

Turnitin Shot Put

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Mathematical simulation approach to diagnose performance limiting factor of shot put technique

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Abstract. The applied mathematics simulation for human motion is one breakthrough of sports biomechanics in sports science. The optimum rate of energy generated in muscles and knees, hips, shoulders and wrists play a significant role and influence the throw distance. Kinetic analysis of parabolic path is predominantly determined by the *speed of release* (V_0), *angle of release* (α) and *height of release* (h_0) at the delivery phase of throwing. The inequality of anthropometry, physical and quality of technique requires coaches to develop mathematical simulation to diagnose performance. This study describes mathematical simulation of *speed* (V_0), *angle* (α) and *height of release* (h_0) against a throw distance. The 28 male sport students (19.3 ± 1.2 years, weight of 68.2 ± 5.5 kg, height of 169.7 ± 5.4 cm) represent a linear shot put (4 kg), recorded with 2 HD cameras in sagittal plane and analysed with kinovea software for kinematic motion. There is significant relationship between *speed* ($p=0.001$), *angle* ($p=0.003$) and *height of release* ($p=0.004$) with performance. The rate of *speed* (7.23 ± 0.75 ms⁻¹), *angle* ($44.67 \pm 9.19^\circ$) and *height of release* was (194 ± 7.72 cm). The greatest shot performance was 12.57 m, applies 7.98 ± 0.02 ms of *speed*, $48.59 \pm 2.18^\circ$ of *angle* and 199.63 ± 2.21 cm of *height*. Mathematical Simulation can be applied to predict shot put performance through kinematic study.

1. Introduction.

The movements of human cannot be separated from the principles of mechanics and physics, which involve physiological organs such as the heart, lungs and *locomotor* organs such as muscles, bones and joints to control force, pressure and form a safe angle to make movements [1]. The applied mathematics simulation for human motion analysis is one of the breakthroughs of sports biomechanics in the field of sports science [2]. Biomechanics of sport is a field of sport science that involves mathematical calculations and physics of kinematics to analyze the influence of forces and natural laws that work on the motion of the human body during physical activity [3]. The quality of human motion is influenced by internal factors of bio-motoric components as well as the amount of applied force, speed and angle acting on the object as external factor [4]. Modeling human motion effectively will avoid injury due to motion errors and also acting as a guide to improve sports performance through the development of design and analysis of optimal training techniques [5]. Algebra mathematical calculations are needed to simplify the model of human body motion with a theoretical approach to physiology, mechanics, and robotics and involve the analysis of forces found in joints and muscles in order to obtain mathematical equations that express the movements of the human body [6].

Shot put is an athletic sport that is competed in the Olympics. The athlete stands on the 2.15 m diameter circular throw sector, gliding linearly by involving maximum contraction of muscles and joints in translational lower extremity to throw a 7.24 kg shot as far as possible by paying attention to the

optimal throw angle to form a parabolic curve properly [7]. In throwing the shot, in addition to the required components of strength, speed and good exploitation, it also requires good control of movement especially during the release phase so that the body does not cross the zone and remain in the throwing field [8]. The factors affecting shot put performance are divided into the physical laws of implement flight phases regarding the constant path of acceleration and biomechanical laws of human movement regarding impulse transfer of force from knee, hip, shoulder and wrist joint to release shot put. Meanwhile, the factors that determine trajectory including horizontal displacement of an implement are speed of release, angle of release and height of release [9].

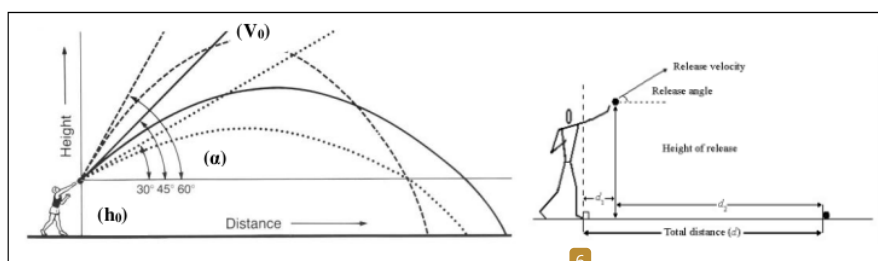


Figure 1. Optimal angle (α) in relation with speed (V_0) and height of release (h_0)

The angle of release and height of release both show (fig.1) a significant aspect in influencing the distance of shot produced, which is conclusively decided by the form in which force is applied [10]. Producing an optimal projectile pathway of shot requires establishing an optimal angle of release between 90° and 0° . Despite a kinematic study reported that the 45° is the optimal angle of release since the value of horizontal and vertical velocity are equal, the optimal angle of release is dependent on an individual proportion ability between applied horizontal and vertical acceleration [8]. Some studies try to explain related to angle of release variable that optimal angle of release for junior male athletes is spread around 40° - 41° , while for females is about 35° - 37° [11]. Another study explains that the optimal angle to get the maximum distance using a parabolic projectile lane is in the range 43° - 47° [12]. Biomechanical analysis studies using samples of elite athletes shot put show that the average angle used by the Olympic athletes ranges from 51° - 54° for males and 48° - 51° for females [13].

The optimal angle of release can be calculated by considering two conditions for example ensuring the landing spot is in the lower end in comparison with the point of height of release and when the point of height of release located in the lower point instead of the landing point [7]. The position of the landing spot that is lower instead of the height of release indicates that the height of the release is in a comparatively positive, where the shot is placed and will be delivered at a higher point than the starting point. So, it allows tolerable flight time thus the requested angle of release can be smaller than 45° and determined by individual anthropometrical profile [7]. The contrary study however shows that the angle of release has less effect to shot-put distance rather than speed of release. However, a significant shift from the optimal release angle might have an adverse effect on athlete performance [14]. The biomechanical study conducted at the world athletic championship reported that the average speed of release possessed by male elite athletes ranged from $13.5 \pm 1.4 \text{ ms}^{-1}$ and had a remarkably great correlation to the distance of shot put shot as far as $20.4 \pm 2.3 \text{ m}$. So, it was concluded that the speed of release is one of the undoubtedly determining factors at which athlete is moving while performing a shot put and will significantly affect the distance [15]. The description of speed release in relation to performance showed other movement analysis which reported that the declining average speed of release about $9.3 \pm 1.7 \text{ ms}^{-1}$ for male junior level in parallel caused a decrease in shot put performance around $15.1 \pm 2.6 \text{ m}$ [16]. The optimal rate of mechanical energy of speed, strength with explosive strengthening power generated in the legs muscles, joints of the ankles, knees transferred to the hips, shoulders, wrists and followed by an explosive extension of the arm in the throw direction plays a significant role at delivery phase and affects the distance of throw [17]. At the same time, kinetic analysis of parabolic flight path in shot put is largely determined by optimum speed of release (V_0), angle of release (α) and height of center of gravity at release (h_0) at the delivery phase of throwing [18].

The inequalities of anthropometric, physical and quality of technique require coaches to develop appropriate mathematical simulation to analyze performance limiting factor of *speed of release*, *angle of release* and *height of release* adjusted to individual profile [19]. Improper distribution between trainings load, technical trainings to the physical ability of athletes becomes one of affecting factors of sports injuries and drop-out of long-term athlete development process [20]. To thoroughly understand relationship between *speed of release*, *angle of release* and *height of release* in a shot put context, there are particular mathematical simulation required to be studied, these being what differences in speed appear, what sequence they exist in and what affects they reforms [19].

2. Methods

This study describes a mathematical approach of model simulation *speed of release* (V_0), *angle of release* (α) and *height of center of gravity at release* (h_0) against distance of throw to predict the performance [21]. The method study is an experimental research with cross-sectional approach and involving 18 male sport students (20.3 ± 2.2 years, body weight of 68.2 ± 5.52 kg, height of 169 ± 5.67 cm), who attended in shot put class for final practical examination [22]. Samples perform 3 times a linear shot put with 4kg implement. The kinematic motion data were recorded with 2 HD cameras installed in approx. 90° sagittal plane within 9m distances to capture a motion and analyzed with kinovea software for kinematic analysis [23]. The following figure shows set-up of cameras.

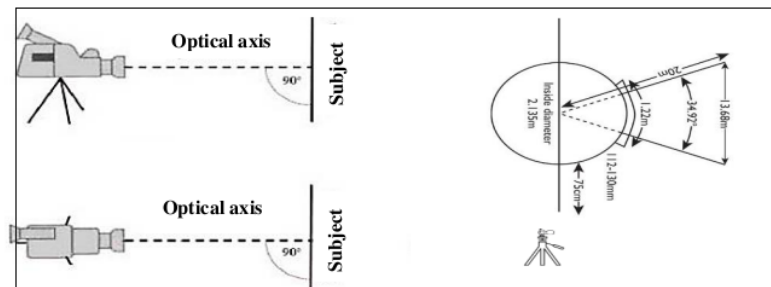


Figure 2. The placement of camera

The experiment procedure was implemented outdoor adjusted to conduct biomechanical analysis of shot put and completed based on the actions without any accidental errors, with the individual presenting the task consistently [24]. The distance between the shot put landing and the throw area is applied to quantify the shot distance, and the size of the shot distance is used to assess the shot put performance. The computer simulation is applied to set up a mathematical design, and the investigated shot distance is stated as a purpose of initial speed and angle of shot. Meanwhile, the numerical method is used to investigate, measure the effect degree of altered factors on shot put distance, establish the primary and secondary relationship between the factors, and present a mathematical principle for the conformation of mathematical shot put training programs. The following is mathematical assumption of relationship between *speed*, *angle* and *height of release* in shot put.

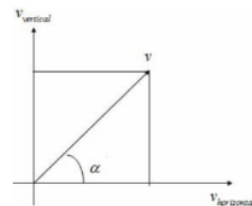


Figure 2. speed relation graph

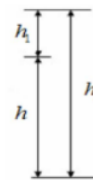


Figure 3. height relation

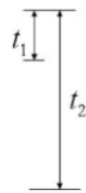


Figure 4. Flight time

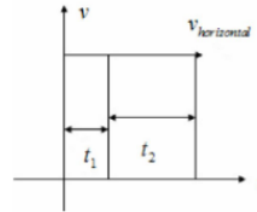


Figure 5. Speed and time relation

The following is remark of symbol description.

- V : The initial speed of release after throwing.
- Vhor. : The initial speed of release in horizontal direction after throw
- Vver. : The initial speed of release in vertical direction after throw
- α : The initial shot angle after throw
- h : The advance distance moving to the first static time,
- h_1 : The highest point from the ground in vertical direction
- h_2 : Ground acceleration after shot
- t : Total time (s) after throw
- t_1 : The time of upward speed in vertical direction after throw
- t_2 : The falling time to the ground from the peak after throw

The following mathematical equation of trajectories is applied as solving simulation according to the graph assumption.

$$V_{horizontal} = v \cos \alpha ; V_{vertical} = v \sin \alpha ; h_1 = \frac{v^2 \sin^2 \alpha}{2g} ; t_1 = \frac{v \sin \alpha}{g} ; t_2 = \frac{\sqrt{2h}}{g} ;$$

$$h_2 = h + h_1 ; t = t_1 + t_2 ; s = \frac{v \cos \alpha}{g} v \sin \alpha + (\sqrt{2gh} + v^2 \sin^2 \alpha) ;$$

3. Result and Discussion

3.1. Result

The descriptive analysis carried out by involving anthropometric aspect which includes height, weight, body height, Resting Heart Rate (RHR) and kinematic variables is explained by the following table.

Table 1. Descriptive statistic of anthropometry and variable of study

Variables	N	Mean	SD	Min	Max
Ages (years)	18	19.3	1.2	18.1	20.5
Weight (cms)	18	68.2	5.2	63	73.4
Weight (Kgs)	18	169.7	5.4	164.3	175.1
Body mass index (Kg/m ²)	18	21.7	2.3	19.4	24
Resting Heart Rate (beat/minutes)	18	65.2	8.4	56.8	73.6
Angle of release (°)	18	44.67	9.19	37.48	52.86
Arm angle of release (°)	18	49.23	6.89	42.34	56.12
Speed of release (mtr/s)	18	7.23	0.75	6.48	7.98
Height of release (cms)	18	194.2	7.72	186.4	201.9
Shot Put Performance (mtr)	18	10.83	1.74	9.09	12.57

The sample shows that the productive age (19.3 ± 1.2 years), possesses a normal body mass index and has no fatigue issues ($BMI\ 21.7 \pm 2.3$; $RHR 65.2 \pm 8.4$). The performance of shot put shows good results for the junior age (10.83 ± 1.74), though the quality of the technique seen from the profile of kinematic illustrates inequality profile. To investigate the performance limiting factor of shot put, we apply a mathematical calculation simulation of variables *speed of release*, *angle of release* and *height of release* to diagnose the relationship and provide the optimal technical model of shot put using kinovea software. The following table shows the numerical simulation.

Table 2. Numerical Simulation of Variables

<i>a</i>	<i>v</i>	<i>h</i>	<i>g</i>	<i>s</i>	<i>a</i>	<i>v</i>	<i>h</i>	<i>g</i>	<i>s</i>
41.09	6.48	190.2	9.8	9.09	49.54	7.52	188.6	9.8	10.85
42.17	6.78	188.5	9.8	9.57	50.17	7.67	189.7	9.8	10.87
39.37	7.07	193.7	9.8	9.63	49.52	6.92	194.2	9.8	10.95
38.76	7.12	186.4	9.8	9.82	52.10	7.23	196.9	9.8	11.23
44.51	6.42	187.2	9.8	10.11	50.77	6.54	198.7	9.8	11.34
42.16	7.45	190.2	9.8	10.27	49.97	6.74	200.1	9.8	11.56
37.48	6.72	188.7	9.8	10.44	52.86	7.18	199.5	9.8	11.87
44.16	6.98	194.2	9.8	10.67	50.64	7.42	201.9	9.8	12.32
47.87	7.23	190.5	9.8	10.83	51.15	7.98	200.7	9.8	12.57

The numerical data above presents the spread of variable speed, angle and height of release profiles on performance. The inequality indicates an asymmetrical pattern between variables and performance. Nevertheless, certain patterns appear to be positive relationship assumptions between variables with achievement (*speed* $7.23 \pm 0.75\text{ms}^{-1}$, *angle* $55.67 \pm 6.19^\circ$, *height of release* $194 \pm 7.72\text{cm}$ and performance $12.57 \pm 1.74\text{m}$). Table of the interrelationship investigation between variables with achievements will be exposed below.

Table 3. Profile of variables in correlation with performance

Group of Performance	Av.s	Av. <i>a</i>	Av. h	Av.v	Max Speed (in ms)	Max Angle (in °)	Max Height (in mtr)
Low	6.75	44.34	191.37	6.39	6.63	41.34	192.37
Medium	10.83	46.35	194.98	7.07	7.28	46.46	190.98
High	12.25	48.59	199.63	7.43	7.98	51.25	199.63

The distribution of data illustrates that *speed and angle of release* has a linear pattern with performance. Increased *speed and angle of release* contribute positively to the improvement of shot put achievements. Samples that showed optimal speed and angle of release appear to not seem to be able to produce great performance due to non-optimal height of release. A variable of *speed and angle of release* must likewise have followed by a variable of *height of release* in a linear pattern to obtain optimal performance. The following graphics illustrate the relationship of shot performance under different speed, angle and height of release.

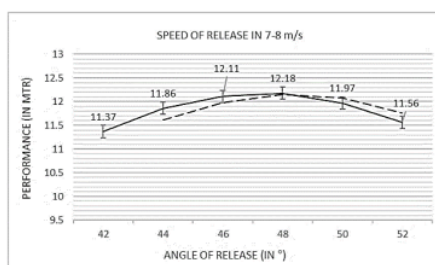


Figure 1. Speed, Angle, performance relation

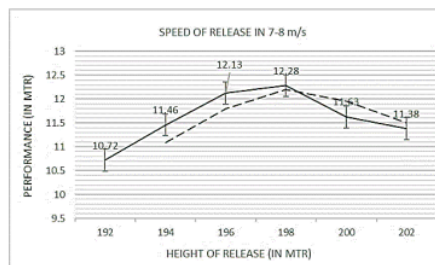


Figure 2. Speed, Height, performance relation

Figure 1 describes the linear interaction between speed and angle on performance. It is highlighted in the previous table 3, which explains that to obtain the greatest shot put performance requires a maximum speed. Shot performance is not particularly determined by speed, but likewise influenced by the angle of release used. A throw with a great speed of 7-8ms-1 however that uses an angle of release greater than 48 degrees will not advance the throw distance. Nevertheless, throwing a shot with an angle of release below than 44 degrees at a speed of 7-8 ms-1 likewise produces less optimal results. It is confirmed that to produce maximum performance requires a maximum *speed of release*, at the same time the proposed angle of release that should be in between 46-48 degrees. Shot performance is likewise affected by the *height of release* aspect. It is highlighted in table 2 that *height of release* has a linear interaction with shot performance. Athletes who have *speeds of release* between 7-8 ms-1 will obtain maximum performance when applying a *height of release* in between 196-198cm. Applying the *height of release* over than 198cm with a speed of 7-8 ms-1 precisely reduces shot performance. This clarifies, *the height of release* must be adjusted to *the speed of release* used at the same execution time. The lack of control between *height* and *speed of release* applied, will not produce the proposed performance. Statistical calculations related to the interrelationship between variables are explained in the table below.

Table 4. Matrix correlation among variable and to shot put performance

Variables	Angle of release	Speed of Release	Height of Release	Shot Put Performance
8				
Angle of release (°)	1.000	0.037	*0.004	*0.003
Speed of release (mtr/s)	--	1.000	0.324	*0.001
Height of release (cms)	--	--	1.000	*0.004
Shot Put Performance (mtr)	--	--		1.000

*significant $r=0.005$

The data appears that performance in shot put was significantly correlated with the angle, speed and height of release. The speed of release has the greatest significance with the performance ($p=0.001$), while the angle of release has medium significance with the performance ($p=0.003$) and height of release has lowest significance with the performance ($p=0.004$) at the time of shot release. On the other side, the angle of release has significant confirmation to the height of release and shows a value of $p=0.004$. This indicates that the optimal height of release is controlled by the optimal angle used. Meanwhile, the value of the interaction between the angle and speed of release expresses no significant effect. It is estimated that the over speed of release used to throw will have difficulty in forming the proposed optimal angle (44-46 degrees). This is expected to the influence of high horizontal force operating on shot and the athlete's body movements during the throw. Based on that estimate, the interrelationship between the angle and the speed of release appears to not have a significant effect. However, height of release at the time of release has some relation to the release angle, velocity of release and performance in shot put.

3.2. Discussion

The variable of speed, angel and height of release have a significant effect on shot put performance expressed in the table above. This is also explained in biomechanics study that factors affecting in shot put performance are divided into an aspect of kinematic motion including a phase of flight trajectory, angle of release and height of release and biomechanical laws of human movement including impulse transfer of force from knee, hip, shoulder and wrist joint to release a maximum speed of release in shot delivery phase [25]. The component of speed of release applied for shot put is the ability to generate explosive movements which are influenced by physical conditions including strength, speed, flexibility and coordination. The athletes' throw with shot using 7 kg implement for men and 4 kg for women, demands the shot put athletes to have great body mass index including body weight, body height, mass of muscle and more dominant in explosive muscle strength to be able to overcome the weight of the shot used. Explosive power is an interrelated relationship of the conditions of the bio-motor strength

and speed in the right portion to obtain optimal explosive capabilities [26]. Increasing muscle strength through the process of muscle hypertrophy is one of the commonly methods used, but having too much muscle mass will actually reduce the ability of speed since the ability to produce maximum speed can only be done if it has a light weight object [27]. It concludes the anthropometric profile is one of the advantages in shot put since it will produce easiness in providing an optimal height of release at delivery phase, while the physical status is a decisive physical factor in supporting kinematic motion of speed of release height of release in shot put [28].

The characteristics of the sample used in this study are sports students, have inequality anthropometric and physical conditions comparing with professional athletes. Therefore, it led to the discovery of several results of new mathematical calculations which then resulted in technical simulations in accordance with the shape and characteristics of the sample. The results prove that the angle of release has significant effect ($p=0.003$) to performance. The optimal angle of release for sample with average height of 169.7 cm and speed of release of 7-8 ms⁻¹ was between 44-46 degrees with a successful throw distance of 12 meters. The obtained simulations of angle in release are expected to be used as guidelines for coaches and shot put athletes who have similar characteristics to the sample and do not apply literature results for different anthropometric profile [29]. These results complement the theory that explains the magnitude of the angle of release. This is exemplified in the angle of release aspect wherein in the projectile theory it is explained that the optimal angle on the parabolic curve for projectile motion is 45 degrees [8]. The results of biomechanical studies on world shot put athletes actually show different results, where the average angle used by athletes who managed to throw with a distance above 20m is 59-61 degrees [13]. In addition, this simulation model also provides confirmation of the decisions of the research results which state that the *angle of release* has less effect to shot-put distance rather than speed of release [28], and states that the angle of release has significant effect ($p=0.003$) to the performance of shot put.

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The speed of release is proven to have the greatest significant effect ($p=0.001$) on achievement in this study. This is also reinforced by the kinematic analysis study of shot put that speed of release is one of the undoubtedly determining factors at which athlete is moving the body backward to the throw direction [30], and pushing arm quickly by delivering the shot to the throwing sector [15]. This opinion refers to the explanation that the initial movement of the delivery phase of the shot put starts by straightening the muscle of knee by driving the body into the throw direction and at the same time pushing the wrist, elbow and arm with the shot explosively by forming an optimal angle towards the throwing sector [31]. This study also explains that variable of height of release has a significant effect ($p=0.004$) on shot put performance. This confirms that anthropometry is also a determining factor in obtaining performance in shot put. This opinion was reported on the results of the motion analysis during males shot put championship and explained that athletes applying speed of release above 13ms⁻¹ and height of release up to 2 meters has an average performance of throw 20-21 meters. Otherwise, athlete that has a height of release below of 2 meters achieves a throw distance of 16-18 meters [15]. Likewise, the results of an analysis of females shot put reported implementing a speed of release of 10-11ms⁻¹ and height of release between 195 meter obtain a performance of 20-21 meters while below of 195 meters producing performance around 17-19 meters [32].

The results of the research may depend on the following aspects associated to shot put variables. This research concludes that speed, angle and height of release are important factors and can be used as parameters to produce better shot put performance. However, it is confirmed that performance of shot put depends on the *angle of release*, *speed of release* and *height of release* [33]. Shot put requires a high level of coordination ability. A series of body movements that combine footwork, arm, body and kinesthetic perception accompanied by carrying 7 kg shot for men and 4 kg for girls, requires good physical ability and coordination. This study did not involve aspects of physical condition, psychological and nutritional status to be tested for their effect with kinematic motion on the performance of shot put [34][35]. Every sample had his own anthropometric profile and different optimum angle of release since individual characteristic in the rate of speed of release and height of release are applied for delivering the shot. To obtain excellent performances, it is not significant to deliver the shot at exactly close to the optimum release angle stated in literature. Throwing with a high speed of release is greatly necessary to achieve a great performance rather than throwing in according to an angle of release stated in study [36].

The point emphasized in this conclusion is that differences in body posture and physical ability must be accompanied by calculation of motion analysis using a mathematical approach to obtain suitable engineering simulations. The control to proportionally composition of each variable in implementing three variables when delivering a shot is required as consideration to obtain maximum performance. The use of literature must be selected and adjusted to the characteristics of athletes in order to get a high validity value.

4. Conclusion

There is a significant correlation between speed of release, angle of release and height of release to shot put performance. The most ideal angle of release and height of release based on mathematical calculations for male athletes with a height of 170-175 cm and a speed of release of 6-7 ms is 44°-46° and 194-196cm. While optimal angle and height of release for athletes who has speed of release of 7-8ms is 46-48 degrees and 196-198cm of height release.

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