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REVIEW

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Kinematic Analysis of Performance of World Class Javelin Throwers

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ABSTRACT

The purpose of the study. Charles Darwin's concept of the struggle for existence is now converted into a struggle for excellence. The ancient spear and hunting in now converted popular athletic sporting events in the form of javelin throw. Science plays a major role in maximizing the javelin throw's horizontal distance. Tremendous research indicates the various kinematic parameters and their role in better performance. The present analytical study discusses the trends of research in javelin performance and their successful implementation in the actual sporting field. The purpose of the study is to compare the different research findings for better javelin performance on kinematic parameters and analysis of biomechanical parameters such as height, weight, BMI, and performance of the last ten Olympic gold medals holders both male and female javelin throwers.

Materials and methods. The meta-analysis was done based on other researchers' research findings. The correlation matrix has been calculated on height, weight, BMI, and performance of ten male and ten female Olympic gold medalists in the javelin throw.

Results. The male and female throwers were positively correlated in height and weight and male throwers were negatively correlated in BMI and height.

Conclusions. Based on the findings of other researchers the meta-analysis on kinematic parameters was discussed and it indicated that javelin performance is related to the biomechanical aspect of sports and height and weight are positively related for the throwers.

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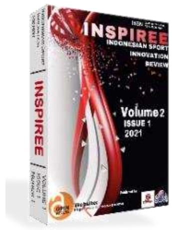

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INTRODUCTION

In *On the Origin of Species*, Darwin (*Charles Darwin*,1859.) claimed that there was a continual 'struggle for existence in nature, in which only the fittest would survive (Van Wyhe, John,2002). In ancient times man had to struggle to survive, they have to run, jump or throw either for escape from harmful animals or for hunting and fighting. The ability to throw is in our DNA. Throwing spears is converted into a popular sport as throwing the javelin and the struggle for existence is converted into the struggle for excellence. It was widely practiced in Ancient Greece and was included in the Olympic

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Games as part of the pentathlon in 708BC. It has been a component of the modern Olympic Games since 1908 for men and 1932 for women (Juha and Vesa,).

The javelin throw was added to the men's Summer Olympic roster in the 1908 Olympic Games in London, while the women's event first appeared in the 1932 Olympics in Los Angeles. The sport was then resurrected in Germany and Scandinavia in the 1870s and gradually developed into its current format, with two-handed and freestyle variations of the event passing out of popularity by the 1920s. Today, the restrictions on the javelins are 800 grams in weight and between 2.6 and 2.7 meters in length for men, and 600 grams in weight and between 2.2 and 2.3 meters in length for women. In contrast to other throwing events, there are strict guidelines for the technique used to throw the javelin, as certain experimental and freestyle methods used in the 1950s were seen as a danger to the audience (*worldofjavelin.com*. 2015).

Evolution of the javelin:

Originally, contestants threw wooden poles (usually made from birch wood) that were fitted with a metal tip. In the 1950s, two brothers from the United States, Bud and Dick Held, developed the Held Javelin, which revolutionized the sport. The Held Javelin had a hollow wooden shaft (later variations were made completely of metal) and flew further than solid wooden javelins. Unfortunately, these javelins were less likely to land point first, which created difficulties when measuring distances. Further developments allowed competitors to throw javelins further than ever before, and by 1984 the world record for men had reached 104.8 meters; a distance that created problems for organizers as it was becoming increasingly unsafe to host javelin events in stadiums. In 1986, several measures were taken to reposition the javelin's center of gravity, forbid the use of special paints of holes that would affect aerodynamics, and increase the likelihood of the javelin landing in the ground (Bartlett & Best, 1988).

Records:

Due to these restrictions and modifications, all records set before 1986 were nullified. Today, the men's Olympic record is 90.57 meters and was set by Norway's Andreas Thorkildsen in 2008, while the women's Olympic record of 71.53 meters was set by Cuba's Osleidys Menéndez in 2004. The world records were both set by Czech athletes; Jan Železný set the men's record with a distance of 98.48 meters in 1996, and

Barbora Špotáková threw 72.28 meters in 2008 to set the women's record. Jan Železný is also the only Olympian to win three gold medals in the javelin throw, between 1992 and 2000, while three other men and two women have claimed back-to-back golds in the event. Historically, Scandinavian countries have been the most successful in this event, with Finland taking seven golds in the men's event, although German women have won the most medals, with a combined tally of five golds and 18 overall medals (Bartlett & Best, 1988). The comparison of men’s and women’s performance of javelin in the summer Olympics is presented in figure-1.

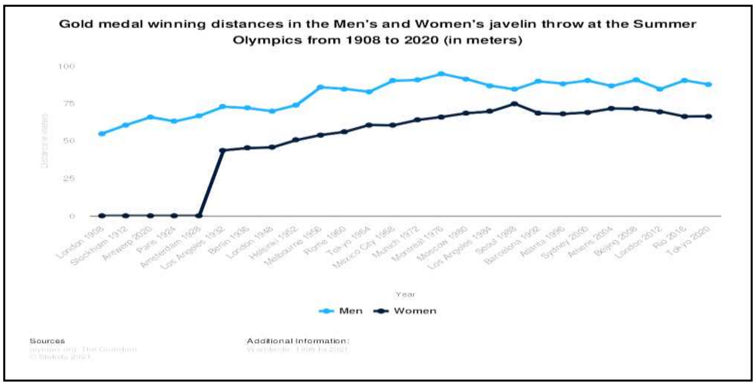

*Figure 1. Comparison of javelin Performance in summer Olympic (*Aaron O'Neill*, 2021).*

Mechanics of Javelin Throw:

The sport-motor goal of javelin throwing is to achieve the longest feasible throwing distance. The athlete attempts to attain this goal, known as "maximization of throwing distance," by utilizing the following throwing elements: approach run, release, braking (final phase), and javelin flight (Hans-Joachim, 1986). Javelin throwing is a highly technical exercise that necessitates the perfect coordination of several joints in various planes of motion. Wind speed and direction, as well as the aerodynamics of the javelin, influence the distance a javelin is thrown. However, javelin release speed and angle are the two most essential and controllable parameters (Barber, 2014).

The javelin used in Olympic competitions was changed in 1986, prompting Olympic throwers to adjust the angle of their release. The aerodynamic force of drag and lift is the center of pressure. The javelin throw is a field sport in which a 2.5 m or 8 ft 2-inch-long spear-shaped javelin is thrown with the intention that it must cover the maximum possible distance. A good throw depends on the height of release, angle of release, and velocity of the release. An increase of 1 meter per second in release velocity increases the throw distance by approximately 5 meters. The world record is 98.48 meters and has been established by Jan Zelezny of the Czech Republic in the year 1996. A javelin throw has four major phases: approach run, crossover period, release phase, and the recovery phase (Brooke. Judson, 2018).

Approach Run	The approach run is the most important part of the javelin throw. The glenohumeral and humeroulnar joints are stretched and flexed during this phase. The soleus, gastrocnemius, hamstrings, quadriceps, and gluteus maximus are the major muscles used.
Crossover Period	The player's torso is oriented to one side throughout the crossover phase, and the javelin's tip is kept at eye level. If the player jumps at this period, he or she tends to lose some of the force that the athlete possesses. Vertical forces cause an unsteady throw and a significant reduction in velocity.
Release Phase	It entails the transfer of momentum created during the approach run to various portions of the body such as the torso, shoulders, arms, hands, and so on. The primary muscles engaged by the player during the release phase are the gastrocnemius, soleus, quadriceps, hamstrings, rectus abdominous, triceps, and rhomboids. The ideal release angle is between 33 and 39 degrees.
Attack Angle	The optimal attack angle is the angle at which the air flows most efficiently around a javelin. Throwing in a headwind causes less lift and speed gain than throwing in a tailwind(Barber, 2014).
Release Angel	No absolute angle will guarantee the farthest distance on each throw. Wind speed and direction change the optimal angle of release significantly. The most common method is releasing the javelin at about a 40-degree angle. Elite throwers now still use this method, but it has become less common in recent years (Brooke. Judson, 2018).
Recovery Phase	The recovery period is the part of the javelin throw where the body decelerates gradually and loses energy in the environment. Implementing appropriate biomechanics and technique during this phase reduces the chance of injury. In this position, the player pulls his rear leg forward to prevent any additional movement that might result in a penalty or foul.

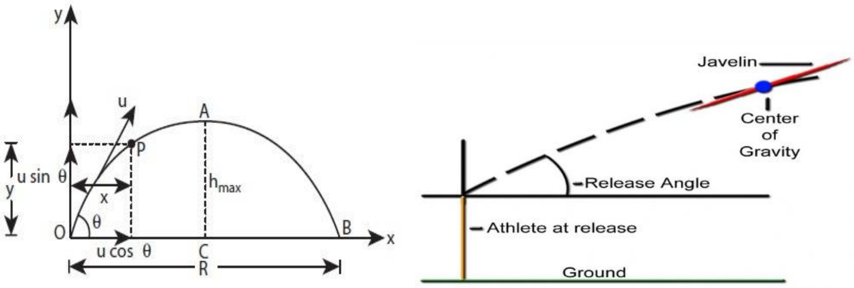

Figure 2. Kinematic parameters of Javelin Throw (Valleala Riku, 2015 Projectile motion, 2012 *)*

Table 1. Parameters of kinematics male and female finalist W Championship (Berlin, 2009)

Male athletics	Results (m)	Release velocity (m/s	Angle of release (°)	Angle of attitude (°)	Angle of yaw (°)	Length of impulse stride (m)	Length of delivery stride (m)	Distance to foul line (m)	Duration of impulse stride (ms)	Duration of delivery stride (ms)	Duration to release (ms)
M.de Zordo (GER)	86,27	29,90	37,3	40,3	3,0	1,96	1,71	1,40	366	253	140
A. Thorkildsen (NOR)	84,78	28,62	35,9	39,2	3,3	2,39	1,89	1,84	400	170	107
G. Martinez (CUB)	84,30	28,33	36,7	35,7	1,8	2,51	1,99	1,45	443	243	124
V.Vesely (CZE)	84,11	26,79	34,6	39,9	5,3	1,92	1,83	0,85	320	180	120
F. Avan (TUR)	83,34	27,44	31,5	35,2	3,7	2,06	1,66	1,07	323	197	163
R. Avramenko (UKR)	82,51	27,93	34,2	41,5	7,3	2,53	1,58	0,65	374	183	137
J. Bannister (AUS)	82,25	27,11	31,5	31,2	0,3	2,39	1,61	0,37	427	193	143
M. Frank (GER)	81,81	27,04	35,2	35,8	0,6	2,13	1,87	1,88	374	213	143
Female athletics											
M. Abakumova (RUS)	71,99	25,11	39,4	43,8	4,4	1,87	1,74	2,36	313	194	140
B. Spotakova (CZE)	71,58	26,27	38,2	42,2	4,0	1,61	1,60	2,54	313	190	147
S.Viljoen (RSA)	68,38	24,42	39,3	43,0	3,7	1,59	1,41	1,66	310	167	113
C.Obergfoll (GER)	65,24	26,48	33,2	35,2	2,0	2,10	1,66	1,20	370	173	143
K. Molitor (GER)	64,32	26,09	38,8	41,3	2,5	1,91	1,51	0,57	433	203	154
K. Mickle (AUS)	61,96	25,10	38,9	43,9	5,0	1,81	1,74	1,91	350	203	130
M. Ratej (SLO)	61,65	27,49	37,3	32,3	5,0	2,51	1,51	1,64	450	164	133
J. Klimesova (CZE)	59,27	24,96	38,6	41,7	3,1	1,66	1,10	1,85	257	287	143

MATERIALS AND METHODS

A qualitative meta-analysis was conducted depending upon the findings of the other researchers and a correlation matrix was calculated to establish the relationship between height, weight, and body mass index of gold medalist Olympic javlers both male and female from 1984 Tokyo Olympics to 2020 Tokyo Olympics. The level of significance was fixed at a 0.05 level of confidence.

In the throwing of the javelin, as in most other throwing events, the distance thrown depends largely on the state (for instance the velocity, angle of release, and position) of the equipment at the point of release (Hubbard & Alaways, 1989). When each component of the throwing skill acts together smoothly and successfully, the result can be awe-inspiring. The Hierarchical diagram (Figure 1) shows the main factors that contribute towards the overall distance thrown. This diagram will help to explain the most important parameters. The hierarchical diagram shows that the angle of the javelin at release and the speed of release are two key parameters in the determination of the total distance thrown. Several studies have analyzed the key factor of air resistance (Hatton & Parkes, 2005) and other complex issues of aerodynamics during the flight of the javelin. However, as Hubbard and Rust (1984) argue, the javelin's flight path cannot be altered once the javelin is released, therefore this study focuses on factors that can be adjusted through training. Factors affecting the performance of the javelin are presented in figure -3.

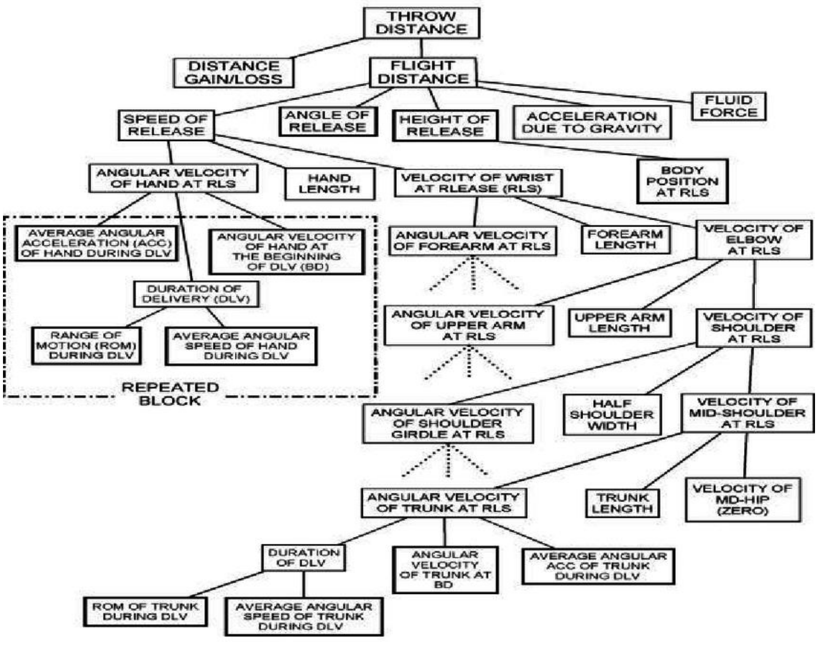

Figure 3. Factors that determine the measured distance of a javelin throw (Chow, Kuenster, and Lim, 2003).

Ten (10) Olympic champion male and female javelin throwers from 1984 Los Angeles to 2020 Tokyo Olympic were studied and their kinematic analysis was done based on height, weight, body mass index, and javelin performance. Table -II. Showed the champion javelin thrower year-wise both male and female.

RESULTS AND DISCUSSION

Research Finding

Various research studies have been conducted which reveal optimum release height and release angle for javelin in respect of athlete for cover greater horizontal distance. The following table discussed their research findings systematically. Various research studies have been conducted which reveal optimum release height and release angle for javelin in respect of athlete for cover greater horizontal distance. The following table discussed their research findings systematically (Table-II).

Table 2. Olympics Gold Medalist Javelin Thrower

ATHLETE NAME	OLYMPIC	HEIGHT in Meters	WEIGHT in KG	THROWING DISTANCE	BMI
		MALE			
Arto Härkönen	1984 Los Angeles	1.90	88	86.76	24.376
Tapio Korjus	1988 Seoul	1.96	102	84.28	26.555
Dainis Kūla	1980 Moscow	1.98	90	91.2	22.959
Pauli Nevala	1964 Tokyo	1.77	88	82.66	28.097
Jan Železný	2000 Sydney	1.86	87	90.17	25.151
Klaus Wolfermann	1972 Munich	1.76	88	90.48	28.414
Andreas Thorkildsen	2008 Beijing	1.88	90	90.57	25.466
Keshorn Walcott	2012 London	1.83	90	84.58	25.466
Thomas Röhler	2016 Rio de Janeiro	1.91	90	90.3	24.671
Neeraj Chopra	2020 Tokyo	1.82	86	87.58	25.966
		FEMALE			
Tessa Sanderson	1984 Los Angeles	1.68	70	69.56 m	25
Petra Felke	1988 Seoul	1.72	74	74.68 m	25
Silke Renk	1992 Barcelona	1.73	71	68.34 m	23.72
Heli Rantanen	1996 Atlanta	1.74	69	67.94 m	22.79
Trine Hattestad	2000 Sydney	1.73	73	68.91 m	24.39
Osleidys Menéndez	2004 Athens	1.75	80	71.53 m	26
Barbora Špotáková	2008 Beijing	1.82	80	71.42 m	24
Ruth Fuchs	1976 Montreal	1.69	71	65.94 m	24.859
Sara Kolak	2016 Rio de Janeiro	1.70	74	66.18 m	25.6
Liu Shiying	2020 Tokyo	1.79	76	66.34 m	23.72

Relationship between the parameters :

Pearson correlation was conducted based on height, weight, Body Mass Index, and throwing performance of the athlete. Table III and IV represents the correlation matrix of male and female javelin Olympic gold medalist in the javelin.

Table 3. Correlation matrix for male throwers

	WEIGHT	HEIGHT	THROWING DISTANCE
HEIGHT	0.597244616 *		
THROWING DISTANCE	-0.352068875	0.260063261	
BMI	0.007272078	-0.763921008 *	-0.42451167

*Significant at .05 level (Critical Value .444)

Table 4. Correlation Matrix For Female Throwers

	WEIGHT	HEIGHT	THROWING DISTANCE
HEIGHT	0.697130091 *		
THROWING DISTANCE	0.396802535	0.196887134	
BMI	0.36480662	-0.411714421	0.241168035

*Significant at .05 level (Critical Value .444)

In the case of Olympic champion male javelin thrower height and weight was positively correlated and BMI and height were negatively correlated, other variables remain unrelated. On the other hand, female javelin throwers only significantly positively correlated in height and weight.

Body Mass Index (kg/ meter^2) is the ratio between weight in kg and height in meter ^{2}. That may be the main reason for a positive correlation between these two components for both male and female throwers. The more height the athlete the less will be his or her BMI, when weight is constant, which was found in the case of male throwers.

The throwers have been found heavier and taller, with long muscular arms and wide shoulders (Bullen, B.A 1971, Cureton 1951; Pere et al 1954; Tanner 1964; Hirata 1968; Muthiah and Venketsvarlu1973). The present study is supported by the findings of the height of the above researchers.

Kinamnetic analysis:

Table 5. Comparative analysis of findings of kinematic parameters of javelin throws

No	Author	Name of the study	Purpose of the study	Observation
1.	Dragan Milanovié, Mladen Mejovsek, Zeljko Hraski (1996)	Kinematic analysis of javelin release characteristics - A case study	The research aimed to compare the javelin release parameters of one Croatian athlete to those of the best male throwers at the 1992 Olympic Games in Barcelona.	The obtained findings revealed substantial differences in several parameters, including javelin release angle, release velocities, knee and elbow angles, grip distance, and peak joint center speed timing. Because certain technical faults have a major impact on the throw's distance, they should be addressed during the training phase to improve the distance.
2	Jose Campos, Gabriel Brizuela, Victor Ram6n, Javier Gamez (2002) .	Analysis of kinematic parameters between Spanish and world-class Javelin throwers	The purpose of this research was to evaluate the differences between the greatest Spanish javelin throwers and a group of world-class javelin throwers, as well as the implications of this.	World-class javelinists throw the javelin faster than national throwers. They accomplish more rotation of the hip and shoulder lines at the moment of release (T3). Throws from a higher posture, increasing the pace between T2 (arrival of the left foot on the ground) and T3.
3	Ching-Hua Chiu (2009)	Discovering Optimal Release Conditions for the Javelin World Record Holders by Using Computer Simulation	The goal of this research is to utilize computer modeling to determine the best release circumstances for world record holders in the javelin.	The release angle was found to be greater and the throwing range to be shorter when the center of mass was further away from the center of pressure.
4	Aleksandra Aleksić-Veljković, Miloš Puletić, Ratko Stanković, Saša Bubanj, Aleksandar Raković, Daniel Stanković (2012)	Kinematic differences in parameters of elite foreign and elite Serbian women javelin throwers	The point of this review is to decide the distinctions in kinematic boundaries between the 2011 Serbian Cup Final female senior lance hurlers (N=10, age 18,3, stature 170,5cm, weight 73,5kg), and the 2011 World Championships senior lance hurlers (N=3, age 27,6, tallness 176,3cm, weight 75,3kg).	The effects and information about the motion parameters during the javelin throwing method need to be used by using coaches and athletes to improve competitive results. Female senior javelin throwers of the 2011 Serbian Cup Final be directed toward further improvement of the javelin throwing technique, especially in the predelivery and the delivery section whilst per impulse and the release stride.
5	Panoutsakopoulos Vassilios Kollias A. Iraklis (2013)	Kinematics of the delivery phase and release parameters of top female javelin throwers	The study's goal was to look at the kinematical characteristics of the delivery phase and the release parameters of today's top female javelin throwers to back up the above-mentioned theory.	The data show that the throw distance is closely connected to the speed with which the javelin is released.
6	Masatoshi Murakami, SatoruTanabe, Masaki Ishikawa, and Akira Ito (2017) .	The Relationship between Approach Run Kinematics and Javelin Throwing Performance	The goal of the study was to better understand the kinematic aspects of efficient throwing motions, such as approach run movements, to improve javelin performance and coaching techniques.	While maintaining an extended position in the blocking leg, it is important to efficiently transfer the horizontal velocity of the center of mass to the rotational velocity of the trunk. As a result, a high arm swing speed may be produced by converting the trunk's rotational velocity, which can aid in generating a high starting velocity.
7	Yo Chen, Yi-Chen Chou, Tang-Yun Lo, Wen-Hsing Chang & Jia-Hao Chang (2019)	Kinematics differences between personal best and worst throws in the	The goal of this study was to discover kinematic variations between personal best and worst throws to give movement correction.	The release postures of the best and worst javelin throw differ. Elbow joint angle, wrist velocity, and hip height all impact throwing performance. From

		actual javelin competition		cross-step to release, throwers may enhance their performance by employing more foot push-off to support their bodies.
8	SamanehMohammadia , Jalalabadi,FatemeNikkho o Amiri (2019)	Analyzing, investigating, and calculating the optimum mode of the parameters affecting the record of the javelin throw including the initial velocity, initial angle, and initial height of the throw	In the javelin throw, three factors (initial velocity V1, initial throw angle・1and initial throw height H) play a fundamental role in an athlete's record. In this study, these factors were expressed, analyzed, and investigated, and the physical, technical and computational parameters with greater precision were also expressed.	For each athlete, an ideal mode of beginning velocity, initial angle, and initial height of throw was found, yielding the maximum record for throwing. The equations of optimal modes are produced for the three aforementioned variables, according to the results.
9	Ratko Pavlović (2020)	Biomechanical Analysis in Athletics: The Influence of Kinematic Parameters on The Results of Javelin Throw of Elite Athletes	The primary goal of the study was to evaluate the relationship and effect of kinematic factors on the success of male and female finalists in the World Championships in Berlin in 2009 and Daegu in 2011.	It was shown that the ejection rate was the only kinematic parameter having a statistically significant impact on the length of the javelin throw, which is consistent with the findings of earlier research.
10	Jamal Abubshara, Osama Abdel Fattah (2021)	The Optimum Release Height for Javelin Throwers in Proportion to Their Lengths	The purpose of this study was to determine the optimal height release for the javelin throw about the length of the world champions in the javelin throw event.	The optimal height release for javelin throw is 105.75 percent of the length of the world champions in this sport. Using the optimal height release for the javelin throw improves the horizontal displacement with the same velocity and angle release.

From the above table, we can understand the techniques of javelin throw are dependent on the biomechanical principles which is further an individualized matter as no two athletes are alike. The kinematic parameters are responsible for a better horizontal distance of javelin are as follows: 1) Release angle, 2) Release velocity, 3) Knee and elbow angle, 4) Position of Centre of gravity of the javelin, 5) Gripping, 6) peak joint center speed timing, 7) hip and shoulder lines at the moment of release, 8) impulse and the release stride, 9) efficiently transfer the horizontal velocity of the center of mass to rotational velocity of the trunk, 10) initial height of the throw, 11) Speed of tail Wind.

The systematic 3D photographic method is helpful to analyze the performance of the javelin and rectifies the mistake if any and the noninvasive EMG technique is useful to measure the amount of force exerted by a particular group of muscles while throwing the javelin.

CONCLUSION

In this analytical study, various research findings have analyzed the kinematic parameters of world-class elite javelin throwers from various countries. So, it can be concluded that the distance of the throw is highly correlated with the speed of the javelin upon its release. A high arm swing speed may be achieved by converting the rotational velocity of the trunk, which may help provide a high initial velocity for an athlete's throwing motion. The greatest and poorest javelin throws have different release stances. Throwing performance is influenced by elbow joint angle, wrist velocity, and hip height. An optimum mode of initial velocity, initial angle, and initial height of throw was obtained for each athlete. Using the optimum height release has a positive effect on the horizontal displacement with the same velocity and angle release. The biomechanical analysis of height, weight, BMI, and performance indicated that both male and female Olympic modelers in javelin were positively related to height and weight, and male athletes were negatively related to BMI and height.

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APPENDIX

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