American Journal of Sports Science
2016; 4(5): 77-83
http://www.sciencepublishinggroup.com/j/ajss
doi: 10.11648/j.ajss.20160405.11
ISSN: 2330-8559 (Print); ISSN: 2330-8540 (Online)

Biomechanical Indicators of Jump Height Among Varied Techniques of Vertical Jump

Abdel-Rahman Ibrahim Akl*, Mohamed Mohamed Doma

Faculty of Physical Education (Abo Qir), Alexandria University, Alexandria, Egypt

Email address:
abdelrahman.akl@alexu.edu.eg (Abdel-Rahman I. A.)
*Corresponding author

To cite this article:
Abdel-Rahman Ibrahim Akl, Mohamed Mohamed Doma. Biomechanical Indicators of Jump Height Among Varied Techniques of Vertical Jump. *American Journal of Sports Science*. Vol. 4, No. 5, 2016, pp. 77-83. doi: 10.11648/j.ajss.20160405.11

Received: July 29, 2016; **Accepted**: August 5, 2016; **Published**: August 21, 2016

Abstract: The purpose of the present study was to determine the biomechanical indicators of jump height among varied techniques of vertical jump and examine if the rate of force development is a valid indicator for vertical jump height or not. Fifteen male high level athletes participated in this study performed three techniques of the vertical jump. Motion data were recorded by a high-speed camera at a frequency of 250 Hz, video point v 2.5 2D motion analyses for kinematic variables, and force platform (MP4060®, Bertec Corporation, Columbus, OH, USA) which measured the ground reaction force at a sampling rate of 1000 Hz. The RFD was calculated as the Peak Force divided by the time taken to achieve the Peak Force, the integration was calculated by OriginPro 8.5 to calculate impulse and work. The results showed a significant difference between techniques in all analyzed variables, a positive significant correlation between vertical velocity, impulse, work, temporal variables with flight height, and the negative significant correlation between the rate of force development with flight height and jump techniques. In Conclusion, this results emphasized the importance of velocity, impulse, and work as indicators when evaluating the vertical jump.

Keywords: Biomechanics, Arm Swing, Jumping, Rate of Force Development

1. Introduction

Assessment of vertical jump performance by using varied systems and tools is continuing processing, because the vertical jump is very important for athletes in many sports for training and testing. A high vertical jump contributes to improve athletic performance, particularly in sports that depend on stretch-shortening cycle such as volley ball, handball, and basketball. Notwithstanding in the last decade, many studies examined the vertical jump techniques but still a bit results not clear. Several studies indicated to the arms has been widely contributed to increase the take-off velocity by 6–10% or more when using an arm swing in countermovement or squat jump, and resulted the enhancement of performance when jumping using an arm swing is due to increased height (28%) and velocity (72%) of the center of mass (COM) at take-off [1-5]. Furthermore, the previous studies indicated to the work done is an important variables to enhance vertical jump performance, because the work depends on the increasing of pushing distance during the concentric phase, due the association between pushing distance and upward arm swing [6-8]. Hence, many studies considered the velocity, impulse, and work are a valid indicators of vertical jump height.

Interestingly, Marques and Izquierdo indicated RFD has been one of the most important variables to explain performance in activities where great acceleration required, and it is strongly related to performance abilities [9]. Several characteristics of force, such as peak force (PF), time to reach peak force (T1) and the rate of force development (RFD) are associated with vertical jump performance. RFD, defined as the rate of force increase in a given time interval, is an important variable to measure the neuromuscular performance of athletes in sports that use explosive muscle contractions [10-12]. Thereby, RFD has been shown to be an important performance variable by some investigators, not only, suggest that RFD and muscular strength in lower limbs play a greater role in vertical jump height than skill, coordination, any motor-learning effect, but also indicate to a strong correlation between RFD and jump height [3, 11-14]. In contrast, other studies have reported a poor relationship between RFD and the vertical jump [3, 15-19]. These contradictions may be due the complex of the biological determinant of the human body. Thus, more studies are required to determine the valid indicators during the vertical jump, and its relationships with jump height by using a different sample, systems, and procedures. Consequently, the purpose of the present study was to determine the biomechanical indicators of jump height among varied techniques of vertical jump and examine if the rate of force development is a valid indicator for vertical jump height or not.

2. Methods

2.1. Participants

Fifteen male high level athletes participated in this study were Handball, Basketball, and volleyball players (age: 20.8 ± 1.21 years; body mass: 82.8 ± 8.57 kg; height: 189.6 ± 8.65 cm). They are 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 Handball, Basketball, and Volleyball Super League. The consent of all players was obtained, and the study was approved by the institutional ethics committee of studies and researches.

2.2. Procedures

The vertical jumps were performed on a 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 Analyses System to capture) at a frequency of 250 Hz, video point v 2.5 2D motion analyses for kinematic variables. In addition, 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 integration was calculated by OriginPro 8.5 SR1 Data Analyses and Graphing Software to calculate impulse (the integral of a force with respect to time), and work (the integral of a force with respect to displacement). The RFD was calculated as the Peak Force divided by the time taken to achieve the Peak Force (Figure 1), according to the following equation:

$$RFD=PF/T_1$$

Where, *RFD*: rate of force development; T_1: Duration from initial Concentric to peak Force; *PF*: peak force.

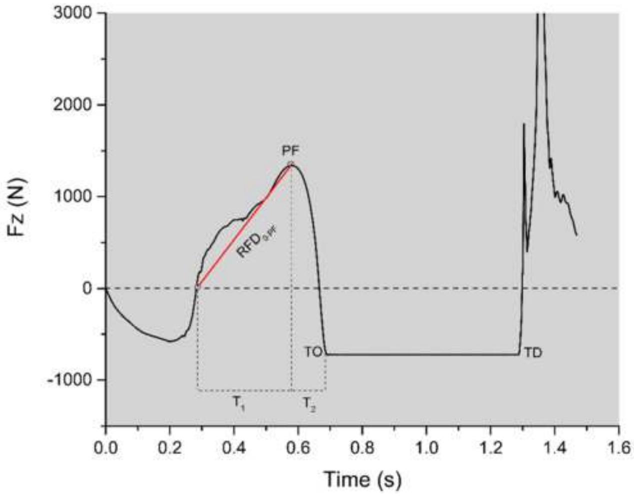

Figure 1. *Force–time curve includes specific time points and overlapping RFD starting from zero (RFD= rate of force development; T_1= Duration from initial Concentric to peak Force; T_2= Duration from peak Force to Takeoff; PF= peak force; TO: takeoff; TD= touch down).*

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 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 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 standardized. 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 three CMJ arm swing, after a 2 min recovery interval performed the CMJ no arm swing, and after a 2 min recovery interval performed the SJ no arm swing, and the best attempt of each technique was selected for analyses.

2.3. Statistical Analyses

For the statistical analyses 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 variables had a normal distribution. After that the analyses of variance (*ANOVA*) and the significant differences between means with using *L.S.D.*

were used to compare results for vertical jump technique (Figures 2, 3), and the Pearson correlation to evaluate the relationships.

3. Results

In figures 2, 3: the mean ±SD values for the vertical jump techniques are presented, as well as the statistical significance of differences between techniques. The results show that jump height was significantly higher in CMJ arm swing than CMJ no arm swing; 16.33% ($P < 0.01$), significantly higher in CMJ arm swing than SJ no arm swing; 22.45% ($P < 0.01$), and non-significantly in CMJ no arm swing and SJ no arm swing. Vertical velocity was significantly higher in CMJ arm swing than CMJ no arm swing; 8.44% ($P < 0.01$), significantly higher in CMJ arm swing than SJ no arm swing; 11.04% ($P < 0.01$), and non-significantly in CMJ no arm swing and SJ no arm swing. The peak force was significantly higher in CMJ arm swing than CMJ no arm swing; 21.74% ($P < 0.01$), non-significantly in CMJ arm swing and SJ no arm swing, and significantly higher in CMJ no arm swing than SJ no arm swing; 20.78% ($P < 0.01$).

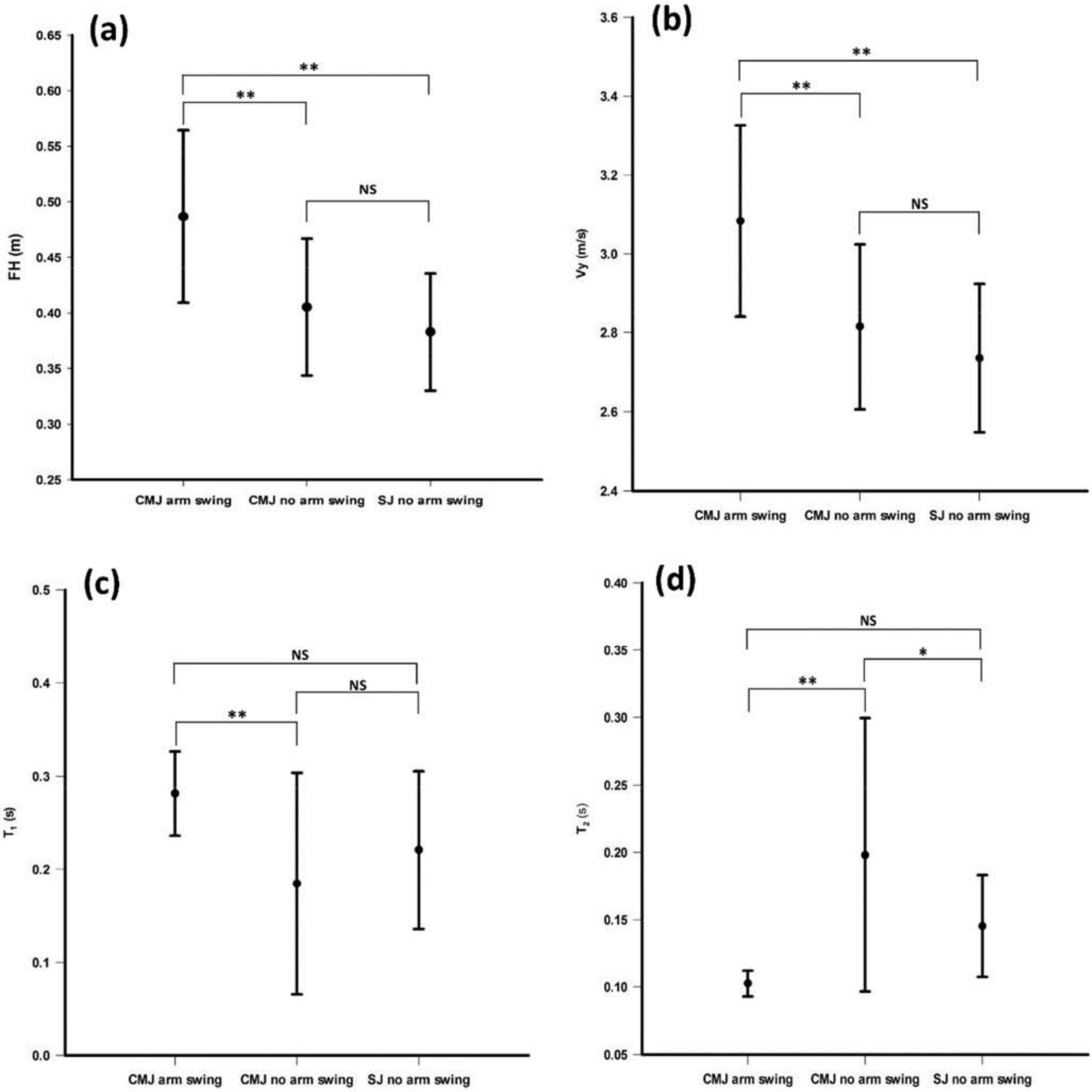

Figure 2. *Flight height (a), vertical velocity (b), duration from initial Concentric to Max Force (c), and Duration from Max Force to Takeoff (d) among vertical jump techniques. Connected dots indicated, (L.S.D. significant: ** =indicates P<0.01; * =indicates P<0.05, NS= indicates non-significant).*

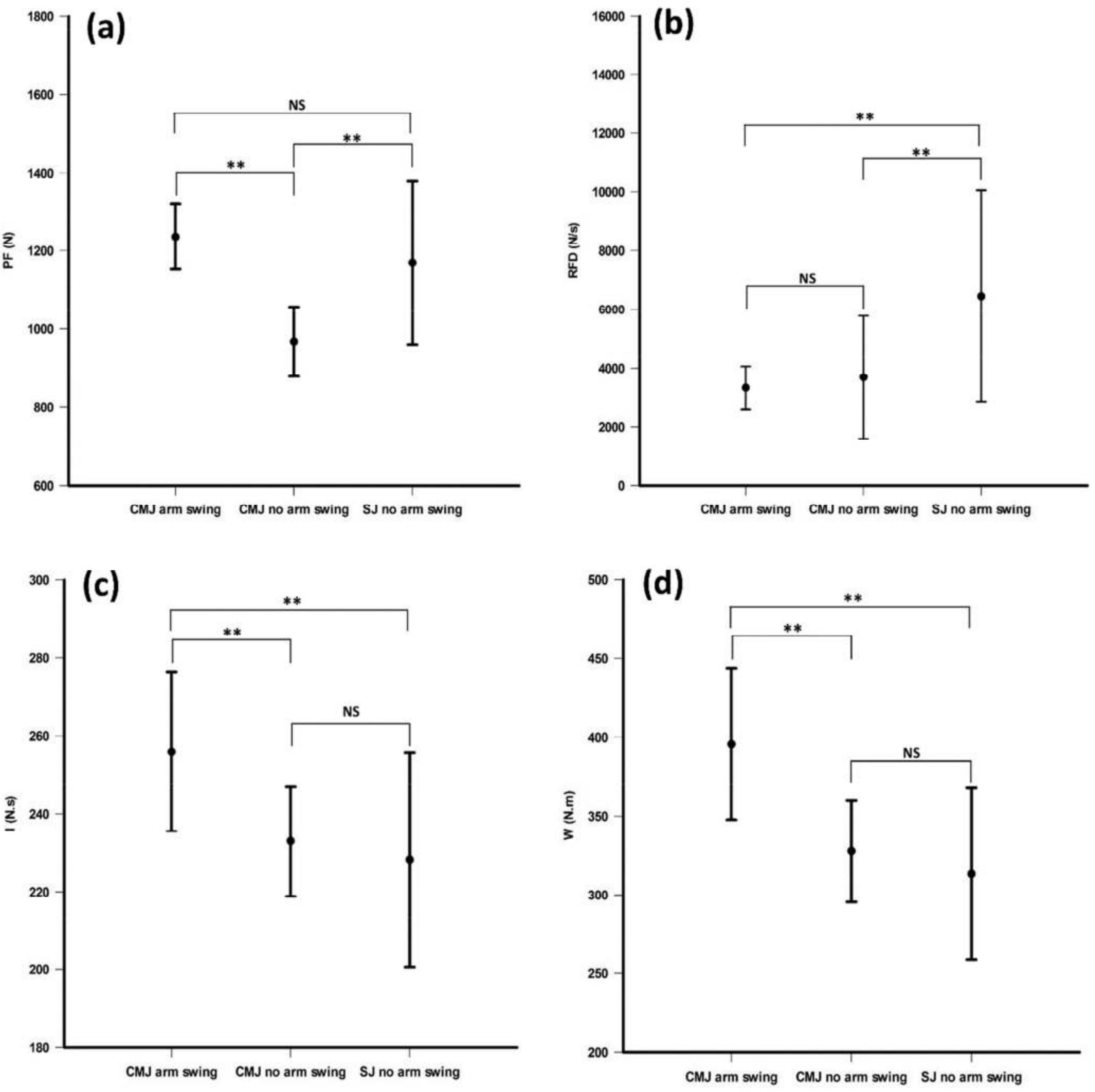

Figure 3. *Peak force (a), Rate of Force Development (b), Impulse (c), and work (d) among vertical jump techniques. Connected dots indicated, (L.S.D. significant: **= indicates P<0.01; *= indicates P<0.05, NS= indicates non-significant)*

The impulse also was significantly higher in CMJ arm swing than CMJ no arm swing; 9.03% ($P < 0.01$), significantly higher in CMJ arm swing than SJ no arm swing; 10.86% ($P < 0.01$), and non-significantly in SJ no arm swing and CMJ no arm swing. The work done was significantly higher in CMJ arm swing than CMJ no arm swing; 17.22% ($P < 0.01$), significantly higher in CMJ arm swing than SJ no arm swing; 20.77% ($P < 0.01$), and non-significantly in SJ no arm swing and CMJ no arm swing. The duration from initial Concentric to Max Force was significantly higher in CMJ arm swing than CMJ no arm swing; 35.71% ($P < 0.01$), non-significantly in CMJ arm swing and SJ no arm swing, and non-significantly SJ no arm swing and CMJ no arm swing. The duration from Max Force to Takeoff was significantly higher in CMJ no arm swing than CMJ arm swing; 50.00% ($P < 0.01$), non-significantly in SJ no arm swing and CMJ arm swing, and significantly higher in CMJ no arm swing than SJ no arm swing; 30.00% ($P < 0.05$). The Rate of Force Development was non-significantly in CMJ arm swing and CMJ no arm swing, significantly higher in SJ no arm swing than CMJ arm swing; 48.58% ($P < 0.01$), and significantly higher in SJ no arm swing than CMJ no arm swing; 42.99% ($P < 0.01$).

***Table 1.** Correlation matrix between variables measured in CMJ arm swing, CMJ no-arm swing, and SJ no-arm swing Performance.*

	Technique	FH	Vy	PF	I	W	T_1	T_2
Technique								
FH	0.555**							
Vy	0.556**	0.999**						
PF	0.156	0.111	0.102					
I	0.473**	0.521**	0.528**	0.173				
W	0.589**	0.862**	0.866**	0.167	0.880**			
T_1	0.261	0.451**	0.460**	-0.147	0.224	0.393**		
T_2	-0.238	-0.453-**	-0.459-**	-0.182	-0.092	-0.317-*	-0.869-**	
RFD	-0.466-**	-0.316-*	-0.320-*	0.562**	-0.256	-0.330-*	-0.655-**	0.398**

Legend: FH = Flight Height; Vy = Vertical Velocity at Takeoff; PF = Concentric Positive peak force; I = Concentric Impulse; W = Concentric Work; T_1 = Duration from initial Concentric to peak Force; T_2 = Duration from peak Force to Takeoff; RFD = Rate of Force Development; **. Correlation is significant at the 0.01 level (2-tailed); *. Correlation is significant at the 0.05 level (2-tailed); Techniques: CMJ with arm swing = 3, CMJ no arm swing = 2, SJ no arm swing = 1.

4. Discussion

This study was carried out to determine the biomechanical indicators of jump height among varied techniques of vertical jump and examine if the rate of force development is a valid indicator for vertical jump height or not.. In several studies the vertical jump performance was split into three phases: 1 – downward phase (eccentric contraction phase), 2 – upward phase (concentric contraction phase), 3 - flight phase. This study focused on the concentric contraction phase because it is considered the most important phase during the vertical jump. When the player is downward to amortization the concentric contraction phase begins, it is the phase in which they are using all the abilities available to the player, and it is acquired from eccentric contraction phase to achieve the height, and in the concentric contraction phase the energy and the movement of each segment of the body is increasing.

The main finding of this study was a significant in flight height (P< 0.01), when compared the three techniques (Figure 2(a)), the flight height is the aim of the performance. Thereby, the biomechanical variables were estimated according to the flight height values.

Figure 2 shows a difference of vertical velocity at take-off among techniques that results indicated to the vertical velocity was higher in CMJ arm swing than CMJ no arm swing and SJ no arm swing, and vertical velocity higher in CMJ no arm swing than SJ no arm swing (Figure 2(b)) [20, 21]. Furthermore, table. 1 shows a positive significant relationship between vertical velocity and flight height (r = 0.999**), and a positive significant relationship between vertical velocity and techniques (r = 0.556**). The results of the present study supported the findings of Akl (2013); Garhammer (1993); Lees et al. (2004); Sayers, Harackiewicz et al. (1999); Richter et al., 2012 in that there indicated the arm swing contribute of enhancement in the height of vertical jump [5-7, 13, 18, 21]. So, this study emphasized of considering the velocity is a good valid indicator can be discriminate among vertical jump techniques.

Notwithstanding, the significant differences of peak force when it was higher in CMJ arm swing then SJ no arm swing than CMJ no arm swing (Figure 3 (a)). In context, the results in the table 1 indicated to a non-significant correlation between peak force and flight height or performance of techniques, although the results indicated that were increases in impulse and work when used the technique of CMJ arm swing higher than CMJ no arm swing and SJ no arm swing (Figure 3(c), Figure 3(d)). Furthermore, table. 1 shows a positive significant correlation between impulse and technique (r = 0.473**), Impulse and flight height (r = 0.521**), work and technique (r = 0.589**), and work and flight height (r = 0.862**). Hence, the impulse, work, and multi-segment coordination may be a more important variables of vertical jump performance than the ability to generate high peak forces [22].

The temporal changes between techniques were significant differences, time from initial to peak force and time from peak force to take-off (Figure 2(c), Figure 2(d)). Furthermore, table 1 shows a positive significant correlation between time to peak force and flight height (r = 0.451**), and negative significant correlations between time from peak force to take-off and flight height (r = -0.453-**). The results indicate to some of the important variables for this phase such as the time of maximum force to takeoff (T2), when the player achieves the maximum force it stops to take advantage of this force on the time from the maximum force instant to takeoff, and the results showed that the maximum force in CMJ arm swing> CMJ no arm, while the time from the maximum force instant to takeoff the CMJ no arm> CMJ arm swing, resulting in a loss of force gained and also not to take advantage of all the energy produced. It led to a reduction in velocity at takeoff where she was in favor of CMJ arm swing, and confirms this the negative correlation between the time of maximum force to takeoff (T2) with velocity at takeoff (-0.459 at 0.01), and the decrease of T2 led to an increase in velocity and then increase in flight height because the relationship between flight height with velocity at takeoff in accordance with the projectile laws, and also a positive relationship between flight height and velocity at takeoff. So, the velocity is a determinant of CMJ height [10]. The results showed also the increase of T2 in the performance of CMJ no arm led to a decrease of flight height compared to CMJ arm swing. While the studies indicated that the arm swing lead to enhancement in the vertical jump by between 6-10% [3]. But when we compared the same variable (T2) between CMJ no arm and SJ no arm, we found this time in SJ no arm lower by 42.86%, as well as maximum force was greater by 17.2%, and though the final result of flight height for CMJ no arm by 7.89%, and is due to benefits achieved during the eccentric contraction phase of storing energy and benefit from them in concentric contraction phase, as well as the enhancement in the impulse by 2.05%, and also the work done during this phase increased by 4.47% in favor of CMJ no arm which indicates that the eccentric contraction phase contributes to increase the height more than the RFD when the player used his abilities correctly.

The unique finding of the present study is that the significant differences of the rate of force development in jump techniques (Figure 3(b)), in addition, table 1 shows a negative significant correlation between RFD and techniques (r = -0.466-**), and negative significant correlation between RFD and flight height (r = -0.316-*). Consequently, the results of the present study indicated to the most important biomechanical variables such as vertical velocity, Impulse, and work. This result probably accepted with the previous studies that indicated to the poor reliability of RFD [23], or non-significant between RFD and jump height [15, 17, 18]. And this is in contrast to previous studies reporting a greater effect of RFD on vertical jump height [11, 13, 14]. However, no studies in the scientific literature appear to address this negative relationship between rate of force development and jump height or jump techniques. Thus, we cannot consider the RFD as an indicator of jump height in the vertical jump.

5. Conclusions

Enhancement of vertical jump height associated with the biomechanical variables such as vertical velocity, impulse, and work especially with arm swing. The surprising result of the present study was the negative significant correlation between RFD with jump height and jump techniques. Notwithstanding, the positive significant correlation between vertical velocity, impulse, and work with jump height and jump techniques. Finally, this results emphasized the importance of velocity, impulse, and work as indicators of jump height when evaluating the vertical jump.

References

[1] A.-R. Akl, "A Biomechanical Comparison of Different Vertical Jump Techniques with and Without Arm Swing," *International Journal of Sports and Physical Education,* vol. 1, no. 1, pp. 14-22, 2015.

[2] P. Floria, and A. J. Harrison, "The influence of range of motion versus application of force on vertical jump performance in prepubescent girls and adult females," *Eur J Sport Sci,* vol. 14 Suppl 1, pp. S197-204, 2014.

[3] M. H. Stone, H. S. O'Bryant, L. McCoy, R. Coglianese, M. Lehmkuhl, and B. Schilling, "Power and maximum strength relationships during performance of dynamic and static weighted jumps," *J Strength Cond Res,* vol. 17, no. 1, pp. 140-7, Feb, 2003.

[4] P. Klavora, "Vertical-jump tests: a critical review," *Strength & Conditioning Journal,* vol. 22, no. 5, pp. 70, 2000.

[5] S. P. Sayers, D. V. Harackiewicz, E. A. Harman, P. N. Frykman, and M. T. Rosenstein, "Cross-validation of three jump power equations," *Medicine and Science in Sports and Exercise,* vol. 31, no. 4, pp. 572-577, 1999.

[6] A.-R. Akl, "The role of biomechanical parameters and muscle activity during eccentric and concentric contractions in vertical jump performance " *Journal of Physical Education and Sport,* vol. 13, no. 3, pp. 430-437, 2013.

[7] A.-R. Akl, "A comparison of biomechanical parameters between two methods of countermovement jump," *International Journal of Sports Science and Engineering,* vol. 7, no. 2, pp. 123-128, 2013.

[8] M. Adamson, N. Macquaide, J. Helgerud, J. Hoff, and O. J. Kemi, "Unilateral arm strength training improves contralateral peak force and rate of force development," *Eur J Appl Physiol,* vol. 103, no. 5, pp. 553-9, Jul, 2008.

[9] J. Cronin, and G. Sleivert, "Challenges in understanding the influence of maximal power training on improving athletic performance," *Sports Med,* vol. 35, no. 3, pp. 213-34, 2005.

[10] G. Papaiakovou, "Kinematic and kinetic differences in the execution of vertical jumps between people with good and poor ankle joint dorsiflexion," *J Sports Sci,* vol. 31, no. 16, pp. 1789-96, 2013.

[11] J. J. González-Badillo, and M. C. Marques, "Relationship between kinematic factors and countermovement jump height in trained track and field athletes," *The Journal of Strength & Conditioning Research,* vol. 24, no. 12, pp. 3443-3447, 2010.

[12] R. Arteaga, C. Dorado, J. Chavarren, and J. A. Calbet, "Reliability of jumping performance in active men and women under different stretch loading conditions," *J Sports Med Phys Fitness,* vol. 40, no. 1, pp. 26-34, Mar, 2000.

[13] A. Richter, S. Räpple, G. Kurz, and H. Schwameder, "Countermovement jump in performance diagnostics: Use of the correct jumping technique," *European Journal of Sport Science,* vol. 12, no. 3, pp. 231-237, 2012.

[14] K. A. Moran, and E. S. Wallace, "Eccentric loading and range of knee joint motion effects on performance enhancement in vertical jumping," *Hum Mov Sci,* vol. 26, no. 6, pp. 824-40, Dec, 2007.

[15] J. D. Pupo, D. Detanico, and S. G. Santos, "Kinetic parameters as determinants of vertical jump performance," *Rev Bras Cineantropom Desempenho Hum,* vol. 14, no. 1, pp. 41-51, 2012.

[16] C. Mebes, A. Amstutz, G. Luder, H. R. Ziswiler, M. Stettler, P. M. Villiger, and L. Radlinger, "Isometric rate of force development, maximum voluntary contraction, and balance in women with and without joint hypermobility," *Arthritis Rheum,* vol. 59, no. 11, pp. 1665-9, Nov 15, 2008.

[17] G. Moir, R. Sanders, C. Button, and M. Glaister, "The influence of familiarization on the reliability of force variables measured during unloaded and loaded vertical jumps," *The Journal of Strength & Conditioning Research,* vol. 19, no. 1, pp. 140-145, 2005.

[18] A. Lees, J. Vanrenterghem, and D. D. Clercq, "Understanding how an arm swing enhances performance in the vertical jump," *Journal of Biomechanics,* vol. 37, pp. 1929–1940, 2004.

[19] W. G. Hopkins, E. J. Schabort, and J. A. Hawley, "Reliability of power in physical performance tests," *Sports medicine,* vol. 31, no. 3, pp. 211-234, 2001.

[20] C. McLellan, D. Lovell, and G. Gass, "The role of rate of force development on vertical jump performance," *J Strength Cond Res,* vol. 25, no. 2, pp. 379–385, 2011.

[21] J. Garhammer, "A Review of Power Output Studies of Olympic and Powerlifting: Methodology, Performance Prediction, and Evaluation Tests," *The Journal of Strength & Conditioning Research,* vol. 7, no. 2, pp. 76-89, 1993.

[22] M. C. Marques, and M. Izquierdo, "Kinetic and kinematic associations between vertical jump performance and 10-m sprint time," *J Strength Cond Res,* vol. 28, no. 8, pp. 2366-71, Aug, 2014.

[23] A. Vanezis, and A. Lees, "A biomechanical analysis of good and poor performers of the vertical jump," *Ergonomics,* vol. 48, no. 11-14, pp. 1594-1603, 2005/09/15, 2005.