International Journal of Sports and Physical Education (IJSPE)
Volume 1, Issue 1, June 2015, PP 14-22
www.arcjournals.org

A Biomechanical Comparison of Different Vertical Jump Techniques with and Without Arm Swing

Abdel-Rahman Akl

Faculty of Physical Education,
Alexandria University,
Alexandria, Egypt.
abdelrahman.akl@alexu.edu.eg

Abstract: *The aim of this study was to examine the differences among vertical jump techniques with and without arm swing using biomechanical analysis and electromyography. Twelve male high level athletes participated in this study. The vertical jumps were performed on strain gage force platform (MP4060®, Bertec Corporation, Columbus, OH, USA), which measured the ground reaction force at a sampling rate of 1000 Hz. Ag/AgCl surface electrodes (SKINTACT, FS-521), Innsbruck, Austria) were placed on Gluteus Maximus, Biceps femoris, Rectus femoris, Vastus lateralis, Vastus medialis, Gastrocnemius lateralis, Soleus, Tibialis anterior EMG signals were recorded and amplified by ME6000 telemetric hardware system (Mega Electronics Ltd., FINLAND) synchronised with the force platform and the motion capture system. Signals were digitised at 1000 Hz with the MEGAWIN version 3.1-b12 software. Study found that the vertical jump techniques are not biomechanically similar, despite the CMJ arm swing and SJ arm swing are probably similar in vertical jump height. While muscles activity are similar, so the muscle coordination is important in jumping but we cannot determine the variations among vertical jump techniques by muscle activity, and this study suggests, when training to improve the vertical jump may be confirm to measure jump performance and several kinetic parameters before and after training program.*

Keywords: *Kinetics, Kinematics, Jumping, EMG, Force platform.*

1. Introduction

Vertical jump with or without countermovement (CMJ or SJ) is a widely used model to study the mechanical behaviour of muscles in vivo and in computer simulations [1, 2, 3, 4, 5, 6, 7, 8].

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 synchronisation of multiple joints and muscles. Previous studies have emphasised the importance of the coordination of segmental actions and the function of particular muscles for enhanced jump performance [8, 9].

Many studies have addressed this problem that related of vertical jump from biomechanical aspects. Recently, Bobbert et al [10] and Vanrenterghem et al [11] studied the effect of different ROM, called sub maximal jump, on jumping height and joint activation patterns in SJ and CMJ and reported that jumping height decreased in the function of the decreasing angular displacement. By now it is accepted that positive work done during vertical jumping depends upon several factors, once of this factors is the muscle activation [2, 8, 9, 11, 12, 13, 14, 15].

The activation (pre- tension) level of the muscles [2, 12, 14, 15],the elastic energy stored and re-used during joint flexion and extension [1, 6, 11], and muscle activation pattern [8, 9, 11, 13]. These factors acting together are believed to cause 3–6 cm greater jump height when jumps are performed with countermovement vs. Squat jumps. This phenomenon was re- ported in most of the studies when the positive work started from semi-squat position (knee angle was approximately 80–100). However, differences were not significant, indicating that not only the time, but also the history of force development affect EMG, which was also demonstrated in the work of Finni et al [16].

Estimating muscle forces during motion is important to the fields of sport, ergonomics and bioengineering, and may contribute to improvements in sports techniques, rehabilitation procedures, product designs and work environments [17].

Muscles participate critically in the execution of human motor tasks. When muscle strength, power, or coordination is impaired, task execution is compromised [18].

The muscle can perform many mechanical functions. A muscle can develop force and power, and over time produce work output. Or it can dissipate mechanical energy if its active fibers are stretched. When its tendon, aponeurosis, and other in- series elastic elements are stretched, energy is stored. The force length velocity property of muscle can stabilise movement with its impedance like function before reflexes become operative [19, 20, 21].

Usually no one muscle can cause the required segmental energetic exchanges. At times, multiple muscles will cause similar segmental exchanges to occur by accelerating the same segments and decelerating others. The co-excited muscles are then called co-functional [22]. Co-functional muscle activity may be required, for example, when segmental energetic exchanges are so high that force production in one muscle is insufficient.

The contributions of individual muscle forces to the reaction forces throughout the body and to the acceleration and deceleration of segments cannot be measured. In fact, rarely can the muscle forces in humans (or animals) be recorded, much less from many muscles simultaneously [23, 24].

Given that we are usually limited to measurements of muscle (EMG) activity, the kinematics of the movement, and the forces exerted by the body on contact objects (e.g., the ground in walking), many musculoskeletal variables escape direct observation [18].

Studies of the neuromuscular system often employ recordings of the electrical activity of skeletal muscle. These electromyographic recordings may be of electrical signals detected within a muscle via needle or wire electrodes or from the surface of the skin via surface electrodes. Surface electromyography (EMG) is frequently used to estimate the amount of muscle activation required for specific tasks [25, 26], and to examine changes in muscle activation as a result of training [27].

Despite the fact that performance improvement is attributed mainly to neural factors, few researchers evaluated simultaneously the changes in performance with the changes in muscle activation using surface electromyography (EMG) [28].Therefore, the purpose of this study was to examine and determine the differences in biomechanical parameters and muscle activity among vertical jump techniques using biomechanical analysis and electromyography, as well as determine the parameters that correlate with vertical jump performance. It was hypothesized that the biomechanical parameters vary among vertical jump techniques because the arm swing contribution and countermovement, and the biomechanical parameters would affect on vertical jump techniques, but the muscle activity may be not vary because the same muscles are working among all vertical jump techniques.

2. METHODS

2.1. Subjects

Twelve male high level athletes volunteered to participate in this study. (age: 19.75 ± 1.14 years; body mass: 85.00 ± 8.32 kg; height: 192.00 ± 7.99 cm). They were athletes in the state of Alexandria, Egypt, and participated in regional and national competitions (Volleyball, Basketball, and Handball).

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 centre 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 velocity 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. And CMJ no arm swing, the athlete did the same previous performance but started at a static standing position with kept hands on the hip. In SJ arm swing, the athlete started the jump from a static position, with the knees at an angle of about 90 degrees, the trunk as vertical as possible, and the hands are free. And SJ no arm swing, the athlete started the jump from a static position, with the knees at an angle of about 90 degrees, the trunk as vertical as possible, and the hands on the waist, the jump was performed without any countermovement, and there was only the concentric action of the agonist muscles involved in the movement. 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 standardised. This stage included about 5-6 CMJ arm swing, CMJ no arm swing and SJ no arm 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 two CMJ arm swing, after a 2 min recovery interval performed the CMJ no arm swing, after a 2 min recovery interval performed the SJ arm swing, and after a 2 min recovery interval performed the SJ no arm swing. The best trail of every technique was selected.

2.3. Procedures

The vertical jumps were performed on 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. The jump height were used to evaluate jump techniques: Vertical jump (VJ) and Flight Height (FH). And two-dimensional analysis, marker position data were obtained by a high-speed motion capture system (Fastec InLine Network-Ready High-Speed Camera, Max TRAQ Motion Analysis System to capture) at a frequency of 250 Hz, video point v 2.5 2D motion analysis for kinematic parameters. Bipolar, Ag/AgCl surface electrodes (SKINTACT, FS-521), Innsbruck, Austria) were placed on Gluteus Maximus (GM), Biceps femoris (BF), Rectus femoris (RF), Vastus lateralis (VL), Vastus medialis (VM), Gastrocnemius lateralis (GasL), Soleus (Sol), Tibialis anterior (TA). The centre to centre distance of the electrodes was 20 mm, prior to mounting the electrodes the skin was shaved, abraded with sandpaper, and cleaned with alcohol. EMG signals were recorded and amplified by ME6000 telemetric hardware system (Mega Electronics Ltd., FINLAND) synchronised with the force platform and the motion capture system. Signals were digitised at 1000 Hz with the MEGAWIN version 3.1-b12 software. EMG full-wave rectification by RMS Averaging [29].

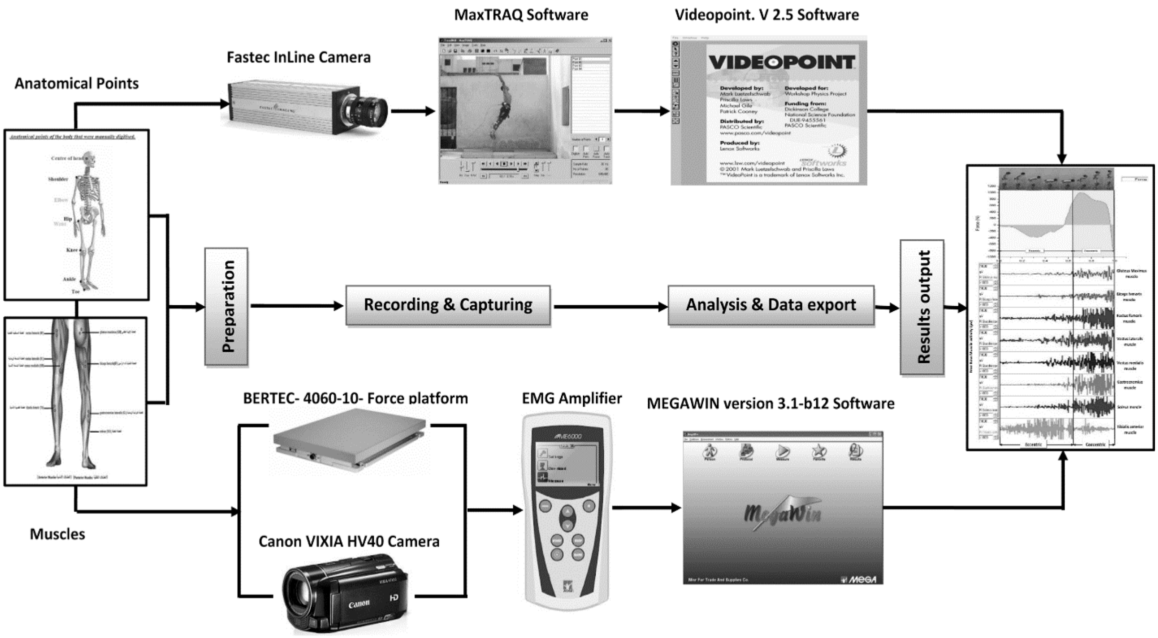


Fig1. *Study procedures.*

2.4. Statistical Analyses

The descriptive statistics, mean ± standard deviation ($M \pm SD$) of parameters were calculated. The Kolmogorov-Smirnov normality test was used to check the normality of the continuous parameters. The repeated measures one-way analysis of variance (*ANOVA*), and the *LSD* test was used in order to determine the differences in jump techniques. The level of significance was accepted as $p<0.05$. Analysis were performed using statistical software (IBM SPSS Statistics 22, SPSS inc., an IBM Co., Somers, NY).

3. Results

Descriptive statistics and analysis of variance (*ANOVA*) of vertical jump techniques (CMJ arm swing, CMJ no arm swing, SJ arm swing and SJ no arm swing) are presented in Table 1. And *LSD* significant of vertical jump techniques are presented in figure 2 to 6(b).

Pearson correlation coefficients among jump techniques and biomechanical parameters are presented in Table 2.

Table1. *Vertical jump and flight height (M ± SD, and ANOVA) measured of vertical jump techniques.*

Parameters (units)	CMJ arm swing		CMJ no arm swing		SJ arm swing		SJ no arm swing		ANOVA	
	M	*S.D*	*M*	*S.D*	*M*	*S.D*	*M*	*S.D*	*F*	*P-value*
VJ (m)	0.61	0.04	0.49	0.03	0.60	0.03	0.44	0.01	106.52	<0.001
FH (m)	0.41	0.02	0.37	0.03	0.40	0.03	0.32	0.02	31.56	<0.001
Fz (N)	1231.67	88.98	970.67	83.31	1238.42	142.16	1151.0	79.38	18.05	<0.001
Vy (m/s)	2.85	0.08	2.68	0.10	2.79	0.10	2.51	0.06	34.21	<0.001
COMy (m)	0.22	0.02	0.16	0.02	0.21	0.01	0.15	0.02	57.81	<0.001
Impulse(N.s)	235.94	20.494	221.74	16.7	230.85	22.87	212.52	19.25	3.21	0.032
Power (N.m/s)	3511.4	278.34	2594.08	205.61	3454.23	451.98	2902.01	241.01	24.67	<0.001

Values are M: mean and SD; ANOVA: analysis of variance; CMJ arm swing- countermovement jump with arm swing, CMJ no arm-countermovement jump without arm swing, SJ arm swing- squat jump with arm swing, SJ no arm swing-- squat jump without arm swing, VJ- vertical jump, FH- flight height, Fz-peak force, Vy-vertical velocity, COMy- centre of body mass height.

Table2. *Correlation matrix among Biomechanical parameters and vertical jump techniques*

	Jump techniques	VJ	FH	Fz	Vy	COMy	Impulse	Power
Jump techniques								
VJ	0.584**							
VH	0.652**	0.871**						
Fz	-0.029	0.449**	0.304*					
Vy	0.660**	0.878**	0.997**	0.309*				
COMy	0.524**	0.861**	0.633**	0.442**	0.640**			
Impulse	0.324*	0.488**	0.271	0.254	0.277	0.461**		
Power	0.224	0.694**	0.620**	0.935**	0.625**	0.602**	0.314*	

*VJ- vertical jump, FH- flight height, Fz-peak force, Vy-vertical velocity, COMy- centre of body mass height, **. Correlation is significant at the 0.01 level (2-tailed); *. Correlation is significant at the 0.05 level (2-tailed); Jump techniques: CMJ arm swing=3, CMJ no arm swing=2, SJ arm swing=1, and SJ no arm swing=0.*

The mean values, standard deviations, and analysis of variance (ANOVA) of the muscles activity during vertical jump techniques are presented in Table 3. Gluteus Maximus (GM), Biceps femoris (BF), Rectus femoris (RF), Vastus lateralis (VL), Vastus medialis (VM), Gastrocnemius lateralis (GasL), Soleus (Sol), Tibialis anterior (TA).

Table3. *RMS activity (µv) of muscles (M ± SD, and ANOVA) measured of vertical jump techniques.*

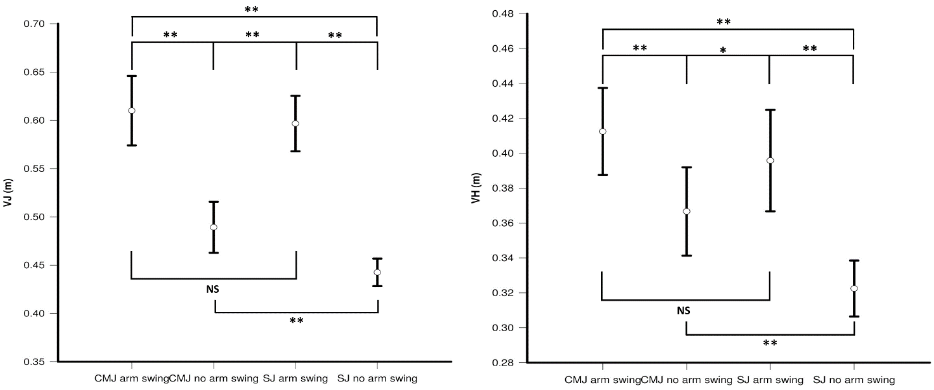
Muscles activity (units)	CMJ arm swing		CMJ no arm swing		SJ arm swing		SJ no arm swing		ANOVA	
	M	*S.D*	*M*	*S.D*	*M*	*S.D*	*M*	*S.D*	*F*	*P-value*
GM (µv)	121.92	49.54	137.92	46.37	116.92	45.05	129.33	51.12	0.43	0.729
BF (µv)	104.92	27.79	98.42	20.55	93.42	25.12	85.58	17.05	1.51	0.225
RF (µv)	165.25	51.21	200.17	60.81	181.00	69.47	224.83	54.28	2.25	0.096
VL (µv)	248.33	81.92	267.75	82.82	282.08	108.54	260.75	61.10	0.33	0.805
VM (µv)	192.75	63.26	228.75	56.46	219.42	80.19	217.50	49.73	0.71	0.554
GasL(µv)	130.08	54.76	139.33	52.49	128.50	65.42	143.83	61.15	0.19	0.903
Sol (µv)	107.33	24.62	126.25	31.64	123.25	42.11	149.17	42.44	2.75	0.054
TA (µv)	162.00	28.18	169.33	56.89	168.50	51.37	144.58	58.11	0.63	0.598

Values are M: mean and SD; ANOVA: analysis of variance; CMJ arm swing- countermovement jump with arm swing, CMJ no arm-countermovement jump without arm swing, SJ arm swing- squat jump with arm swing, SJ no arm swing-- squat jump without arm swing, GM-Gluteus Maximus, BF-Biceps femoris, RF-Rectus femoris, VL-Vastus lateralis, VM-Vastus medialis, GasL-Gastrocnemius lateralis, Sol-Soleus, TA-Tibialis anterior.

4. Discussion

The purpose of the current investigation was to examine the differences among vertical jump techniques (countermovement jump with arm swing, countermovement jump without arm swing, squat jump with arm swing, and the squat jump without arm swing), using biomechanical analysis and electromyography.

The finding of the present study showed that significant among vertical jump techniques in jump height (VJ-VH) (Figure 2), peak force (Fz), vertical velocity (Vy), centre of body mass height (COMy), Impulse, and power (Table 1). These finding are in line with many studies who reported significant changes in jump height [5, 16, 30], peak force, velocity, centre of mass height at take-off, impulse, and power. The present data contribute important knowledge to the determinant factors found in vertical jump performance at different techniques. It is important to observe high values of correlation among the velocity, centre of mass height, impulse, and power produced during the vertical jump techniques with the height of jump techniques (Table 2) [31, 32, 33, 34].



(a) **(b)**

Fig2. *The jump height among vertical jump techniques*

Legend. *(a) Vertical Jump (VJ), (b) Vertical Height (VH), Connected dots indicated, (** indicates P<0.01; * indicates P<0.05)*

And describes the results of the force among the vertical jump techniques (Table 1), and differences among jump techniques of force (Figure 3), due to the impact of arm swing on reposition the Centre of mass and then increase the resistance as a result of gravity, requiring greater force production during the concentric contraction to increased strength in SJ arm swing and CMJ arm swing, which illustrates the importance of force in determining the height of vertical jump (Table 1, 2). And the coordination may be a more important determinant of vertical jump performance and increase the centre of body mass height and the take-off velocity [31, 35].

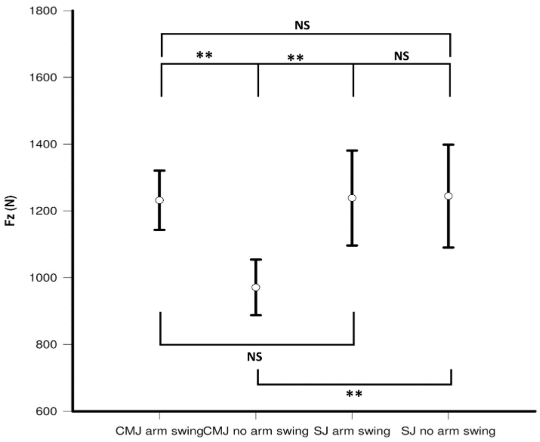


Fig3. *Peak Ground Reaction Force (Fz) among vertical jump techniques.*

Legend. *Connected dots indicated, (** indicates P<0.01; * indicates P<0.05)*

The centre of body mass height (COMy) during take-off is one of the parameters that reflect the range of the player's benefit from peak force as a result of the full extension of the lower limb segment. And also the benefit of arm swing to increase this distance and that contribute to the production and increase the kinetic energy during the jump. As well as increasing the power through increased velocity during the take-off, as evidenced by the relationship of COMy with High jump (Table 2), as well as the parameter that differentiates among vertical jump techniques (Figure 4), and demonstrates the importance of the contribution of the coordination of the arms during lower limb segments extension to achieve higher vertical distance [36].

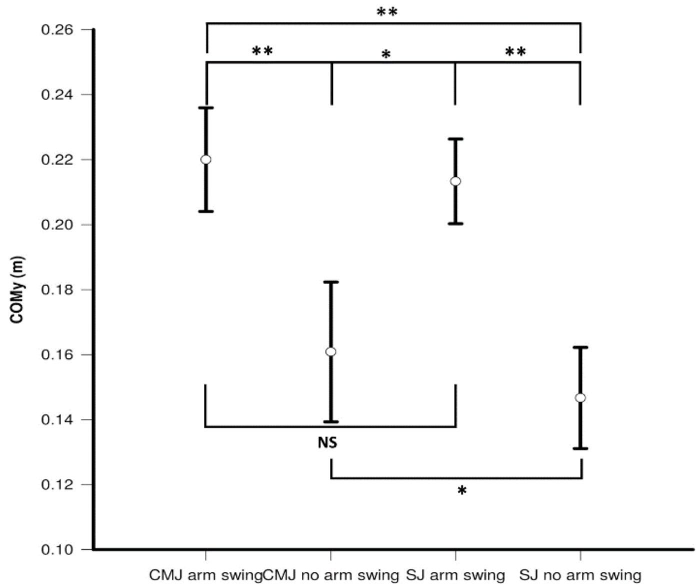


Fig4. *Centre of Body Mass height at take-off (COMy) among vertical jump techniques.*

Legend. *Connected dots indicated, (** indicates P<0.01; * indicates P<0.05)*

And demonstrates the results of impulse among the vertical jump techniques, and differences among jump techniques of impulse (Figure 5), and the increase might be due of acquiring a more positive impulse as a result of arm swing, and more increase CMJ arm swing performance than CMJ no arm swing as a result of two factors, arm swing and movement of preliminary at take-off, and the impulse is an important parameter in vertical jump performance and emphasise that its relationship with the vertical jump distance (Table 2) [36, 37].

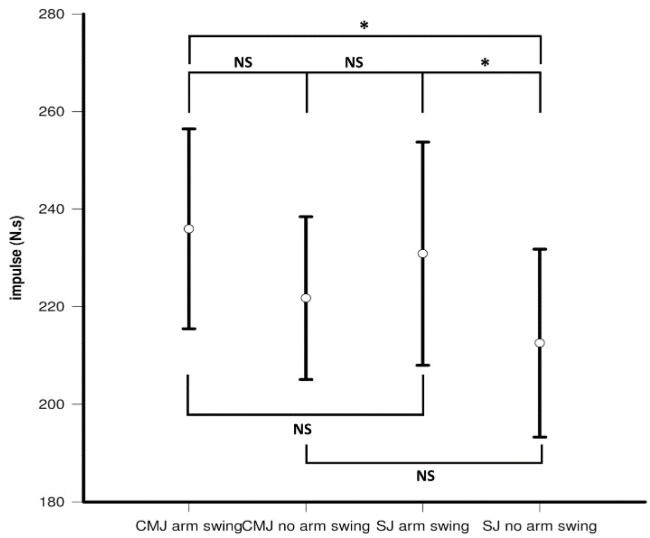
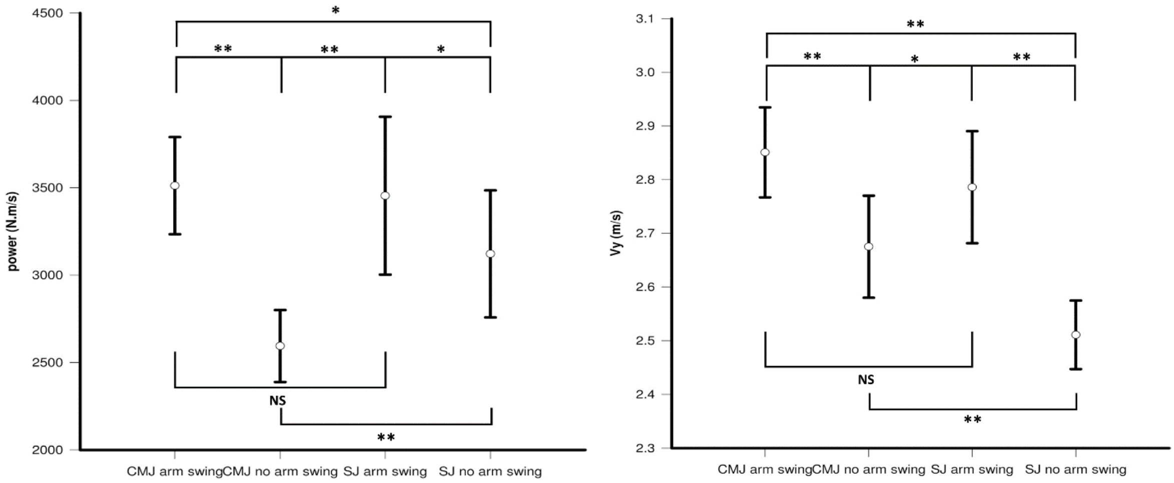


Fig5. *Impulse among vertical jump techniques.*

Legend. *Connected dots indicated, (** indicates P<0.01; * indicates P<0.05)*

The results showed the relationship between power and jump height (Table 2), and also increase the power with techniques that use arm swing (Table 1; Figure 6), and also with the velocity due the relationship between power and velocity, power is directly dependent on velocity (power= force * velocity), the peak power produced during jumping performance is always attained when the velocity is close to maximum value during the concentric phase, and this maximum velocity is intimately related to the take-off velocity, which is well known to determine vertical jump height (Table 2), [37, 38]. And we can note it according several authors [39, 40], power output generation is one of the key predictors of performance in athletic movements. In this context, CMJ height has been shown to have important correlations with power during vertical jump (Table 2). My study also confirms previous findings in which power was shown to be one of parameter can predict of vertical jump height because the relationship with jump height (Table 2) [31].



(a) *(b)*

***Fig6**. Vertical velocity and power at take-off among vertical jump techniques*

Legend. ***(a)** Vertical velocity at take-off (Vy) and **(b)** power, Connected dots indicated, (** indicates P<0.01; * indicates P<0.05)*

Table3. Shows the muscles activation of selected lower limb muscles in the current investigation, the muscles activity was not significantly different. Despite The muscle can perform many mechanical functions. A muscle can develop force and power, and over time produce work output. But the muscle activation in current investigation is no significant changes among vertical jump techniques, this finding agreed with Gollhofer et al & Häkkinen et al [5, 30]. The activation (pre- tension) level of the muscles, the elastic energy stored and reused during joint flexion and extension, and muscle activation pattern [2, 8, 9, 11,12, 14],these factors acting together are believed to cause 3–6 cm greater jump height when jumps are performed with countermovement vs. Squat jumps. This phenomenon was reported in most of the studies when the positive work started from semi-squat position. However, differences were not significant, indicating that not only the time, but also the history of force development affect EMG, which was also demonstrated in the work [16]. And muscle activation demonstrates to contribution of the coordination of the arms during lower limb segments extension to achieve higher vertical distance [19, 20, 21].

5. Conclusion

Vertical jump is very important in sports and high vertical jump contributes to successful athletic performance in many individual and game sports, this study found that the vertical jump techniques are not biomechanically similar (Table 1), despite the CMJ arm swing and SJ arm swing are probably similar in vertical jump height (Figure 2). Therefore, similarity of movement may not be the most important factor for training to vertical jump performance, but the aim is determine the requirements of every vertical jump technique to know how we can improve it. While muscles activity are similar (Table 3), so the muscle coordination is important in jumping performance but we cannot determine the variations among vertical jump techniques by muscle activity. This study suggests that while the impulse and power increased, the vertical jump increased (as indicated by GRF). Furthermore, when training to improve the vertical jump may be confirm to measure jump performance and several kinetic parameters before and after training program, for example peak force, impulse, and power because the relationship between these parameters and vertical jump. And emphasizing the importance and role of arm swing while performing vertical jump. Thus, the additional impulse from arm swing in vertical jump is an important base contributing to high vertical jump

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