

Research article

Biomechanical properties of the discus throw: analytical case study of the Paralympic record holder in the F33 category



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ABSTRACT

Purpose: The study aims to determine the kinematic and kinetic characteristics of the discus throwing competition for the Paralympic record holder in the F33 category, the champion Hani Al-Nakhli, silver medalist in the London 2012 Paralympic and the World Champion in the discus throw (height: 1.71 m, weight: 96 kg, age: 35 years, training age: 14 years).

Methods: The player's performance was photographed during a training session in the middle of the competitive phase of the 2021/2022 season using three GoPro Hero 6 cameras, each set at a frame rate of 60fps. A video-based motion and skill analysis tool for Windows was used to choose the best approach for creating a 3D biomechanical analysis.

Results: The values of the Paralympic champion were presented and discussed, and the researchers improved the player's ability to work—increasing the acceleration distance of the disc by up to 1.85 m with an acceleration within a period of 0.40 s. Thus, high-speed rates of up to 16.77 m s^{-1} was achieved during the launch, with the disposal of the disc at an angle of clearance of 37° and a starting height of 1.36 m, resulting in 27 m. The values of the kinetic analysis represented the need to increase the tangential potential energy of the body by 1884 J during disposal while increasing the tangential kinetic energy of the body by a value of 9.93 J. This is achieved by increasing the rotational kinetic energy of the body of the player to reach high achievement distances for class F33. It is recommended to use the results of the variables in the training process to prepare champions for the discus throwing competition.

1. Introduction

Discus throw (or, disc throw) is a track and field event with a high degree of physical and technical demands. Performance for able-bodied athletes includes seven stages: discus holding, standby, preliminary swinging, rotation, throwing position, disposal, and, finally, balance after the throw. However, for F33 athletes, and given the nature of the performance on the stationary chair, the rotational phase is reduced compared to the technical stages, making it difficult to increase the acceleration of the disc by shortening its acceleration distance. Recently, the difficulty is further increased due to the inability to use their feet during throwing (O'Riordan et al., 2004; Jensen, 2010).

Disposal is considered the most important stage of performance in the competition, where the final indicators of launch appear. These are velocity release, angle of release, and height of the disc at the time of launch. It is necessary to try to adjust the motor performance of the player to achieve ideal values for these variables (Tweedy, 2002; Leigh et al., 2008).

The performance of the seated players in achieving the required distances depends on the interaction between the method and technique of throwing and the player's evaluation of the chair (Frossard et al., 2005, 2012). The player has the right to choose the seat, but the chair is fixed (O'Riordan et al., 2004). A significant correlation has been shown between handicap, classification, and performance, which in turn affects the height of the disposal point, the angular velocity of the upper part, trunk, starting speeds, the distances achieved, body momentums, and the forces that can be produced (Haake, 2009). Data from this kind of research can help coaches and players in international competitions and tournaments, and it provides a database to help develop throwing techniques and make them more effective. The use of biomechanics is an objective method to determine performance and increase understanding of the components and mechanisms that affect performance (Sarah and Frossard, 2012).

The athletic performance of healthy people is well known, but there is little understanding of the complexities of the athletic performance of people with disabilities; further understanding, clarification, and analysis

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of their performance are needed (Kuiken, 2012). The biomechanical analysis of people with disabilities helps in resolving the conflict between biomechanics and training for individuals with disabilities, as it shows the complexity of training players and solving their problems through kinetic and/or kinematic variables (Frossard et al., 2005). Biomechanics analysis is more important for disabled players in explaining and clarifying performance, as the disability of the players leads to differences in basic functional abilities between the disabled and the healthy (McNamee, 2011). The biomechanical analysis allows for better technical execution which reduces risk factors and injuries resulting from training loads and movements on the chair; kinematic analyses can help identify the anatomical and physiological range of motion of the joints and ways of using them more effectively (Błaszczyszyn et al., 2019). In addition, kinetic analysis is necessary to determine the forces acting on the disc distance achieved (McNamee, 2011).

Looking at the reference studies on the F33 category, we find that they are very limited. There is not enough information or mechanical knowledge about disabled disc players, which prompted researchers to try to develop a biomechanical model for discus throwing for one of the world champions at the level of the Paralympic Games. This study aims to determine the kinematic and kinetic characteristics of F33 discus throwing for the champion of Saudi Arabia for the Paralympic Games.

2. Methods

2.1. Procedures

The data was extracted from the kinetic and kinematic analysis of the best attempt among the eight discus throws performed by the Paralympic champion in the F33 category. The attempts were performed after a 30-minute warm-up, including a 15-minute of moving around in a wheelchair, followed by joint movements, muscle stretching, and preparatory exercises with rubber bands and light discs (600 g). The athlete was also subjected to three attempts to become familiar with the competition disc before starting the video recording. The eight throws took place under the same conditions (e.g., throwing chair, wind speed) as the Paralympic competitions and the athlete benefited from 3 min of rest after each throw. The athlete was photographed with three cameras, a three-dimensional analysis was carried out using specific software and the best performance in terms of kinetics and kinematics was described.

2.2. Participant

This study was conducted on the Paralympic record holder in the F33 category, Hani Al-Nakhli whose characteristics are mentioned in Table 1.

Table 1. Basic and anthropometric characteristics of the Paralympic record holder in the F33 category.

Variable	Value
Age (year)	35
Experience (year)	14
Height (cm)	171
Weight (kg)	69
Distance record (m)	34.65
Chair height (cm)	74
Chair width (cm)	50
Chair length (cm)	72
Player classification	F33
Palm length (cm)	20
Forearm length (cm)	26
Upper arm length (cm)	33
Arm length (cm)	70
Chest circumference (cm)	94
Waist circumference (cm)	84

All stages of the experiment were conducted following the Helsinki Agreement (World Medical Association, 2013), and ethics approval was obtained from the Saudi Paralympic Athletics Federation and the Research Ethics Committee at King Faisal University, Saudi Arabia (KFU-REC-2021-OCT-EA0004). The athlete was informed of the objectives, stages of the study, and possible effects that could result from it. He signed informed consent.

2.3. Technical analysis

The player's 3D biomechanical measurements were carried out through a three-dimensional imaging procedure using three GoPro Hero 6 cameras, each set at a frequency of 60 frames/sec. Camera 1 was placed behind the player, with the direction of the lens identical to the direction of the throwing path, at a height of 1.20 m and 5 m from the player. Camera 2 faced the player's chest while he sat at the beginning of the throw, at 5 m from the player and a height of 1.20 m. Camera 3 was placed right behind the player during the beginning, before throwing, making an angle of 45° with the direction of the throw, and is 7 m away from the bowler at a height of 1.20 m. The throw was made on a three-dimensional drawing scale with a length of 1 * 1 * 1-meter, biomechanical analysis was done using a video-based motion and skill analysis tool for Windows (Skill-spector, version 1.3.2, Video4coach), and the extraction of the three-dimensional biomechanical variables under study was done (Figure 1).

2.4. Outcomes

The extracted variables were classified into kinematic and kinetic characteristics. The kinematic variables were 48 in number and included variables related to time and throw indicators; discus and body center of gravity variables during the performance analysis moments; and joint angles during the different phases of the throw. While the kinetic variables were 16 in number and included parameters related to the potential energy and the momentum of motion of the body's center of gravity and the disc and kinetic energy of the body's center of gravity during the different phases of the throw.

3. Results

3.1. Kinematic characteristics

Table 2 shows the temporal analysis and launch indicators of the best attempt performed by the athlete. The temporal analysis of the preliminary swinging time, the basic throwing time, and the time of the throw were 3.56, 0.40, and 3.96 s, respectively. The values of the launch indicators for the disc launch angle, disc launch height, and disc launch speed were 35°, 1.36 m, and 16.77 m/s, respectively.

It is clear from Table 3 that the horizontal displacement of the discus has the highest value during the moment of contact loss, at 1.74 m. The highest value of the vertical displacement of the discus during the end of contact with the disc is 0.35 m, and the highest value of the transverse displacement of the discus during the end of contact with the disc is 0.90 m. The highest value of the net displacement of the discus during the end of contact with the disc is 1.95 m. It is also clear that the horizontal displacement of the center of gravity of the body is the highest value during the moment of the end of contact loss by 0.017 m, and the highest value of the vertical displacement of the center of gravity during the loss of contact with the disc is 0.033 m. The highest value of the transverse displacement of the center of gravity during the loss of contact with the disc is 0.071 m. The highest value of the net displacement of the center of gravity of the body during the loss of contact with the disc is 0.078 m.

It is also clear that the horizontal velocity of the discus has the highest value during the moment of the end of contact loss at 3.97 m s⁻¹, and the highest value of the vertical velocity of the discus during the loss of contact with the disc is 13.84 m s⁻¹. The highest value of the transverse velocity of the discus during the loss of contact with the disc is 9.43 m

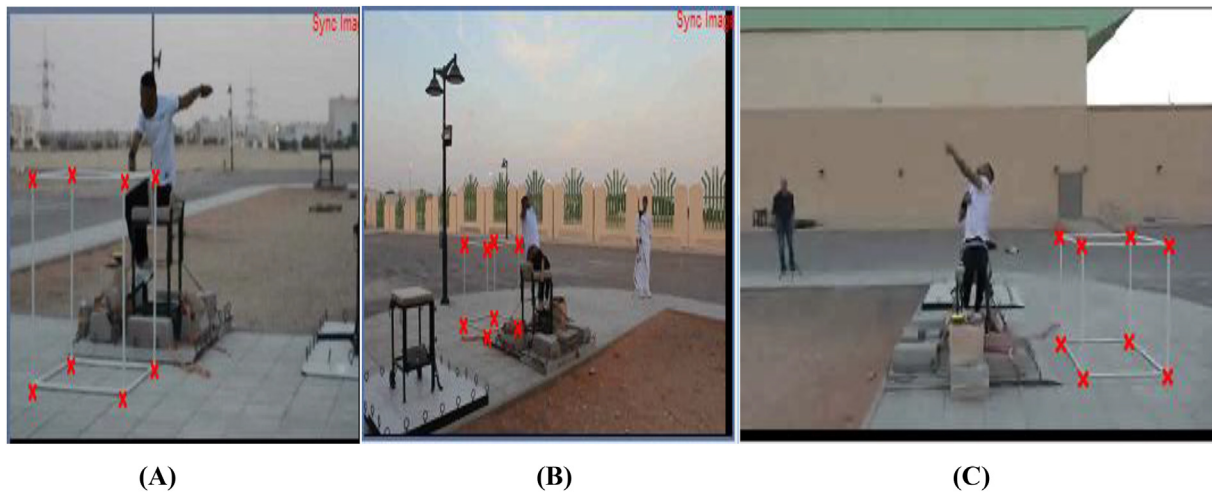


Figure 1. Images of the athlete's best throw in the F-33 category. Image (A) shows the initial phase of the preliminary swing captured by camera 1 located just behind the athlete; image (B) shows the beginning of the throw (Power-position) taken by camera 3 placed to the right and behind the athlete; image (C) illustrates the moment of the throw captured by camera 2 placed just in front of the athlete's chest. The red marks indicate the 1*1*1-meter three-dimensional scale used to control the photographic settings.

Table 2. Results of the temporal analysis and launch indicators in the Paralympic record holder in the F33 category.

Variables	Value
Achieved distance (m)	27
Preliminary swinging time (sec)	3.56
Basic throw time (sec)	0.40
Throw time (sec)	3.96
Disc launch angle (degree)	35.00
Disc launch height (m)	1.36
Disc launch speed (m.sec ⁻¹)	16.77

s⁻¹, and the highest value of the net velocity of the discus during the loss of contact with the disc is 16.77 m s⁻¹. It is also clear that the horizontal velocity of the center of gravity of the body has the highest value during the moment of contact loss, at 0.44 m s⁻¹, and the highest value of the vertical velocity of the center of gravity during the loss of contact with the disc is 0.28 m s⁻¹. The highest value of the transverse velocity of the center of gravity during the end of the connection with the disc is a rate of 0.45 m s⁻¹, and the highest value of the net velocity of the center of gravity during the loss of contact with the disc is 0.59 m s⁻¹.

It is also clear that the horizontal acceleration of the discus has the highest value during the moment of contact loss, at 148 m s⁻¹, and the highest value of the vertical acceleration of the discus during the loss of contact with the disc is 155 m s⁻¹. The highest value of the transverse acceleration of the discus during the loss of contact with the disc is 106 m s⁻¹, and the highest value of the net acceleration of the discus at the end of the connection with the disc is 239 m s⁻¹. It is also clear that the horizontal acceleration of the center of gravity of the body has the highest value during the moment of contact loss, at 4.25 m s⁻¹, and the highest value of the vertical acceleration of the center of gravity of the body during the loss of contact with the disc is 5.72 m s⁻¹. The highest value of the transverse acceleration of the center of gravity of the body during the end of contact with the disc is 10.88 m s⁻¹, and the highest value of net acceleration at the body's center of gravity during the loss of contact with the disc is 11.80 m s⁻¹.

Table 4 presents the results regarding angles of the body joints during the moments of performance analysis for the player's best throws. The highest value of the ankle joint angle was 111° at the moment of the start of the basic push. The value of the knee joint angle was 87° during the same moment, and the hip joint angle was the highest value of 123 during

the moment of loss of contact with the disc, while the shoulder joint angle had the highest value of 88° during the moment of the end of preliminary swings. The right elbow joint angle had the highest value of 177 at the beginning of the basic push. The angle of the right wrist joint had the highest value during the moment of the end of the preliminary swings and the start of the basic push by 155°. The left ankle joint angle had the highest value during the moment of the end of the preliminary swings and the start of the basic push, with a value of 100°. The left knee joint angle had the highest value at the end of the preliminary swing and the start of the basic push, with a value of 83°. The left hip angle had the highest value at the end of the preliminary swing, with a value of 114°. The left shoulder joint angle had the highest value during the moment of the end of the preliminary swing, with a value of 98°. The left elbow joint angle had the highest value during the moment of the beginning of the primary swings with a value of 162°, and the angle of the left wrist joint had the highest value during the moment of losing contact with the disc, at 176°.

It is also evident that the angular velocities of the body joints during the moments of performance analysis for the player's best throws have the highest value for the angular velocity of the right ankle joint, 162°. sec⁻¹, during the moment of the end of preliminary swings. The angular velocity of the right knee joint was 113°. sec⁻¹ at the same moment. The angular velocity of the right hip joint had the highest value of 89°. sec⁻¹ during the moment of the end of contact with the disc, while the angular velocity of the right shoulder joint had the highest value, at 200°. sec⁻¹ during the moment of the end of contact with the disc. The angular velocity of the right elbow joint had the highest value of 92°. sec⁻¹ during the moment of losing contact with the disc. The angular velocity of the right wrist joint had the highest value during the moment of loss of contact with the disc, at 141°. sec⁻¹.

The angular velocity of the left ankle joint had the highest value during the moment of the start of the primary basic push and during the moment of loss of contact with the disc at a value of 5°. sec⁻¹. The angular velocity of the left knee joint had the highest value during the beginning of the basic push, at a value of 19°. sec⁻¹. The angular velocity of the left hip joint had the highest value of 114°. sec⁻¹ during the moment of loss of contact with the disc. The angular velocity of the left shoulder joint had the highest value during the moment of losing contact with the disc, with a value of 323°. sec⁻¹. The angular velocity of the left elbow joint had the highest value during the moment of losing contact with the disc, with a value of 368°. sec⁻¹. The angular velocity of the left wrist joint had its highest value during the moment of losing contact with the disc, with a value of 297°. sec⁻¹.

Table 3. Results of the kinematic variables of the disc and the center of gravity during the moments of performance analysis for the Paralympic record holder in the F33 category.

Variables	Performance analysis moments			
	End of preliminary swinging	Start of basic push	End of contact with the disc	Loss of contact with the tool
Disc horizontal displacement (m)	0.01	0.03	1.70	1.74
Disc vertical displacement (m)	0.02	0.03	0.35	0.19
Disc transverse displacement (m)	0.01	0.06	0.90	0.61
The net displacement of the disc (m)	0.02	0.08	1.95	1.85
Horizontal displacement of the body's COG (m)	0.007	0.016	0.017	0.001
The vertical displacement of the body's COG (m)	0.011	0.015	0.025	0.033
Transverse displacement of the body's COG (m)	0.006	0.010	0.052	0.071
The net displacement of the body's COG (m)	0.014	0.024	0.060	0.078
Disc horizontal speed (m.sec ⁻¹)	0.49	1.07	3.97	0.76
Disc vertical speed (m.sec ⁻¹)	0.34	1.91	10.45	13.84
Disc tangential velocity (m.sec ⁻¹)	0.72	1.76	5.19	9.43
Disc Net speed (m.sec ⁻¹)	0.93	2.81	12.33	16.77
The horizontal velocity of the body's COG (m.sec ⁻¹)	0.14	0.26	0.37	0.44
The vertical velocity of the body's COG (m.sec ⁻¹)	0.20	0.08	0.08	0.28
Transverse velocity of the body's COG (m.sec ⁻¹)	0.14	0.22	0.45	0.25
The net velocity of the body's COG (m.sec ⁻¹)	0.28	0.35	0.59	0.58
Disc horizontal acceleration (m.sec ⁻²)	32.80	3.90	148	88
Disc vertical acceleration (m.sec ⁻²)	39.82	38.71	155	14
Disc transverse acceleration (m.sec ⁻²)	24.83	27.47	106	105
The net acceleration of the disc (m.sec ⁻²)	57.26	47.62	239	138
The horizontal acceleration of the body's COG (m.sec ⁻²)	4.25	1.76	2.25	1.46
The vertical acceleration of the body's COG (m.sec ⁻²)	4.98	0.82	5.72	4.34
Transverse acceleration of the body's COG (m.sec ⁻²)	1.67	5.74	0.85	10.88
The net acceleration of the body's COG (m.sec ⁻²)	6.75	6.06	6.21	11.80

COG: Center of gravity; The best result is in bold.

Table 4. The results of kinematic variables of the angle of body joints during the moments of performance analysis of the Paralympic record holder in the F33 category.

Variables	Performance analysis moments			
	End of preliminary swinging	Start of basic push	End of contact with the disc	Loss of contact with the disc
Right ankle joint angle (degree)	109	111	109	110
Right knee joint angle (degree)	86	87	85	84
Right hip joint angle (degree)	80	77	120	123
Right shoulder joint angle (degree)	88	85	37	29
Right elbow joint angle (degree)	171	177	34	38
Right wrist joint angle (degree)	155	155	151	142
Left ankle joint angle (degree)	100	100	93	93
Left knee joint angle (degree)	83	83	80	81
Left hip joint angle (degree)	114	112	90	95
Left shoulder joint angle (degree)	98	94	84	94
Left elbow joint angle (degree)	160	162	152	143
Left wrist joint angle (degree)	166	162	172	176
Angular velocity of the right ankle joint (degrees.sec ⁻¹)	162	7	53	28
Angular velocity of the right knee joint (degrees.sec ⁻¹)	113	1	35	14
Angular velocity of the right hip joint (degrees.sec ⁻¹)	9	66	89	67
Angular velocity of the right shoulder joint (degrees.sec ⁻¹)	78	67	200	160
Angular velocity of the right elbow joint (degrees.sec ⁻¹)	41	32	71	92
Angular velocity of the right wrist joint (degrees.sec ⁻¹)	139	5	53	141
Angular velocity of the left ankle joint (degrees.sec ⁻¹)	0	5	4	5
Angular velocity of the left knee joint (degrees.sec ⁻¹)	19	5	4	0
Angular velocity of the left hip joint (degrees.sec ⁻¹)	50	46	109	114
Angular velocity of the left shoulder joint (degrees.sec ⁻¹)	49	144	313	323
Angular velocity of the left elbow joint (degrees.sec ⁻¹)	68	72	89	368
Angular velocity of the left wrist joint (degrees.sec ⁻¹)	103	123	28	297

The best result is in bold.

3.2. Kinetic characteristics

Table 5 presents results regarding the quantities of horizontal, vertical, transverse, and net values for the momentum of the body's center of gravity and of the discus during the moments of performance analysis for the player's best throws. The quantity of horizontal momentum for the center of the body had the highest value at the loss of contact with the disc, at $42.34 \text{ kg m s}^{-1}$. The amount of vertical momentum of the body's center of gravity had the highest value while losing contact with the disc, at $27.10 \text{ kg m s}^{-1}$. The amount of transverse momentum of the body's center of gravity had the highest value at the end of contact with the disc, at $43.66 \text{ kg m s}^{-1}$. The amount of net momentum obtained by the body's center of gravity had the highest value at the end moment of contact with the disc, at $56.63 \text{ kg m s}^{-1}$. The horizontal momentum of the discus had the highest value at the end of its contact with the athlete's hand, at 7.95 kg m s^{-1} . The vertical momentum of the discus had the highest value when it lost contact with the athlete's hand, at $27.68 \text{ kg m s}^{-1}$. The transverse momentum of the discus had the highest value at the end of its contact with the athlete's hand, at $18.87 \text{ kg m s}^{-1}$. The net momentum obtained by the discus had the highest value at the end of its contact with the athlete's hand, at $33.54 \text{ kg m s}^{-1}$.

The horizontal potential energy of the center of gravity of the body was 242 J at the end of contact with the disc. The vertical potential energy of the center of gravity of the body had the highest value, at 1274 J , when losing contact with the disc. The tangential potential energy of the center of gravity of the body had the highest value, 1884 J , during the moment of losing contact with the disc. The net potential energy of the center of gravity had the highest value of 2286 J during the moment of losing contact with the disc. The horizontal kinetic energy of the center of gravity of the body was 9.34 J during the moment of losing contact with the disc. The vertical kinetic energy of the body's center of gravity had the highest value, 3.83 J , at the loss of contact with the disc. The tangential kinetic energy of the center of gravity had the highest value, 9.93 J , at the end of contact with the disc. The net kinetic energy of the center of gravity had the highest value of 11.85 J during the moment of the end of contact with the disc.

4. Discussion

The purpose of this study is to provide reference information for athletes, coaches, and others involved in developing evidence-based

training programs, and designing throwing frames and rules for the throwing event. It attempts to identify the kinematic and kinetic characteristics of the world record holder and silver medalist at the London 2012 Paralympic Games in the F33 category, Hani Al-Nakhli through quantitative variables. The best throw obtained in the eight tests was 27 m , this performance can be considered a good performance considering the conditions of the experiment (training) and compared to his Paralympic and world record. This was the result of several factors: the preliminary swinging time of 3.56 s , which in turn affected the starting speed, which reached 16.77 m s^{-1} —which was the most important and influential factor in the performance of the discus throw and in determining the time of the throw, 3.96 s . This helped to achieve an ideal starting angle of 35° ; research has shown that this angle should range between 35 and 37° (Leigh et al., 2008). The height of the throw at the moment of disposal was 1.36 m . All these factors led to a great throw (Franciosi et al., 2010). Similar results were recorded by Guebli et al. (2021) in the kinematic analysis of discus throwing by athlete Saifi Nassima, two-time Paralympic gold medalist and three-time world champion in the F57 discus throwing class.

The horizontal displacement of the discus reached 1.74 m from the end of the preliminary swings until the loss of contact with the disc. This distance is suitable for achieving discus acceleration, as the Paralympic player showed a great ability to achieve discus net speeds of 16.77 m s^{-1} during disposal; the net speed variable is the most important indicator for achieving an ideal discus distance, and this is what the player showed compared to the corresponding speed levels for the player at the same level Frossard (2012). Furthermore, Liu and Yu (2021) reported that increasing the angular momentum can help to increase the release rate and therefore reduce the flight distance. The decrease in the top left angular momentum is likely associated with the increase in aerodynamic distance in long runs. The disc must maintain a certain orientation during flight to gain aerodynamic distance (Hubbard and Cheng, 2007).

In F33 throwing competitions, it is important to achieve balance on the chair and maintain its stability. Perhaps this is one of the things that places restrictions on movement according to the nature and performance characteristics, which shows a decrease in the displacement rates at the body's center of gravity while reaching the rates of transverse displacement, 0.07 m . This calls attention to increasing the displacement rates and improving the variables of the throwing arm as much as possible, to obtain a high achievement distance (Sands, 2008; Tweedy and Vanlandewijck, 2011). The results also noted a remarkable

Table 5. The results of the quantities of horizontal, vertical, transverse, net of the center of gravity of the body movements and the Disc during the moments of performance analysis of the Paralympic record holder in the F33 category.

Variables	Performance analysis moments			
	End of preliminary swinging	Start of basic push	End of contact with the disc	Loss of contact with the disc
Horizontal momentum of the body' COG (kg.m.sec^{-1})	13.32	24.84	35.21	42.34
Vertical momentum of the body's COG (kg.m.sec^{-1})	19.03	7.90	7.79	27.10
The tangential momentum of the body's COG (kg.m.sec^{-1})	13.44	21.25	43.66	24.41
The net momentum of the body's COG (kg.m.sec^{-1})	26.84	33.63	56.63	55.88
The horizontal momentum of the Disc's COG (kg.m.sec^{-1})	0.99	2.14	7.95	1.52
Net of vertical momentum of the Disc's COG (kg.m.sec^{-1})	0.68	3.82	20.90	27.68
Transverse momentum of the Disc's COG (kg.m.sec^{-1})	1.43	3.52	10.39	18.87
The net momentum of the Disc's COG (kg.m.sec^{-1})	1.87	5.62	24.65	33.54
Horizontal potential energy of the body's COG (Jules)	233	241	242	227
Vertical potential energy of the body's COG (Jules)	1253	1257	1266	1274
Transverse potential energy of the body's COG (Jules)	1823	1827	1866	1884
The net potential energy of the body's COG (Jules)	2224	2231	2268	2286
Horizontal kinetic energy of the body's COG (Jules)	0.92	3.21	6.46	9.34
Vertical kinetic energy of the body's COG (Jules)	1.89	0.32	0.32	3.83
Transverse kinetic energy of the body's COG (Jules)	0.94	2.35	9.93	3.10
The net kinetic energy of the body's COG (Jules)	2.30	4.00	11.85	10.56

COG: Center of gravity; The best result is in bold.

difference in the vertical velocity variable of the disk from the time of the start of the thrust, which reached 1.91 m s^{-1} , to the time of the end of the contact with the disk, which reached 10.45 m s^{-1} . This difference of approximately 8 m s^{-1} shows the player's ability to increase the vertical velocity rates of the discus during the basic push phase. The process of increasing speed during the different stages of performance helps in achieving better performance and a positive impact on the distance achieved (Tweedy et al., 2012).

One of the important matters for class F33 discus-throwing players is to try to harmonize the speed through the perfect division of the ratios of the disc velocities on the three axes and levels of momentums (Liu and Yu, 2021). We notice that the discus's horizontal velocity during the end of contact with the disc reached 3.97 m.s^{-1} , and the vertical velocity reached 10.45 m s^{-1} at the end of the contact, which is the largest ratio, while the tangential speed represented a value of 5.19 m s^{-1} , as the second-largest value in discus speeds. This is because of two important factors. The first of these is related to the nature of the circular path that the discus takes, increasing the rates of transverse speed, which is evident from the 3D analysis, and which is necessary for the analysis of this competition. The second factor is related to the attempt to deepen the player while throwing the discus at the bottom, to increase the rates of the vertical velocities of the discus during disposal and release of the discus. This is because the vertical velocity represents the largest factor in the disposal of class F33 discus players (Frossard et al., 2010).

Others important matters related to the increase in the rates of force exerted by the body and transmitted to the discus are the acceleration variables, shown in Table 3. It is noticed that vertical acceleration rates are increased by a great margin, reaching 155 m s^{-1} , while the vertical acceleration values of the center of the body's gravity are lowered during the end of contact with the disc by a value of 5.72 m s^{-1} . The matter here is mainly related to the position of the player resulting from the use of the wheelchair and the comparatively fixed position (Liu and Yu, 2021; Chen et al., 2021). It is noticeable that the player could achieve vertical acceleration with the arm—sufficient to have a good effect on the discus (Frossard, 2012). Examination of the angular displacements of the F33 Paralympic champion player showed that convergent values are revealed for the lower extremity variables resulting from the fixation with inefficient differences. Changes were observed in the angles of the throwing arm's joints—elbow decreasing and wrist increasing. This indicates the nature of the ideal discus throw (Panoutsakopoulos and Kollias, 2012), as the decreasing of the elbow angle improves the player's ability to achieve good follow-through after throwing, through flexion and absorption of the force, while increasing the rates of the wrist joint angle to achieve the full kinetic transfer of force until the moment of disposal and loss of contact with the disc (Haake, 2009). The angular velocities of the joint indicate the player's ability to exert muscular force on muscle groups that are fixed on two connections to the player's body (Keogh, 2011). Results noted an increase in the angular velocities of the throwing arm and the hip joints on the same side as the throwing arm at the loss of contact with the disc. We also note that the elbow joint achieved the maximum angular velocity of the arm at $368^\circ \cdot \text{sec}^{-1}$, which demonstrates the ability of the muscle groups working on the straightening elbow joint to exert high rates of force during disposal and follow-up significantly (Linthome, 2001). During the end of contact with the disc it reached $89^\circ/\text{sec}$, and during the loss of contact with the disc, it increased by approximately $307^\circ \cdot \text{sec}^{-1}$, which is a large shift in the angular velocity rates (Wolbring, 2012).

The results showed that the changes in velocity greatly affected the rates and other motion values, whether for the body or the disc. The disc motion quantities reached their highest values during the disposal and loss of contact with the disc, as the highest values of the disc vertical movement variable reached a value of $27.68 \text{ kg.m.sec}^{-1}$ so that the player reached net motion rates of $33.56 \text{ kg.m.sec}^{-1}$. Controlling the motion quantities in the ideal direction of the disc trajectory led to the efficiency obtained in competition (Frossard et al., 2007; Fuss, 2008). Also, the increase in the rates of movement values of the body from the discus is caused by the significant increase in the mass of the player, due to the

discus. Although the rate of the body's speed is lower than the speed of the discus, there is an increase in the body's rates of movement of mass, which is due to the increase in body mass (Čoh et al., 2008).

In agreement with Harasin et al. (2010), the values of potential energy do not differ much during the performance stages. Given the potential and kinetic energy, the characteristics and nature of the player's throw as a category F33, the throw from the wheelchair, the stability of the mass, the height of the player from the ground, and the acceleration of gravity, the potential energy is greatly affected by the height of the body's center of gravity from the base of the fulcrum (Chen et al., 2021; Frossard, 2012).

The full ability of the player, as a result of falling under the influence of the acceleration of gravity, is largely achieved on the transverse plane of the center of gravity of the throwing player's body by 1884 J . On the other hand, we find that the values of the transverse energy at the center of gravity of the body achieved the highest rates on the transverse plane, with a value of 9.93 J . This demonstrates the need to exert the energy of rotational movement of the player's body, to achieve high speeds during disposal, which in turn results in high achievement distances (Curran and Frossard, 2012; Nadeau et al., 2008).

5. Study limitations

Although the current study has certain strengths, it must also be acknowledged that it suffers from some limitations, each of which needs to be discussed and addressed in future research. First, the measurements were taken during a training session and not during real competition. According to Fernandez-Fernandez et al. (2015), real competitive environments elicited greater psychophysiological responses in athletes throughout the day. Additionally, the relationship between hormone levels, self-reported stress scores, and workload was more clearly correlated during real competitions than during training sessions. Verbal encouragement was continuously given to the athlete during the session and specific instructions were provided by the coaching staff to push the athlete beyond their limits. Second, in such a study, it made more sense to use a larger number of synchronized cameras (6 or 12 cameras) placed at different locations to capture the smaller discus performance variables. However, in the case where the experiment takes place outdoors in the real launch area and not in a hall, it is very difficult to use such a large number of cameras and three synchronized cameras are enough to carry out a 3D analysis (Guebli et al., 2021). Finally, this is a descriptive-analytical study in which the authors aimed to give the reader a clear idea of the discus throwing technique of the Paralympic winner in the F33 category. However, comparing Al-Nakhli's throwing technique to that of other champions in the same or a different category is likely to provide interesting and useful data for coaches and others interested in the field. Therefore, it is of greater interest to complement the present study with other studies that consider the kinetic and kinematic differences of discus throwing between different champions.

6. Conclusions

The biomechanical characteristics of the Paralympic record holder in the F33 category serve as a starting point for building specific exercises for the discus throwing competition and identifying the critical stages and conditions that affect performance and levels of achievement. Several important points represented the player's ability to work to increase the acceleration distance of the discus to up to 1.85 m . At the same time, the player achieved acceleration within the shortest period, specifically, 0.40 s to achieve high speeds of up to 16.77 m s^{-1} through a disposal angle of 37° and a launch height of 1.36 m . The values of the kinetic analysis represent the need to work on increasing the tangential potential energy of the body by 1884 J during disposal, with tangential kinetic energy of the body at a value of 9.93 J . This is achieved by exerting rotational energy movement on the player's body to achieve high achievement distances for the F33 category. This study helps

provide basic information for the interaction between performance, sitting position, and throwing method, according to the classification of the handicapped.

7. Practical implications

Within the confines of our study, the current findings can help coaches and disabled athletes in the F33 category to improve their discus throw performance and achieve numerical excellence. There are several points to consider, including the throwing angle, which should not be less than 35°. To achieve this level, it is best to select tall players with a long torso and long limbs, to achieve the highest landing point height. The second parameter to consider is the cruising speed, which should be increased to more than 16.77 m/s by improving the impact time on the disc to less than 0.40 s. The angular velocity of the wrist joint is also very important (not less than 297°) to guarantee a net momentum of the discus's center of gravity not less than 33.54 kg m s⁻¹ and total potential energy of the body not less than 2286 J.

Declarations

Author contribution statement

Majed M. Alhumaid; Ibrahim I. Atta: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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