |
| Knee angle at Low point (deg) | 106.53 | 9.78 |  93.90 | 6.68 | 13.45 | 4.04 | P˂ 0.001 |
| Ankle angle at Low point (deg) | 80.79 | 5.57 |  76.19 | 4.24 | 6.04 | 2.47 | P˂ 0.02 |
| Hip angle at TO (deg) | 173.78 | 8.12 |  176.69 | 13.52 |  -1.65 | -0.68 | NS |
| Knee angle at TO (deg) | 185.93 | 4.96 |  181.74 | 5.77 |  2.31 | 2.04 | P˂ 0.05 |
| Ankle angle at TO (deg) | 139.13 | 2.68 |  140.89 | 2.08 |  -1.25 | -1.95 | NS |
| NS=Non-significant. |  |  |  |  |  |  |  |

As shown in Table (2), Arm swing was strongly correlated with Maximum force, Velocity at TO, Kinetic Energy at TO, and Potential Energy at TO. And Maximum height was strongly correlated with Height at TO, Maximum force, Velocity at TO, Kinetic Energy at TO, Potential Energy at TO and Impulse at TO.

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| **Table 2****Correlation matrix between parameters (Maximum height, Height at low point, Height at TO, Maximum force, Velocity at TO, Kinetic Energy at TO, Potential Energy at TO, Impulse at TO) and arm swing.** |
| **parameters** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
| **1** | Arm swing |  |  |  |  |  |  |  |  |
| **2** | Maximum height  | \*\*0.896 |  |  |  |  |  |  |  |
| **3** | Height at low point | \*\*0.627 | 0.332 |  |  |  |  |  |  |
| **4** | Height at TO | \*\*0.850 | \*\*0.825 | \*0.456 |  |  |  |  |  |
| **5** | Maximum force | \*\*0.866 | \*\*0.758 | \*\*0.772 | \*\*0.652 |  |  |  |  |
| **6** | Velocity at TO | \*\*0.720 | \*\*0.842 | 0.269 | \*\*0.551 | \*\*0.615 |  |  |  |
| **7** | Kinetic Energy at TO | \*\*0.618 | \*\*0.779 | 0.069 | \*\*0.628 | \*\*0.550 | \*\*0.574 |  |  |
| **8** | Potential Energy at TO | \*\*0.681 | \*\*0.704 | 0.251 | \*\*0.889 | \*\*0.889 | 0.299 | \*\*0.781 |  |
| **9** | Impulse at TO | 0.351 | \*\*0.483 | -0.056 | \*0.453 | 0.337 | 0.156 | 0.898\*\* | \*\*0.773 |
| Correlation is significant at the 0.01 level (2-tailed). \*\* |
| Correlation is significant at the 0.05 level (2-tailed).\*Table (3) indicated that Arm swing was strongly correlated withKnee angle at low point**.**

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| **Table 3****Correlation matrix between lower limb angles and arm swing** |
| **parameters** | **1** | **2** | **3** | **4** | **5** | **6** | **7** |
| **1** | Arm swing |  |  |  |  |  |  |  |
| **2** | Hip angle at Low point  | 0.382\* |  |  |  |  |  |  |
| **3** | Knee angle at Low point  | 0.621\*\* | 0.385\* |  |  |  |  |  |
| **4** | Ankle angle at Low point  | 0.437\* | 0.076 | 0.804\*\* |  |  |  |  |
| **5** | Hip angle at TO  | -0.132 | 0.409\* | -0.107 | -0.201 |  |  |  |
| **6** | Knee angle at TO  | 0.372 | 0.554\*\* | 0.145 | -0.014 | 0.670\*\* |  |  |
| **7** | Ankle angle at TO | -0.357 | -0.171 | -0.362 | -0.094 | 0.099 | 0.156 |  |
| Correlation is significant at the 0.01 level (2-tailed). \*\* |
| Correlation is significant at the 0.05 level (2-tailed).\* |

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**Discussion:**

Most of the Biomechanical parameters were affected by arm swing, as height of center of body mass at low point (Height at low point) is one of the most important parameters for the countermovement jump with arm swing (CMJ arm swing) as it contributes in determining work done during the takeoff, which positively affects the kinetic energy, as evidenced by the following relationship:



Differences between the performance CMJ with arm swing and CMJ without arm swing for the lower limb angles at low point instant of the joints for performance CMJ arm swing, mean that the damping in performance CMJ without arm swing was more evident from the differences in parameter (Height at low point) at low point instant of the joints, and was in favor of performance CMJ without arm swing (-0.44 ± 0.05 m), which had a negative impact on the vertical jump through excessive bending of the lower limb joints.

 Difference between high center of body mass at takeoff (Height at TO) between CMJ with arm swing (0.22 ± 0.02 m) and CMJ without arm swing (0.16 ± 0.02 m) was the largest value of CMJ with arm swing. It was a very important parameter for increasing the height of jump, through the positive correlation between Height at TO and maximum height (r=0.825\*\*), and also the positive correlation between arm swing and Height at TO (r=0.850\*\*), (table 2).

The parameter of vertical velocity at takeoff (Velocity at TO) was the most important parameter that affects maximum height and that it has a positive correlation with flight height, as evidenced by the following relationship:



 Positive correlation was found between the maximum height and vertical velocity at TO (r= 0.842\*\*), (table 2) (Lees et al., 2004; Fantini et al., 2006; Chen et al., 2008; Jakobsen et al., 2012; Faulkinbury et al., 2011; Linthorne, 2001; Fukashiro et al., 2005; Park et al., 2008).

 These results indicate the importance of kinetic energy at takeoff (Kinetic Energy at TO) as it is related to height of jump and arm swing, reflecting its importance and also because of its correlation with velocity at TO which is one of the most important parameters of vertical jump (Lees et al., 2004; Requena et al., 2012; Linthorne, 2001; Bobbert, 2002). This is evidenced by the following formula:



 Results of Impulse at TO were largest for jump with arm swing. Impulse at TO is considered as one of the most important parameters for vertical jump performance (table 2) (Rodacki et al., 2002; Requena et al., 2012; Vaverka et al., 2009; Kurz et al., 2011; Kümmel et al., 2011; Linthorne, 2001; Shan, 2000; Park et al., 2008).

 Results of the lower limb ​​angles during maximum damping of the joints (Angles at low point) in order to CMJ with arm swing to the appropriate height, as it allows appropriate damping that increases the height of jump. This is confirmed with the correlation between the hip angle and knee angle at maximum damping instant of the joints (table 3), and through the positive correlation between the lower limb angles and arm swing, where there is a perfect range for knee angle during vertical jump (between 100 ° to 130 °) (Clanseyand Lees, 2010; Lees et al., 2004; Hochmuth, 1971).

While in CMJ without arm swing, damping was greater than CMJ with arm swing as evidenced by the values ​​of the angles which led to the loss of the positive impact of the force gained and led to the loss of a large part due to increased torque on the lower limb joints as a result to surpass the perfect range for knee angle (Clanseyand Lees, 2010).

 Results showed full stretching of the lower limb joints at takeoff (Angles at TO), especially in the hip, to help high center of body mass at takeoff, which contributes in increasing the height of jump because of correlation between height at TO and maximum height (tables 1-2).

 Finally, The differences between the CMJ with arm swing and the CMJ without arm swing on parameters of Knee angle at TO, Height at TO, Velocity at TO, Kinetic Energy at TO, Maximum height, and Potential Energy at TO for the CMJ arm swing ranged between 2.31% to 37.5%. The most important of these parameters was the Velocity at TO, as it contributes to flight height (Pupo et al., 2012). This was confirmed by the correlation between maximum height and Velocity at TO, (table 2). As for Height at TO, Kinetic Energy at TO, Potential Energy at TO and Impulse at TO parameters, they were all important and contribute in increasing jump height (table 2). Percentage of improvement of Maximum height was 27.08% for the CMJ with arm swing. This improvement is due to the work of the arms through the acquisition of additional impulse during the performance CMJ with arm swing (Lees et al., 2004; Feltner et al., 1999; Harman et al., 1990; Harrison and Moroney, 2007).

**Conclusion:** The additional impulse from arm swing in vertical jump is an important base contributing to high vertical jump, as indicated in many of the studies dealing with the importance and role of arm swing while performing vertical jump. In depth study of CMJ with and without arm swing to determine the relative contribution of arm swing in improving jump height and determine the importance of compatibility of the additional impulse by arms noted that arm swing led to an improvement in the CMJ with arm swing by 27.08%, which demonstrates the important role of arm swing in the performance in countermovement jump.

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