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Relationship between Discus Throwing Performance and Kinetic and Kinematic Indicators in the F33 Paralympic Record Holder

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Abstract

The study investigated the kinematic and kinetic-related indicators affecting the distance achieved in the discus throwing competition of the Paralympic Games, and investigate the biomechanical indicators affecting each moment within the performance of discus throwing in the Paralympic Games class F33. The researchers assessed the performance of the world Paralympic champion, Hani Al-Nakhli (height: 1.71 m; weight in kg: 69; age: 35 years old; years of training: 14). The participant's performance was filmed in three dimensions by employing GoPro Hero 6 cameras (x3) which were set to take shots at a rate of 60 frames per second, for 16 throw attempts. The best eight correct attempts to conduct the 3D biomechanical analysis were selected using Skillspector software. Statistical analyses were performed to identify the variables most related to achieving the maximum total throwing distance using Pearson's correlation during the performance for each moment. Specifically, the biomechanical indicators affecting the achievement of the maximum throwing distances for the F33 player were identified using the linear kinematic variables of the tool; namely: (i) the trans-verse acceleration of the disc, (ii) the linear kinematic variable of the player's body represented in the horizontal acceleration of the body's center of gravity, and (iii) the angular kinematic variable represented in the angular velocity of the left thigh. These measurements took into ac-count the other complete biomechanical characteristics to achieve these indicators as required.

Keywords: Paralympic; Disability sport; Para sport; Para athletes; Discus throw; F33; Saudi Arabia

1. Introduction

Discus throwing is an athletic event comprising seven stages of movement: (i) holding the discus, (ii) the stand-by, (iii) preliminary swings, (iv) rotation, (v) assuming the throwing position, (vi) disposal, and (vii) regaining balance after throwing (Chen et al., 2021). In the F33 discus throw class, however, it is noted that because of the way the biomechanics of a para-athlete discus thrower in a fixed chair work, the lack of the rotation phase (as mentioned above) makes it hard for the thrower to speed up the discus because it shortens the distance needed to do so (Chow & Mindock, 1999).

Achieving correct biomechanics in the seated discus throw reduces risk factors and the potential of injury to the para-athlete due to physical loads and movement occurring when seated in the chair, and determines the range of motion in terms of the anatomical and physiological aspects of the para-athlete’s joints and how these movements can be made more effective; therefore, to determine physical forces that impacted the total discus throw distance achieved, kinematic analysis was required (McNamee, 2011; Norman & Moola, 2011). Biomechanical indicators can distinguish the developments in the mastery of skillful athletic performance among athletes and para-athletes of all abilities — from beginners to Olympic champions. The analysis of biomechanical indicators is also useful in enhancing an athlete’s individual development as well as creating special training methods and strategies that may help their performance. The use of biomechanical indicators also aims to solve motor problems and discover necessary and accurate information related to achieving performance enhancement. Finally, biomechanical indicators help with the formulation of physical and technical training content for preparation programs (Lin & Yu, 2021; McNamee, 2011).

In the discus event, the disposal stage represents the most crucial aspect of the athlete's performance; the quality of the launch of the discus in this stage is determined by three factors: (i) release velocity, (ii) release angle, and (iii) discus height at release. Therefore, it is crucial to adjust the player's motion performance in these three indicators of the disposal stage to achieve maximum throwing distance. Several studies show the average values of launch indicators at 24.5 as the average launch speed for world champion discus throwers and 36 degrees as the average launch angle for discus world champions (Banja et al., 2022; Chen et al., 2021; Coh et al., 2008).

In the extant literature on the performance of F33 discus throwers, we found it difficult to identify specific results for the above-mentioned biomechanical values involved in this discipline. This gap in the literature prompted the researchers to conduct the present study to identify the effect of biomechanical variables on the performance of para-athletes in the F33 discus throwing class (Frossard et al., 2010; Harasin et al., 2010; Panoutsakopoulos & Kollias, 2012). Therefore, this study aimed to identify and measure the kinematic and kinetic indicators associated with achieving maximum throwing distance in the F33 discus event and identify the movements affecting each of the above-mentioned seven stages.

2. Materials and Methods

2.1. Procedures

This case study explores the relationship between the F33 Paralympic champion's discuss performance and kinetic and kinematic parameters. In order to accomplish this, eight throws were made during a training session under identical conditions to real competitions, and each attempt was filmed and analyzed. The attempts to throw were preceded by a 30-minute warm-up consisting of 15 minutes of wheelchair mobility, joint motions, stretching of key muscle groups, and preparing using lighweight discs (600 g) and elastic training bands. There were also three throws before the video recording began to help the thrower get used to the official throwing disc. The eight throws were done the same way as in the Paralympics, with the same throwing chair and wind speed. After each throw, the athlete had 3 minutes to rest. Each attempt was filmed with three cameras so that a three-dimensional (3D) movement analysis could be done. This included a performance analysis of the movements, finding and measuring the kinematic and kinetic indicators related to the distance thrown, and separating the biomechanical indicators for each moment during the F33 discus throw.

2.2. Participant

Paralympic and world champion discus thrower Hani Al-Nakhli served as the research's participant; at the time of the study, he was 35 years old, had been training for 14 years, was 1.71 meters tall, weighed 69 kg while seated in a chair designed specifically for his impairment, and had set a record of 34.65 meters at the London Paralympics, where he won silver in a combined F32/33/34 class. Under tournament conditions, the best eight throws out of 16 throws were chosen for analysis; filming took place after the thrower had been briefed on the research and its goals. The study took place as per the Helsinki Agreement (World Medical Association, 2013); the Research Ethics Committee at King Faisal University, Saudi Arabia, granted ethical approval (KFU-REC-2021-OCT-EA0004) and the Saudi Paralympic Athletics Federation. After he was informed of the study's objectives, the study procedure, and the potential consequences of taking part, the participant filled out a signed consent form.

2.3. Technical analysis

The participant was filmed in three dimensions to obtain 3D biomechanical measurements by employing GoPro Hero 6 cameras (x3) which were set to take shots at a rate of 60 frames per second. Camera 1, located facing the back of the subject with its lens facing the direction of the discus throw, was set 1.20 m above the ground at a distance of 5 meters. Camera 2, which was directed at the subject's chest area, captured the initial movements of the throw, was set at 5 meters from the subject and 1.20 meters above the ground. Camera 3, located immediately behind the subject, captured the initial pre-throw movement; it was set at a 45-degree angle to the throwing vector and was located 7 meters from the subject 1.20 meters above the ground. Taking a 3D drawing scale of 1 * 1 * 1 meter in length, placed at the seated position where the subject was photographed. The biomechanical analysis was carried out using the 3D biomechanical analysis program SkillSpector, and the 3D biomechanical variables under study were extracted. Figure 1 (below) provides an overview of the directions for the imaging lenses for the three cameras.

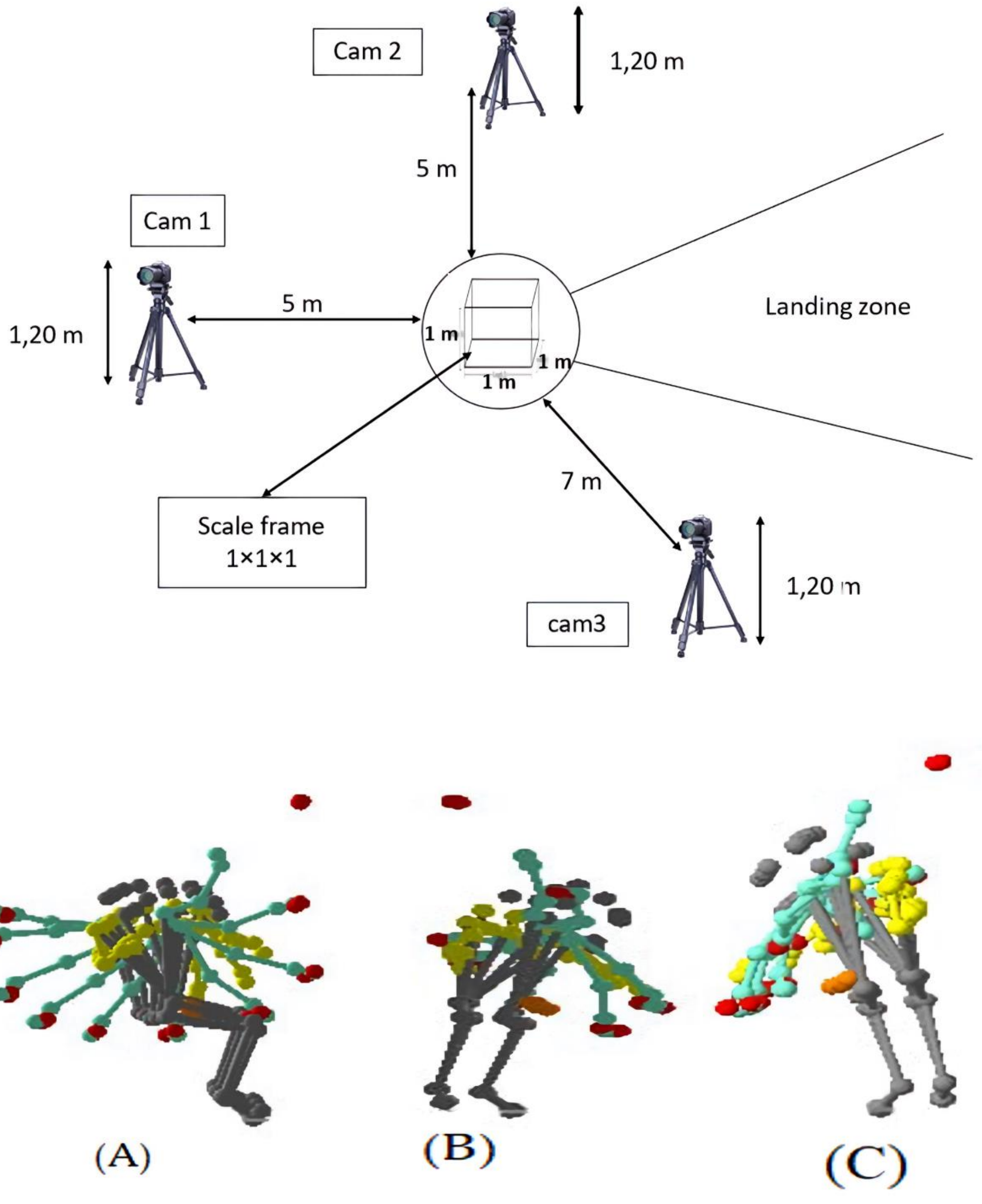

Figure 1. Positioning of cameras and 3D analysis of the player's performance while throwing with three cameras in the F-33 category. Image (A) shows the performance analysis sequence for all body points taken with Camera 1 located immediately behind the player; Image (B) shows the performance analysis sequence for all body points taken with Camera 3 placed to the right and behind the player; Image (C) shows the sequence of performance analysis of all body points with camera 2 directly in front of the athlete's chest and provides a copy of the analysis results. Circles in red, disc; circles in green, throwing arm; circles in yellow, non-throwing arm

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2.4. Statistical analysis

The biomechanical analysis was conducted using SkillSpector (version 1.3.2, Video 4coach), a 3D biomechanical analysis program, and extracting the 3D biomechanical variables, which included time analysis variables, launch indicators, and achieved throwing distances. Arithmetic means, standard deviations, and correlations of the time analysis relating the initial swings, complete throws, and the launch indicator variables (angle, launch height, and launch speed) were calculated using SPSS 26 (IBM, United States). The arithmetic means, standard deviations, and correlations of the linear kinematic variables, angular kinematic variables, and linear kinetic variables during the moments of performance analysis were also calculated.

3. Results

In line with the aim of this study, the results were presented in terms of correlations between the distance achieved and parameters related to time, kinematic indicators, and kinetic indicators, both globally and for the different stages of the throw, such as the end of the preliminary swing, the start of the basic push, the end of contact with the discus, and the loss of contact with the discus. In addition, the means and standard deviations of all variables were presented in tables added in the "Supplements" section (Supp 1, 2, and 3).

Correlation analysis showed that distance achieved was inversely related to preliminary swing time (r = -0.731, *p* 0.05) and throw time (r = -0.727, *p* 0.05), but positively related to discus throw height (r = 0.707, *p* 0.05) and throw speed (r = 0.984, *p* 0.01; Table 1).

Table 1. Correlation between the temporal analysis and release indicators with the achieved throwing distance.

Variables		M	SD	The distance achieved
1	The distance achieved (m)	25.94	0.64	**1**
2	Preliminary swing time (sec)	8.14	2.47	**-0.731***
3	Basic throwing time (sec)	0.39	0.02	0.460
4	Total throw time (sec)	8.52	2.48	**-0.727***
5	Release angle (degrees)	38.13	3.27	0.193
6	Release height (m)	1.24	0.10	**0.707***
7	Release velocity (m/s)	14.29	1.42	**0.984****

Note: Results are presented as mean (M) and standard deviation (SD). * $p<0.05$, ** $p<0.01$ significantly correlated with the distance achieved.

Table 2 shows that the distance achieved was positively correlated with the disc's horizontal velocity and horizontal acceleration at the completion of the initial swing, the disc's vertical, tangential, and total velocities at the end and at the point of release of the discus, and the disc's vertical velocity at the point of release of the disc. The correlation coefficient's relative values were 0.643, 0.816, 0.917, 0.630, 0.874, 0.974, 0.835, and 0.660, respectively. In contrast, the distance achieved was negatively correlated with the body's COG transverse velocity (r = -0.627, $p < 0.05$) and horizontal disc acceleration (r = -0.640, $p < 0.05$) at the end of the preliminary swing; with the vertical disc dis-placement (r = -0. 659, $p < 0.05$) at the point of release of the discus; with the discus' vertical acceleration (r = -0.682, $p < 0.05$) and body COG horizontal acceleration (r = -0.841, $p < 0.01$) at the moment of disc contact loss.

Table 2. The relationship between the distance achieved and the linear kinematic variables during the different stages of the discus throw.

Variables		The distance achieved			
		End of preliminary swing	Start of basic push	End of contact with discus	Loss of contact with discus
1	Discus horizontal displacement (m)	0.594	0.614	0.366	0.299
2	Discus vertical displacement (m)	-0.556	-0.302	**-0.659***	-0.482
3	Discus transverse displacement (m)	-0.279	-0.007	0.331	-0.128

4	Net displacement of the discus (m)	-0.313	-0.089	0.130	0.196
5	Horizontal displacement of the body's COG (m)	-0.074	0.303	0.135	-0.161
6	The vertical displacement of the body's COG (m)	0.000	0.019	-0.222	-0.079
7	Transverse displacement of the body's COG (m)	0.210	-0.240	-0.413	-0.157
8	Net displacement of the body's COG (m)	-0.460	0.105	-0.129	-0.157
9	Discus horizontal speed ($m.sec^1$)	**0.643***	0.610	-0.069	0.168
10	Discus vertical speed (m.sec1)	-0.316	-0.235	**0.917****	**0.974****
11	Discus tangential velocity ($m.sec^1$)	-0.021	0.051	**0.630***	**0.835****
12	Discus net speed ($m.sec^1$)	-0.089	-0.061	**0.874****	**0.984****
13	The horizontal velocity of the body's COG ($m.sec^1$)	0.144	0.502	0.337	-0.383
14	Vertical velocity of the body's COG ($m.sec^1$)	0.376	0.101	0.414	**0.660***
15	The transverse velocity of the body's COG ($m.sec^1$)	0.037	**-0.627***	0.053	-0.051
16	The net velocity of the body's COG ($m.sec^1$)	0.316	0.348	0.242	-0.109
17	Discus horizontal acceleration ($m.sec^2$)	**0.816****	**-0.640***	-0.118	0.071
18	Discus vertical acceleration ($m.sec^2$)	-0.020	0.039	0.397	**-0.682***
19	Discus transverse acceleration ($m.sec^2$)	0.244	-0.006	0.430	0.329
20	Net acceleration of the discus ($m.sec^2$)	0.530	-0.362	0.135	-0.144
21	Horizontal acceleration of the body's COG ($m.sec^2$)	0.034	-0.217	-0.548	**-0.841****
22	Vertical acceleration of the body's COG ($m.sec^2$)	0.005	-0.133	0.614	-0.324
23	Transverse acceleration of the body's COG ($m.sec^2$)	-0.405	0.069	-0.190	0.111
24	Net acceleration of the body's COG ($m.sec^2$)	-0.072	-0.159	-0.204	-0.096

Note: * p<0.05, **p<0.01 significantly correlated with the distance achieved. COG: Center of gravity; The best results are highlighted in bold.

Regarding the angular kinematic variables, Table 3 reveals that the left hip joint angle during the first three phases of the throwing motion (r = 0.632, 0.719, and 0.739, $p < 0.05$ for all); the left shoulder joint angle at the point of loss of contact with the disc (r = 0.899, $p < 0.01$) and at the time of loss of contact with the tool (r = 0.884, p < 0. 01); left elbow joint angle at the end of contact with the discus (r = 0.665, $p < 0.05$); and left-hand wrist joint angular velocities at the start of the basic push (r = 0.631, $p < 0.05$) and at the time of loss of disc contact (r = 0.806, $p < 0.01$) were positively correlated with the level of achievement. The distance achieved also correlated, but negatively, with left ankle joint angular velocities at the point of release of the disc (r = -0.666, $p < 0.05$).

Table 3. The relationship between the distance achieved and the angular kinematic variables during the different stages of the discus throw.

Variables		The distance achieved			
		End of preliminary swing	Start of basic push	End of contact with the discus	Loss of contact with the discus
1	Right ankle joint angle (degrees)	0.280	0.310	0.269	0.212
2	Right knee joint angle(degrees)	-0.194	-0.146	-0.288	-0.269
3	Right hip joint angle (degrees)	0.587	0.419	0.151	0.088
4	Right shoulder joint angle (degrees)	-0.218	-0.009	-0.483	-0.494
5	Right elbow joint angle (degrees)	-0.136	0.117	-0.356	-0.272
6	Right wrist joint angle (degrees)	0.459	0.619	-0.041	-0.251
7	Left ankle joint angle (degrees)	0.092	0.045	0.008	-0.048
8	Left knee joint angle (degrees)	0.084	0.136	0.028	0.057
9	Left hip joint angle (degrees)	**0.632***	**0.719***	**0.739***	0.457
10	Left shoulder joint angle (degrees)	0.593	0.586	**0.899****	**0.884****
11	Left elbow joint angle (degrees)	0.178	0.134	**0.665***	0.071
12	Left wrist joint angle (degrees)	0.100	-0.050	-0.040	0.179
13	Angular velocity of the right ankle joint ($degree.sec^1$)	0.355	0.231	0.399	0.450
14	Angular velocity of the right knee joint ($degree.sec^1$)	0.526	-0.017	0.353	0.175
15	Angular velocity of the right hip joint ($degree.sec^1$)	0.165	0.039	-0.350	-0.483
16	Angular velocity of the right shoulder joint ($degree.sec^1$)	-0.235	-0.619	0.417	-0.209
17	Angular velocity of the right elbow joint ($degree.sec^1$)	-0.435	-0.523	-0.184	-0.597

18	Angular velocity of the right wrist joint (degree.sec[1])	-0.275	-0.534	-0.116	0.324
19	Angular velocity of the left ankle joint (degree.sec[1])	-0.201	-0.381	**-0.666***	-0.534
20	Angular velocity of the left knee joint (degree.sec[1])	0.188	0.362	-0.502	-0.531
21	Angular velocity of the left hip joint (degree.sec[1])	-0.004	0.025	0.208	-0.533
22	Angular velocity of the left shoulder joint (degree.sec[1])	-0.339	0.061	0.317	0.342
23	Angular velocity of the left elbow joint (degree.sec[1])	-0.163	0.215	0.045	-0.060
24	Angular velocity of the left wrist joint (degree.sec[1])	0.479	**0.631***	0.094	**0.806****

Note: * p<0.05, **p<0.01 significantly correlated with the distance achieved. The best results are highlighted in bold.

Table 4 illustrates, the distance achieved by the Paralympic champion is positively correlated with seven linear kinetic variables. These variables were (1) the vertical momentum of the body COG at the point of release of the discus (r = 0.657, $p < 0.05$); (2) the horizontal momentum of the discus COG at the end of the preliminary swing (r = 0.644, $p < 0.05$); (3) the net vertical momentum of the discus COG at the point of release of the discus (r = 0.657, $p < 0.05$). 05); (3) the net vertical momentum of the disc COG at the end of disc contact (r = 0.917, $p <$ 0.01) and at the loss of disc contact (r = 0.973, $p < 0.01$); (4) the transverse momentum of the disc COG at the end of tool contact (r = 0. 631, $p < 0.05$) and at the moment of loss of tool contact (r = 0.835, $p < 0.01$); (5) the net momentum of the disc COG at the moment of the end of tool contact (r = 0.873, $p < 0.01$) and at the moment of loss of tool contact (r = 0.984, $p <$ 0. 01); (6) body COG transverse potential energy (r = 0.650, $p < 0.05$) at the end of the preliminary swing; and (7) body COG vertical kinetic energy (r = 0.637, $p < 0.05$) at the moment of tool contact loss. In addition, there is an inverse correlation at the 0.05 level between the body's COG vertical potential energy variable at the end of tool contact and the transverse momentum of the body's COG at the point of the initial acceleration, with r values of -0.637 and -0.627, respectively, plotted as a function of the level of achievement.

Table 4. The relationship between the distance achieved and the linear kinetic variables during the different stages of the discus throw.

	Variables	**The distance achieved**			
		End of preliminary swing	Start of basic push	End of contact with the discus	Loss of contact with the discus
1	Horizontal momentum of the body’s COG (kg.m.sec[1])	0.137	0.501	0.348	-0.376
2	Vertical momentum of the body's COG (kg.m.sec[1])	0.362	0.102	0.403	**0.657***
3	Tangential momentum of the body's COG (kg.m.sec[1])	0.028	-0.610	0.055	-0.034
4	Net momentum of the body's COG (kg.m.sec[1])	0.299	0.347	0.250	-0.100
5	Horizontal momentum of the discus' COG (kg.m.sec[1])	**0.644***	0.611	-0.066	0.170
6	Net of vertical momentum of the discus' COG (kg.m.sec[1])	-0.314	-0.236	**0.917****	**0.973****
7	Transverse momentum of the discus' COG (kg.m.sec[1])	-0.022	0.053	**0.631***	**0.835****
8	Net momentum of the discus' COG (kg.m.sec[1])	-0.086	-0.059	**0.873****	**0.984****
9	Horizontal potential energy of the body's COG (Jules)	-0.061	0.027	0.061	0.066
10	Vertical potential energy of the body's COG (Jules)	-0.515	-0.494	**-0.637***	-0.605
11	Transverse potential energy of the body's COG (Jules)	**0.650***	0.599	0.616	0.569
12	The net potential energy of the body's COG (Jules)	0.071	0.061	-0.094	0.011
13	Horizontal kinetic energy of the body's COG (Jules)	0.161	0.399	0.337	-0.398
14	Vertical kinetic energy of the body's COG (Jules)	0.394	0.010	0.206	**0.637***
15	Transverse kinetic energy of the body's COG (Jules)	-0.110	**-0.627***	0.207	0.001
16	The net kinetic energy of the body's COG (Jules)	0.208	0.272	0.324	-0.323

Note: * p<0.05, **p<0.01 significantly correlated with the distance achieved. COG: Center of gravity. The best results are highlighted in bold.

4. Discussion

4.1. Kinematic indicators

Our data revealed a correlation between the accomplished distance and the duration of the throw, particularly the preliminary swing, as well as the launch height and velocity. Several studies have demonstrated the significance of the discus launch height index, which is second only to the tool launch velocity (Curran & Frossard, 2012; Frossard et al., 2010), with average values of 1.28 meters and 14.29 meters per second, respectively. In addition, when performing the discus throw, other key aspects include the subject's performance, completing the technical procedures in a short amount of time, and avoiding exaggerated preparatory swings that cause loss of concentration and prolong the throw's execution time (Curran & Frossard, 2012; Frossard et al., 2010).

Thus, to improve throwing performance, it is necessary to work on increasing the horizontal speed rates of the discus at the point of the competition of the initial swings, which will increase the horizontal acceleration rates of the discus during the same moment; this is evident in the direct relationship with the achievement distance (Abdelkader et al., 2021), which is consistent with several studies on the need to implement the preliminary swings in the horizontal track correctly and the acquisition of a large acceleration distance allow the generation of rates of speed up to the throwing and launching of the discus from the throwing hand (Frossard, 2012), where the value of the horizontal speed of the discus at the end of the preliminary swings was 0.43 m / s, as shown in Supp 1.

We also note that there was a direct correlation between the achievement distance of the vertical speed variable at the point when contact ended and the moment of losing contact with the discus; this helps to increase the speed rates obtained during the launch of the discus, the importance of which has been shown by many researchers (Tweedy & Vanlandewijck, 2011), who confirm that the indicators of the launch of the discus characterize the development in the performance of discus throwing, namely, the launch speed, the launch angle, and the launch height. This is shown by the results in terms of the need to increase the vertical, transverse, and net speed rates that are obtained during the point at which contact with the discus ended and the point at which contact was lost with the discus, as their values were 1.16 m/s, 12.06 m/s, and 7.51 m/s), respectively, during the launching moment (see Supp1) (Frossard et al., 2013).

Another crucial factor related to performing the movements required by the discus throw in the F33 class is that when sitting on the chair, the subject attempts to achieve vertical velocity with the body’s center of gravity while losing contact with the discus. This is important because a positive relationship was evident between the above and the total throwing distance; perhaps the performance of downward swings may help the subject to compensate for the stability provided by the chair; this hypothesis is in line with several studies (Banja, 2007; O’Riordan et al., 2004) on the need to increase the body’s vertical COG velocity rates at the point at which contact with the discus ends, which represents a speed of 0.22 m/s (see Supp 1).

At the point at which the basic push begins, the subject must reduce the horizontal and transverse guidance of the discus, as the subject needs to increase the rate of vertical guidance in a downward direction in preparation for the performance of the subsequent deepening of the discus and then the height of the discus to achieve an ideal performance of the launching indicators of the discus (Frossard et al., 2005; Linthome, 2001).

Our findings indicated also that the subject, during the performance of the throw, should try to rotate the body during swings and throwing by increasing the rates of the angle of the left hip joint during the stages of performance, which allows the possibility to increase the acceleration distance and generate maximum rates of speed and acceleration for the discus, which distinguishes high-level throwers from their low-level counterparts, where the angle of the left hip joint during the moment of the end of contact with the discus achieves an angle of 91 degrees (Leigh & Yu, 2007; Norman & Moola, 2011).

The most important aspect of the performance is the attempt to increase the rates of the angle of the shoulder joint of the throwing arm during the end of the performance and the loss of contact with the discus, which ensures the achievement of ideal acceleration rates for the discus in addition to the rates of force transmitted to the discus during throwing in the appropriate spatial paths for movement; here, the angle of the left shoulder joint was 88 degrees during the loss of contact with the discus (Supp 2) (Chow et al., 2000; Frossard, 2012).

Since the throwing arm includes three links (the humerus, the forearm, and the palm of the hand), it is necessary, to maintain the full extension of the arm, to try to increase the angle of the elbow joint of the throwing arm to ensure good kinetic transfer of force without any loss of strength during the movement from the humerus to the forearm. This was one of the most important aspects highlighted by the results of the present study, which also contributes to the process of increasing the launch height through the full extension of the joints of the throwing arm, as the value of the elbow joint angle during the end of contact with the discus was 142 degrees and this had a direct significant correlation with the achievement of maximum throwing distance (Alhumaid & Atta, 2022; Haake, 2009; Tweedy et al., 2012).

Further, another important aspect of the performance of discus throwing in the F33 class is to fully stabilize the two legs, as it becomes clear that there is an inverse relationship between the variable angular velocity of the left ankle with the achievement of maximum throwing distance. Therefore, the subject should stabilize the ankle joints of both legs as much as possible if they wish to achieve maximum throwing distance. This finding is consistent with several studies related to the technical performance of the discus throw (Kuiken, 2012), which emphasize good contact with the ground to obtain high levels of strength that can be transferred to the discus in later stages, and emphasize correct control of the movements and good fixation to the chair (Burkett et al., 2011).

When performing the discus throw, the force produced from the beginning stages means that the player must try to control the transfer of these forces to the throwing hand as this is the final link of the thrower's body to the discus. During this final connection, the subject must try to increase the rates of the angular velocity of the hand-wrist joint during the end of contact and during the loss of contact, which was 105 degrees/sec during the disposal stage (Supp 2) in order to produce the ideal acceleration of the discus and achieve a large throwing distance. This factor is emphasized in the current study as it is consistent with increasing the speed rates during the discus launch (Laferrier et al., 2012; McGinnis, 2005).

4.2. Kinetic indications

Findings indicated that the amounts of vertical movement during the loss of contact with the discus are important and that the player should try to increase the amounts of vertical movement as much as possible. This is achieved by increasing the rates of vertical speed with large mass rates to enable the subject to achieve larger amounts of movement, which shows that the mass of the subject is a crucial factor in achieving a large throwing distance (Frossard et al., 2008; Keogh, 2011).

According to the kinematic characteristics of the seated discus throw and their importance in achieving large throw distances, we note that the corresponding kinetic variables play the largest role. The vertical, transverse, and net movement quantities have the greatest effect. Likewise, the horizontal, vertical, transverse, and net velocities showed the same strong correlation with the achievement distance. This indicates that the mass of the thrower is of the utmost importance, as the greater the mass of the thrower, the greater its ability to influence the launch of the discus. Also, increasing the rates of the vertical, horizontal, transverse, and net momentum of the discus is crucial in increasing the throwing distances achieved in this study of an F33 discus thrower; their values were 2.32, 24.12, 15.02, and 28.59 kg m/s, respectively (see Supp 3) (Franciosi et al., 2010; Sands, 2008; Morriën et al., 2017).

Given the kinetic and potential energy generated during the discus throw, it is necessary to work on increasing the rates of the vertical kinetic energy of the body's COG at the point at which contact with the discus is lost, along with reducing the rates of the vertical potential energy of the body's COG at the point when contact with the discus is lost. The above highlights the importance of increasing the rates of the vertical velocity of the body's COG when completing the final push and disposal to achieve an effective throwing movement (Banja et al., 2022; Błaszczyszyn et al., 2019; Leigh et al., 2008).

5. Study Limitations

Despite the strengths of the current study, it is also subject to two main limitations that must be acknowledged and potentially addressed by future researchers. First, the study was conducted under training conditions, not under competition conditions. This is relevant because, as Fernadez-Fernandez et al. (2015) pointed out, performing under competitive conditions elicits greater psychophysiological responses from athletes which may improve their performance. Also, there are clearer correlations between athletes' self-reported stress scores, hormone levels, and workload under competitive conditions compared to under training conditions. That said, in the present study, the subject was given specific throwing instructions and continuous verbal encouragement by the coach to help them achieve maximum throwing distances. Second, the present study only used three cameras to capture a 3D view of the subject's throwing performance. This may have caused more minor aspects of the throwing performance to be overlooked. The researchers recommend, therefore, that future studies use more (6–12) synchronized cameras located at different points around the thrower to capture the more subtle aspects of the discus throw performance. That said, for experiments that are carried out in an outdoor throwing area (i.e., not indoors), using such a large number of synchronized cameras is challenging; other researchers maintain that using three synchronized cameras is adequate to perform an accurate 3D analysis of the throwing performance (Guebli et al., 2021).

6. Conclusions

In order to achieve maximum effectiveness in discus throwing in the F33 class, it is necessary to take into account the values of the biomechanical characteristics and indicators of the critical moments within the performance. The success of each consecutive stage is linked to the success of the previous stage. The analysis of the seated discus throw also aims to address motor problems, discover the necessary and accurate information related to the performance of the throw, and formulate the physical and technical training content of education and training programs for youth and adult discus throwers. Bio-mechanical indicators have the greatest impact on achieving maximum throwing distance and reaching high levels of performance, considering the homogeneity in exerting force in the appropriate spatial paths. This allows the discus to be disposed at the ideal angle and the appropriate height while working to increase the acceleration rates of the discus as much as possible, starting from the basic push to the disposal of the discus.

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