ISSN 1750-9823 (print)
International Journal of Sports Science and Engineering
Vol. 07 (2013) No. 02, pp. 123-128

A Comparison of Biomechanical Parameters between Two Methods of Countermovement Jump

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(*Received August 24, 2013, accepted September 9, 2013*)

Abstract: The purpose of the present study was to compare of biomechanical parameters between countermovement jump with arm swing and countermovement jump no arm swing, and investigate the effect of arm swing to enhance the performance of countermovement jump. Five male high level athletes participated in this study were volleyball players (age: 20.2 ± 1.06 years; body mass: 82.77 ± 19.3 kg; height: 189.6 ± 9.34 cm). The two methods of countermovement jumps were performed on a strain gage force platform, high-speed motion capture system 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 variables were analyzed: Maximum height, Low point, Height at TO, Maximum force, Velocity at TO, Kinetic Energy at TO, Potential Energy at TO, Impulse at TO, and the angles of lower limb at low point and take off. To examine the importance of biomechanical parameters on countermovement jump, a comparison between countermovement with arm swing and countermovement no arm swing and a correlations between arm swing and biomechanical parameters were used. The results showed, the performance (countermovement) was better among CMJ arm swing than CMJ no arm swing, of the parameters (Maximum height, Maximum force, Velocity at TO, Kinetic Energy at TO, Potential Energy at TO), and Arm swing was strongly correlated with Maximum force, Velocity at TO, Kinetic Energy at TO, Potential Energy at TO, and Knee angle at Low point. 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. Finally, the percentage contribution arm swing in improving jump height was noted that arm swing led to an improvement in the CMJ arm swing by 27.08%.

Key words: Biomechanics, vertical jump, arm swing, force platform**.**

1. Introduction

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

In the vertical jump, as well as in many sports skills, the arms are swung vigorously upward during take-off to enhance performance [19].

The 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 of all human beings and requires the coordination and synchronization of 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 [2, 22, 31].

In a vertical jump, there are two ways to propel the body's center of mass (CM) upward: 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 upward, 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

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of the muscles [3, 16, 33].

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 [26].

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 [10, 14, 32].

The arms has been widely reported that take-off velocity can be enhanced 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 [11, 19, 21, 29].

The purpose of the present study was to compare of biomechanical parameters between countermovement jump with arm swing and countermovement jump no arm swing, and investigate the effect of arm swing to enhance the performance in countermovement jump.

2. Material and Methods

2.1. Participants

Five male high level athletes participated in this study were volleyball players (age: 20.2 ± 1.06 years; body mass: 82.77 ± 19.3 kg; height: 189.6 ± 9.34 cm). They were athletes in the state of 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.

2.2. Measures

To perform CMJ arm swing, the athlete started at a static standing position with hands are free, and the jump was preceded by a countermovement of acceleration below the center of gravity achieved by flexing their knees to about 90 degrees, an angle that was observed and visually controlled by the examiner. During the jump, the trunk was kept as vertical as possible, and the athlete was instructed to jump at the highest possible speed and to the highest point that they 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 no arm swing, the athlete did the same previous performance but started at a static standing position with kept hands on the hip.

2.3. Procedures

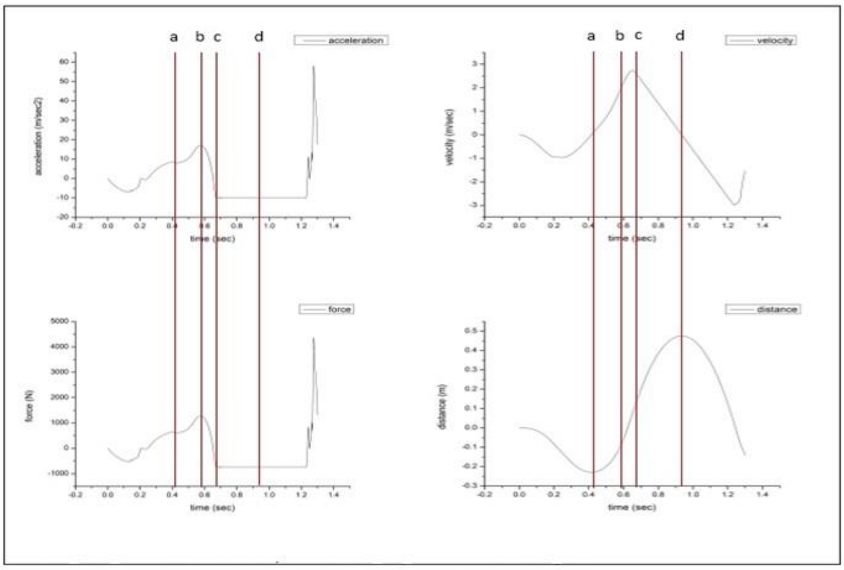

Figure 1: The acceleration, force, velocity and distance curves of countermovement jump.

Before data collection, the 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 no arm swing at intervals of about 1 min, and the number of jumps depended on the movement technique that each individual presented. After that, the athletes performed three CMJs arm swing and, after a 2 min recovery interval, the CMJs no arm swing. 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.

2.4. 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 arm swing and CMJ no arm swing, and the Pearson correlation to evaluate the relationships between CMJ parameters and arm swing.

3. Results

Table 1: Descriptive values (mean ± SD), and Comparison (Change Ratio %), (t-test) of parameters measured in CMJ arm swing and CMJ no-arm Performance.

parameters	CMJ arm swing		CMJ no arm swing		Change Ratio	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.

Table 1 shows the compares the results of biomechanical parameters for CMJ arm swing and CMJ no arm swing.

According to the results in Table 1, the performance (countermovement) was better CMJ arm swing than CMJ no arm swing, of the parameters (Maximum height, Maximum force, Velocity at TO, Kinetic Energy at TO, Potential Energy at TO).

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.

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).**

And also shown in Table 3, Arm swing was strongly correlated with Knee angle at low point.

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).*

4. Discussion

The most of Biomechanical parameters were affected by arm swing, that the parameter height center of body mass at low point (Height at low point) 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:

$$\int_{y_i}^{y_{to}} (F_{GRF} - mg)\, dy = 1/2 m v_{to}^2$$

The differences between the performance CMJ arm swing and CMJ no arm swing for the lower limb angles at low point instant of the joints for performance CMJ arm swing, means that the damping in performance CMJ no 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 no arm swing (-0.44 ± 0.05 m), which had a negative impact on the vertical jump through excessive bending of the lower limb joints.

The contrast high center of body mass at takeoff (Height at TO) between CMJ arm swing (0.22 ± 0.02 m) and CMJ no arm swing (0.16 ± 0.02 m) was the largest value of CMJ arm swing, It was important parameter to increase 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 affect the maximum height and that it relates by a positive correlation with flight height, as evidenced by the following relationship:

$$y_{flight} = y_{peak} - y_{to} = \frac{v_{to}^2}{2g}$$

And the positive correlation between the maximum height and vertical velocity at TO (r= 0.842**), (table 2) [4, 6, 7, 9, 15, 19, 20, 23].

It is clear from these results, the importance of parameter kinetic energy at takeoff (Kinetic Energy at

TO) is related to height of jump and also arm swing, reflecting its importance and also because of its correlated of velocity at TO which is one of the most important parameters of vertical jump [1, 19, 20, 25]. And is evidenced by the following formula:

$$\mathrm{KE} = 1/2 m \nu_{\mathrm{to}}^2$$

While the results of Impulse at TO is the largest jump in arm swing, and is considered the Impulse at TO of the important parameters for vertical jump performance (table 2) [17, 18, 25, 27, 28, 30].

And the results of the lower limb angles during maximum damping of the joints (Angles at low point) in order to CMJ arm swing to the extent appropriate, which allows appropriate damping increases the height of jump, and confirms this the correlation between the hip angle and knee angle at maximum damping instant of the joints which is evident from (table 3), and the same table through the positive correlation between the lower limb angles and arm swing, where there are perfect range for knee angle during vertical jump, it ranges between 100 ° to 130 ° [5, 13, 19].

While in CMJ no arm swing was damping is greater than CMJ 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 [5].

The 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 to increase the height of jump because of its correlation between height at TO and maximum height as evidenced by (tables 1-2).

Finally, The differences between the CMJ arm swing and the CMJ no arm swing in parameters 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, and rates ranging between 2.31% to 37.5%. The most important of these parameters the Velocity at TO, where contribute to flight height.24 And was confirmed by the correlation between the maximum height and Velocity at TO, (table 2), then come parameters; Height at TO, Kinetic Energy at TO, Potential Energy at TO and Impulse at TO parameters are important and contribute to increase jump height which is evident from (table 2), and also the percentage of improvement in parameter Maximum height 27.08% for the CMJ arm swing, this improvement is due as a result of the work of the arms through the acquisition of additional impulse during the performance CMJ arm swing [8, 11, 12, 19].

5. Conclusion.

The additional impulse from arm swing in vertical jump is an important base contributing to high vertical jump, has indicated many of the studies to the importance and role of arm swing while performing vertical jump, but with depth in the study between CMJ arm swing and CMJ no arm swing to determine the percentage contribution 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 arm swing by 27.08%, which demonstrates the importance of the role of arm swing in the performance in countermovement jump.

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