Journal of Physical Education and Sport ® (JPES), Vol. 25 (issue 4), Art 82, pp. 764 - 772, April 2025
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Biomechanical determinants of elite high jump performance in Egypt: Part 2, the percentage contributions of biomechanical indicators and special factors to achievement level

IBRAHIM I. ATTA*[1], ABDULMALEK K. BURSAIS[2], MOHAMMED S ALIBRAHIM[3], MAJED M. ALHUMAID[4], AHMED K . HASSAN[5], MOHAMED FRIKHA[6], ANWAR AL-NUAIM[7]
[1234567]Department of Physical Education, College of Education , King Faisal University , Al-Ahsa 31982, SAUDI ARABIA

Published online: April 30, 2025
Accepted for publication: April 15, 2025
DOI:10.7752/jpes.2025.04082

Abstract
This study on high jump biomechanics was performed during the 2020 Republic Championships of Egypt, That aimed to determine the percentage contributions of biomarkers and special factors to the level of achievement. The sample consisted of 16 competitors (average weight : 87 kg, height : 1.98 m, age : 30 years). To capture three-dimensional data, Six GoProHero 6 digital cameras were used, operating at 120 frames per second. The biomechanical analysis program Skillspector was used to analyze 48 attempts, with three attempts for each athlete. A multiple regression analysis was conducted to determine the contributions of the most important biomechanical indicators as well as several special factors to performance level , Which is considered to be the key to the success of high jump education and training as it provides a clear vision for coaches to develop their training programmes. In addition to the initial push and its impact on the performance level, the study identified six indicators as special factors: the vertical kinetic energy of the body's center of gravity at the beginning of the flight, the right wrist's net velocity at maximum knee flexion, the horizontal potential energy of the body's center of gravity at the beginning of take-off, the braking time to take-off, the net velocity of the body's center of gravity at the maximum flight altitude, and the angle of the hip joint of the take-off leg at the end of the take-off. The contribution rates of these biomechanical indicators to performance were 71%, 13%, 9%, 4%, 3%, and 1%, respectively.
Keywords: Biomechanical indicators, Special factors, Contributing percentage, High jump, Three-dimensional

Introduction

Biomechanics is concerned with the study of motor behavior in light of general physical laws and principles. Applied to sports, biomechanics refers to the study of motor pathways related to sports skills and the development of technical and sporting performance. Biomechanics can thus help to find solutions to develop skill levels following the most recent theories concerning sports training (Dobbs et el., 2015; Ae et el., 2008]). Biomechanical performance indicators are a measure of the mechanical conditions of the relevant variables where the human body is characterized in terms of mechanical movement. Kinetic and kinematic indicators are called special factors because their improvement is correlated with the athletes' skill and performance level, in competitors from elite levels to beginners (Pleša et el., 2022; Mariano et el.,2021). There are two categories of special indicators: kinematic indicators, which address the geometric description of human movements, enable comparison of the body's measurements, dimensions, and connections, as well as calculation of these characteristics of individual performances to choose the optimal characteristics of their movements. Kinetic indicators are responsible for detecting movement mechanisms, the reasons for their occurrence, and the changes occurring during movement.

These also include strength and energy indicators (Kim et el., 2011; Dapena,1992). A high jump competition consists of multiple phases: an approach phase, where the competitors build up their speed before jumping; a take-off phase, where the competitors use their leg strength to push themselves upwards, and a flying phase, where the competitors extend their bodies and bend their backs to cross the crossbar. Finally, in the landing phase, the athletes aim to land safely on the mat without dislodging the bar (Nicholson et el., 2019 ; Johnston et el., 2015). The approach phase consists of a curve with 10–12 steps. The initial part of the approach curve is a straight line, and the second part is a curve with 4-5 steps (Kim et el., 2015; Bermejo et el., 2011). The take-off phase is the most crucial phase of the high jump, as it determines the jump's success; in this phase, horizontal kinetic energy is converted into vertical energy, and horizontal speed is converted into vertical speed.

Corresponding Author: IBRAHIM I. ATTA, E-mail: iatta@kfu.edu.sa

The result is determined by the period between the moment the take-off foot begins to touch the ground until it loses contact. The take-off time ranges from 0.14 to 0.18 seconds (Panoutsakopoulos , Kollias, 2012; Becker, 2015). Several key mechanical indicators govern a successful take-off. These include the angle of the trunk, the angle of inclination both forward and backward, the angle of the take-off leg's knee, the angle of the free leg's thigh, and the additional push that comes from the movement of the arms. During take-off, the force of the vertical push of the body's COG is the most significant factor in achieving the maximum height (Sado et el., 2018; Schiffer, 2012). In the flight phase, the competitor can still modify his body position and posture to enhance his performance by controlling the direction and movement of the limbs. This ability affects adjustments while crossing the bar, where proper control will maximize height and minimize potential errors (Sattler et el.,2015; Van Caekenberghe et el.,2021). Thus, biomechanical indicators are special factors through which the measurements and dimensions of the body, its connections, and the kinematic properties of different athletes can be compared. They are also the most important indicators through which the development and improvement of skill level and performance can be studied (Adashevskiy et el.,2013; Ae et el., 2008).

Given the technical difficulty of the high jump, it is considered one of the most complex track and field events and is difficult to teach and train. The lack of previous studies on Egyptian high jumpers and the weakness of the Egyptian level prompted the present study, where the aim is to determine biomechanical performance indicators and special factors relevant to high jump performance. Such knowledge is considered the key to the success of teaching and training for the high jump, as it can identify deficiencies and weaknesses in performance and avoid them during the training process. This will allow coaches to develop their educational and training programs to reach the highest possible level in competition (Goldmann et el., 2015; Sado et el., 2022). The study aims to identify the contribution rates of biomechanical performance indicators and the special factors affecting the performance and the achievement level in the high jump for Egyptian elite athletes.

Methods

Procedures

The data were collected by filming the competitors' performances using six digital cameras. A three-dimensional performance analysis was conducted to identify and measure biomechanical indicators and influential factors during several stages of the high jump.

Participants

Egyptian elite athletes (average weight 87 kg, height 1.98 meters, chronological age 30 years) participated in this study. Measurements were collected during the 2020 Republic Championships. Three best attempts were recorded from each athlete (48 attempts in total). 6 GoProHero6 digital cameras were used, and their frequency was set at 120 frames/second. The athletes' anthropometric and basic measurements were taken after they had received an explanation of the goals and objectives of the research and before participation. Written consent was obtained from all athletes, as well as permission from the Egyptian Athletics Federation to conduct the study during the tournament. The study followed the Helsinki Convention (World Medical Association, 2013), and approval was attained from the King Faisal University Ethics Committee (KFU -REC-2025 -JAN - ETHICS2815).

Measurements

Sixteen athletes were filmed through 48 attempts using 3D imaging. 6 GoProHero6 cameras were set at a height of 120 cm, and the frequency of the cameras was 120 frames/second. Synchronization between cameras was performed by taking a three-dimensional scale drawing of an area with dimensions 1 × 1 × 1 m where the athletes were photographed. Using the kinetic analysis program Skillspector, a three-dimensional biomechanical analysis was conducted to determine and quantify biomechanical variables and indicators during performance. The arithmetic mean, standard deviation, multiple linear regression coefficients, contribution rates of variables, indicators, and biomechanical special factors influencing the completion distance and performance effectiveness in the high jump were among the variables recorded.

Statistical analysis

The standard deviation and mean were measured for the general biomechanical variables, moment variables (moments of the start of the take-off, the take-off leg maximum knee flexion, end of take-off, start of flight, and the body's maximum height during flight), and temporal analysis variables. the Multiple regression was conducted using the STEPWISE method to determine the relationships between the variables and the achievement level in the high jump and the independent variables significantly related to the achievement of height.

The variables identified could then be used to build a predictive model for the relationship between height achieved and biomechanics. Statistical analyses were conducted using SPSS statistical package (version 26; SPSS Inc., Chicago, IL, USA). Results are showed as standard deviation (SD), mean ±.

Results

Statistical description of the biomechanical variables of the research sample are showed in Table (1). Statistical description of biomechanical variables during different performance phases of the research sample are presented in Table (2).

Multiple regression analyses of the biomechanical indices, ratios, and specific factors contributing to improved performance in the high jump are listed in Table (3).

Table (1) Statistical description of the biomechanical variables of the research sample (n=48).

	biomechanical variables	**mean**	**SD**
1	Achievement -m.	1.95	0.07
2	COG's speed - end of take-off-m/s.	3.13	0.58
3	COG's angle of flight - degree	58	3.21
4	COG's Height -end of take-off-m.	1.46	0.09
5	Horizontal braking -m.	0.12	0.08
6	Vertical braking -m.	0.08	0.08
7	net braking-m.	0.17	0.11
8	Horizontal push -m.	0.27	0.08
9	Vertical push -m.	0.34	0.10
10	Net push -m.	0.43	0.13
11	fourth to the last step distance -m.	1.36	0.13
12	third to the last step distance -m.	1.33	0.11
13	second to the last step distance -m.	1.49	0.13
14	last step distance -m.	1.57	0.35
15	fourth-to-last step average speed -m/s.	5.06	0.55
16	third to last step average speed -m/s.	5.52	0.68
17	second to last step Average speed -m/s.	5.38	0.44
18	last step Average speed -m/s.	7.55	2.08
19	take-off time of fourth to last step -S.	0.18	0.02
20	fourth to last step Flight time-S.	0.11	0.02
21	fourth to last step time -S.	0.28	0.03
22	fourth to last step rhythmic coefficient	1.68	0.29
23	third to last step take-off time -S.	0.17	0.04
24	third to last step Flight time-S.	0.09	0.02
25	third to last step time -S.	0.25	0.05
26	third to last step rhythmic coefficient	1.95	0.37
27	second to last step take-off time -S.	0.16	0.03
28	second to last step Flight time -S.	0.13	0.03
29	second to last step time -S.	0.29	0.03
30	second to last step rhythmic coefficient .	1.31	0.32
31	last step take-off time-S.	0.17	0.04
32	last step Flight time -S.	0.06	0.02
33	last step Time -S.	0.22	0.04
34	last step rhythmic coefficient .	3.56	0.68
35	Braking -S.	0.09	0.03
36	push -S.	0.11	0.03
37	take off -S.	0.19	0.03
38	take-off Rhythmic coefficient	0.78	0.35

Note: SD: standard deviation; COG: Center of gravity

Table (2) Statistical description of biomechanical variables during the different performance phases of the research sample (n=48).

biomechanical variables			**Start of take-off**		**Ascending leg maximum flexion**		**Take-off end**		**Start of flying**		**Flight maximum altitude**	
			mean	**SD**	**mean**	**SD**	**mean**	**SD**	**mean**	**SD**	**mean**	**SD**
1	thrust of kinematics Links	free leg Horizontal speed-m/s.	3.62	0.87	1.78	0.97	1.13	0.64	0.88	0.53	2.36	0.91
2		free leg Vertical speed-m/s.	0.91	0.57	3.46	2.01	4.09	0.94	3.28	0.78	2.76	1.07
3		free leg net velocity-m/s.	3.77	0.86	4.26	1.34	4.31	0.77	3.49	0.59	3.71	1.15
4		right arm Horizontal speed-m/s.	2.89	1.41	3.52	2.25	5.59	1.25	6.15	1.55	1.78	1.48
5		right arm Vertical speed-m/s.	1.84	1.06	3.39	1.87	3.73	1.58	2.83	1.48	2.14	1.69
6		right arm net velocity-m/s.	3.56	1.44	5.39	1.68	6.84	1.52	6.85	1.81	3.03	1.86
7		left arm Horizontal speed-m/s.	2.83	0.88	3.42	1.08	4.18	0.94	3.48	1.16	3.03	1.56
8		left arm Vertical speed-m/s.	1.59	0.78	4.75	3.37	6.21	2.38	4.83	2.85	1.55	1.25
9		left arm net velocity-m/s.	3.32	0.99	6.12	2.98	7.58	2.24	6.19	2.48	3.72	1.22

10	thrust angle kinematics	free leg Ankle joint angle-deg.	108	18	141	38	123	57	94	53	131	16
11		free leg Knee joint angle-deg.	78	28	113	64	104	37	86	31	91	19
12		free leg Hip angle-deg.	175	5	167	9	139	25	138	18	158	14
13		joint angle of right shoulder -deg.	73	58	76	67	122	28	133	17	61	43
14		joint angle of right elbow-deg.	105	53	82	56	109	61	131	42	163	16
15		right wrist joint angle-deg.	162	16	162	8	148	8	157	12	167	8
16		joint angle of Left shoulder-deg.	8	6	17	13	101	44	137	32	14	15
17		joint angle of Left elbow-deg.	142	15	97	65	59	43	83	47	164	12
18		left wrist joint angle-deg.	159	13	157	22	163	9	167	9	167	8
19		free leg hip joint Angular velocity-Deg/s.	135	109	189	103	448	258	263	213	258	153
20	basic thrust kinematics	take-off leg Horizontal speed -m/s.	2.38	0.57	1.21	0.49	1.45	0.38	1.47	0.25	3.16	1.38
21		take-off Vertical speed-m/s.	0.48	0.28	0.66	0.52	2.39	0.49	2.98	0.68	2.81	0.43
22		take-off leg net velocity-m/s.	2.46	0.52	1.49	0.39	2.83	0.32	3.39	0.46	4.32	1.08
23		takeoff leg angle of ankle joint -deg.	168	8	168	8	171	6	166	11	153.09	12.41
24		take-off leg angle of Knee joint -deg.	173	5	166	8	179	3	177	3	93.09	12.42
25		take-off leg angle of Hip joint -deg.	167	4	164	6	169	5	166	6	154.26	17.16
26		take-off leg Angular velocity of knee joint - Deg/s.	107	54	48	32	36	35	82	72	186	108
27	COG's kinematics	COG's height -m.	1.11	0.05	1.18	0.08	1.46	0.09	1.58	0.08	2.26	0.15
28		COG's horizontal velocity -m/s.	2.58	0.48	2.26	0.29	2.04	0.19	2.05	0.23	2.91	0.46
29		COG's vertical velocity-m/s.	0.35	0.32	1.69	0.85	3.28	0.63	3.12	0.58	0.38	0.68
30		COG's net velocity -m/s.	2.64	0.42	2.88	0.56	3.88	0.53	3.74	0.48	2.99	0.54
31		COG's Horizontal acceleration -m/s2.	7.88	5.98	13.29	13	4.64	3.15	3,91	2,67	6.64	7
32		COG's Vertical acceleration -m/s2.	16.14	11.78	22.04	14.6	5.34	5.73	5,59	5.04	8.48	4.57
33		COG's net acceleration -m/s2.	20.2	9.22	30.76	9.46	7.51	5.48	7.75	4.3	11.98	5.23
34	COG's kinetics	COG's horizontal momentum -kg.m/s.	221	28	191	18	168	17	171	19	238	41
35		COG's vertical momentum-kg.m/s.	21	16	137	68	289	27	273	34	22	25
36		COG's net momentum -kg.m/s.	222	28	242	36	336	29	322	33	242	41
37		COG's horizontal force .	408	276	528	412	251	246	196	119	582	449
38		COG's vertical force.	1599	796	2413	816	536	455	596	359	675	436
39		COG's net force .	1683	766	2514	771	627	468	646	341	993	426
40		COG's horizontal potential energy.	1277	248	1398	257	1564	247	1619	247	2418	228
41		COG's vertical potential energy.	918	58	958	59	1188	98	1282	103	1844	158
42		COG's net potential energy.	1578	196	1702	208	1972	204	2072	201	3045	239
43		COG's Horizontal kinetic energy.	295	79	218	41	173	32	174	38	348	114
44		COG's vertical kinetic energy	3.68	4.24	138	132	502	75	448	89	6.93	14
45		COG's net kinetic energy	299	79	359	119	674	96	623	104	355	112

Note: SD: standard deviation; COG: Center of gravity

Table (3) Multiple regression analysis of biomechanical indicators and special factors contributing to improving the level of performance in the high jump (n=48).

	Biomechanical Indicators	**Coefficients**	**R square**	**R square change**
		B		
1	(Constant)	1.67	70 %	
	COG's vertical kinetic energy at the beginning of flight	0.001		70%

2	(Constant)	1.75	83%	
	COG's vertical kinetic energy at the beginning of flight	0.001		70%
	net velocity of the right wrist at maximum knee flexion.	-0.021		13%
3	(Constant)	2.03	92%	
	COG's vertical kinetic energy at the beginning of flight	0.001		70%
	net velocity of the right wrist at maximum knee flexion.	-0.023		13%
	COG's horizontal potential energy at the beginning of take-off.	0.0003		9%
4	(Constant)	2.68	96%	
	COG's vertical kinetic energy at the beginning of flight	0.001		70%
	net velocity of the right wrist at maximum knee flexion.	-0.022		13%
	COG's horizontal potential energy at the beginning of take-off.	0.0005		9%
	Braking time to take-off	0.746		4%
5	(Constant)	2.09	99%	
	COG's vertical kinetic energy at the beginning of flight	0.001		70%
	net velocity of the right wrist at maximum knee flexion.	-0.020		13%
	COG's horizontal potential energy at the beginning of take-off.	0.0006		9%
	Braking time to take-off	0.788		4%
	COG's net velocity at maximum flight altitude.	0.001		3%
6	(Constant)	2.05	100%	
	COG's vertical kinetic energy at the beginning of flight	0.001		70%
	net velocity of the right wrist at maximum knee flexion.	-0.020		13%
	COG's horizontal potential energy at the beginning of take-off.	0.0004		9%
	Braking time to take-off	0.821		4%
	COG's net velocity at maximum flight altitude.	0.001		3%
	The take-off leg hip joint angle at the end of the take-off.	0.0001		1%

Dependent Variable: The level of performance in the high jump

Table (3) presents a multiple regression analysis of the biomechanical characteristics and their contributions to improve the level of performance in the high jump.

The six variables are listed in the following order: COG's vertical kinetic energy at the beginning of the flight, the net velocity of the right wrist during maximum knee flexion, COG's horizontal potential energy at the beginning of take-off, the braking time to take-off, COG's net velocity during the maximum flight altitude, and the take-off leg hip joint angle at the end of the take-off. The respective contribution percentages were 70%, 13%, 9%, 4%, 3%, and 1%. Collectively, these variables achieved a full predictive capability (R2=100%), underscoring their combined significance in biomechanical modeling and their potential utility in enhancing high jump performance through targeted training interventions.

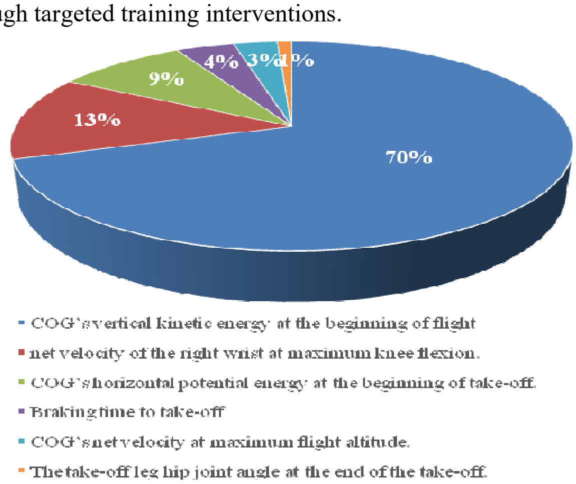

Figure (1) The percentage contributions of biomechanical indicators to the high jump performance

The first indicator:

With a contribution of 70%, the vertical kinetic energy indicator of the body's COG at take-off was the most important biomechanical indicator. as the predictive equation of regression is:

Y = a + b1 x1 = (1.67) + (0.001) (173)

The second indicator:

With a contribution of 13%, the right wrist's net velocity indicator at maximal knee flexion was the second most significant biomechanical indicator of the performance. The predictive equation of regression is:

Y= a+b1 x1 + b2 x2 = (1.75) + (0.001) (173) + (-0.021) (5.38)

The third indicator:

With a contribution rate of 9%, the horizontal potential energy indicator of the body's COG at the beginning of the take-off was the third biomechanical indicator that contributed most to improving the performance level of the skill among the research sample, as the predictive equation of regression is:

Y= a+b1 x1 + b2 x2 + b3 x3 = (2.03) + (0.001) 173) + (-0.023) 5.38) + (0.0003) (1276)

The fourth indicator:

With a 4% contribution, the take-off braking time indicator was the fourth most significant biomechanical indicator that contributed to improving the performance level, as the predictive equation of regression is:

Y= a+b1 x1 + b2 x2 + b3 x3 + b4 x4

= (2.68) + (0.01) (173) + (-0.022) (5.23) + (0.005) (1276) + (0.746) (0.074)

The fifth indicator:

With a contribution of 3%, the net velocity indicator of the body's COG during the maximum flight altitude ranks as the sixth most significant biomechanical indicator that contributed to improving performance level; the predictive equation of regression is:

Y= a+b1 x1 + b2 x2 + b3 x3 + b4 x4 + b5 x5

= (2.09) + (0.001) 173)) + (-0.020) 5.83) + (0.0006) (1276) + (0.788) (0.074) + (0.001) (3)

The Sixth indicator:

With a 1% contribution, The take-off leg hip joint angle indicator at the end of the take-off period ranks as the sixth most significant biomechanical indicator that contributed to improving performance. The predictive equation of regression is as follows:

Y= a+b1 x1 + b2 x2 + b3 x3 + b4 x4 + b5 x5+ b6 x6

= (2.05) + (0.001) 173)) + (-0.020) 5.38) + (0.0004) (1276) + (0.821) (0.074) + (0.001) (3) + (0.0001) (168)

where a = a constant; b1 = the regression coefficient for COG's vertical kinetic energy indicator at the beginning of flight; x1 = the value of COG's vertical kinetic energy indicator at the beginning of flight; b2 = The regression coefficient for the net velocity indicator of the right wrist at maximum knee flexion; x2 = the value of the net velocity indicator of the right wrist at maximum knee flexion; b3 = the regression coefficient value for COG's horizontal potential energy indicator at the beginning of take-off; x3 = the value of COG's horizontal potential energy indicator at the beginning of take-off; b4 = The regression coefficient for the braking time indicator to take off; x4 = the value of the braking time indicator of the take-off; b5 = the regression coefficient for COG's net velocity indicator at the maximum flight altitude; x5 = the value of COG's net velocity indicator at the maximum flight altitude; b6 = The regression coefficient for The take-off leg hip joint angle indicator at the end of the take-off, and x6 = value of The take-off leg hip joint angle indicator at the end of the take-off.

Discussion

Based on the findings of both the current and the previous study, high jumper launch indicators are among the most significant factors influencing performance. As such, trainers should focus on these indicators during the initial stages of training and education. Consequently, it is important to be able to increase the angle of flight of the jumper's COG at the beginning of the flight. The goal of the high jump is to reach the greatest height, and this depends crucially on converting horizontal speed to vertical speed through the best flight angle while maintaining speed (Leite, 2013; Nicholson et el., 2022).

The take-off stage is a critical phase between approach and flight, i.e., between contact with the ground and loss of contact, where horizontal speed is converted to vertical speed, and horizontal kinetic energy to vertical kinetic energy. This phase passes through a braking stage that works to impede movement. Therefore, the jumper needs strength, and training to control all these factors to reach the best height. In addition to the additional push, force, and speed, the movements of the free leg and the arms during the performance must be optimized (Leite, 2013
; Rao et el., 2014).

The multiple regression equations and contribution percentages clearly show that the kinetic energy variables related to the body's COG at the beginning of the flight, the potential energy of the body's COG at the beginning of the take-off, and the net velocity of the body's COG at the maximum flight altitude represent the most important indicators and biomechanical factors for the jumper, as the first indicator of the kinetic energy of the body's COG at the beginning of the flight represented the largest contribution of 71%, hence the necessity of increasing kinetic energy as much as possible at the beginning of the flight to reach maximum height (Sado et el., 2020; Pavlovic, 2017).

It is clear from the results of the multiple regression and the contribution rates that it is necessary to increase the horizontal potential energy indicator of the body's COG at the beginning of the take-off. The jumper works to convert this energy into kinetic energy at the end of the take-off. From the performance indicators and their contribution rates, we note the need to achieve a high net velocity indicator of the body's COG at the maximum flight height, as the height of the body's COG at the maximum flight height represents a 3% contribution to performance level (Adashevskiy et el.,2013; solehto et el., 2007).

Several additional push variables were crucial for increasing the participants' achievement levels. It is necessary to improve the right arm's position and velocity at the point of maximum knee flexion; this variable had a 13% contribution rate. This is supported by multiple studies demonstrating the need to direct the free limbs (additional push) in a way that increases the rate at which the body's COG generates speed to achieve flight distance. The synchronization between the vertical velocity variables, the angular velocity of the free leg, and the horizontal velocity of the right arm is important due to its ability to control body connections and joint angles without exaggerating the positions to achieve maximum performance (Milan ,2010; Coh, Supej, 2008).

Reducing the take-off braking time is necessary, as indicated by the multiple regression results and the contribution rates of the indicators. This variable had a 4% contribution rate to high jump height; hence, it is necessary to increase the duration of the push without causing the body's COG to decrease in speed. Because this variable had a significant impact on performance, reducing braking time requires a large amount of muscular strength to be applied in a very short time (Dapena, , Flickin, 2006; Nicholson et el.,2018).

The thigh angle indicator variable for the take-off leg also plays an important role in stabilizing the take-off leg relative to the upper body. To achieve success rates the kinetic transfer of force from the ground to the upper part of the body, the thigh angle variable of the take-off leg at the end of the take-off contributed 1% to the performance (Agar-Newman , Klimstra,2015; Pleša et el., 2022).

Study limitations.

Although the current study has certain strengths, it also has many limitations, that need to be discussed and addressed in future research. In such studies, a large number of athletes is required for accurate results. All jumpers participating in the tournament participated in the study, and 48 three-dimensional attempts were analyzed.

Secondly, in such studies, more cameras (6-12) could be used to capture all the variables during performance and to conduct a three-dimensional analysis, but only six high-quality cameras were available to photograph the athletes.

Finally, this is a descriptive and analytical study that aims to determine the contribution rates of biomechanical variables and special factors on the effectiveness of achievement in the high jump, through which information can be provided to assist coaches and those interested in this field during the education or training process or to conduct complementary studies for future development.

Conclusion

A set of biomechanical variables that characterize the human body as a mechanical system were employed as performance indicators. There are two kinds of indicators: kinetic and kinematic. These are referred to as special indicators, since they always improve along with an increase in the degree of skill and performance mastery, starting from the beginner to the elite level. A high jump competition relies on a set of abilities that are dependent on indicators that are essential for education and training. Reaching the maximum height possible is the aim of the high jump. This is accomplished during the take-off phase by converting horizontal speed and kinetic energy into vertical speed and momentum that can be utilized to modify the body during flight to clear the crossbar at the highest possible height. Several biomechanical indicators are relevant at each stage. This study identified six indicators and special factors (COG's vertical kinetic energy at the beginning of flight, the net velocity of the right wrist at maximum knee flexion, COG's horizontal potential energy at the beginning of take-off, the braking time to the take-off, COG's net velocity at the maximum flight altitude, and the take-off leg hip joint angle at the end of the take-off).

Funding statement

This work was supported by the Deanship of Scientific Research, King Faisal University, Saudi Arabia [Project No. KFU-REC-2025-JAN- ETHICS2815].

Data availability statement

The data will be made available upon request.

Acknowledgments

We thank all the players who agreed to participate in the study. We thank the Egyptian Athletics Federation for their cooperation and for allowing the study to be conducted at the time of the tournament.

Conflict of interest: we declare no conflict of interest.

References:

Leite, W.(2013).Biomechanical analysis of running in the high jump. *Pedagogics, psychology, medical-biological problems of physical training and sports*, *17*(2), 99-105. *doi: 10.6084/m9.figshare.639261.*

Dapena, J.(1992).Biomechanical studies in the high jump and the implication to coaching, *Track & Field Quarterly Review ,George D. Gales, editor,* 92(4), 7-8.

Schiffer, J.(2012).Plyometric training and the high jump. *New Studies in Athletics*, *27*(3), 9-21.

Dobbs, C. W., Gill, N. D., Smart, D. J., & McGuigan, M. R .(2015).Relationship between vertical and horizontal jump variables and muscular performance in athletes. *The Journal of Strength & Conditioning Research*, *29*(3), 661-671 , *doi:10.1519/jsc.0000000000000694.*

Sado, N., Yoshioka, S., & Fukashiro, S.(2020).Non-extension movements inducing over half the mechanical energy directly contributing to jumping height in human running single-leg jump, *Journal of Biomechanics October 113(2):110082. ,doi:10.1016/j.jbiomech.2020.110082*

Milan C.(2010).Biomechanical characteristics of take-off action in high jump-a case study. *Serbian Journal of Sports Sciences, 4(4).*

Adashevskiy, V. M., Iermakov, S., & Marchenko, A. A.(2013).Biomechanics aspects of technique of high jump, physical education of students,vol.2, pp. 11-17, *SSRN Electronic Journal. doi:10.2139/ssrn.2444335.*

Van Caekenberghe, I., Derave, W., Lenoir, M., Segers, V., Aerts, P., & De Clercq, D.(2021).Traditional high jump Gusimbuka Urukiramende: Could early 20th century African athletes beat Olympic champions?. *Journal of Sports Sciences*, *39*(16), 1800-1806, , https://doi.org/10.1080/02640414.2021.1898175.

Agar-Newman, D. J., & Klimstra, M. D.(2015).Efficacy of horizontal jumping tasks as a method for talent identification of female rugby players. *journal of strength and conditioning research, 29(3), 737–743. , doi:10.1519/jsc.0000000000000683.*

Nicholson, G., Bennett, T. D., Bissas, A., and Merlino, S.(2019).Biomechanical Report for the IAAF World Indoor Championships 2018*: High Jump Men. Birmingham, UK,* International Association of Athletics Federations. Available online at: https://www.iaaf.org/about-iaaf/documents/research

Panoutsakopoulos V, Kollias I, A.(2012).3D Biomechanical Analysis of Women's High Jump Technique, *New Studies in Athletics* ·IAAF, *27*(3), 31-48.

Dapena, J., & Flickin, T. K.(2006).Scientific services project–high jump. *Biomechanics Laboratory, Dept. of Kinesiology, Indiana University. USA,.*

Nicholson, G., Jongerius, N., Tucker, C. B., Thomas, A., Merlino, S., & Bissas, A.(2022).The association between hip-shoulder separation angles and technique characteristics in world-class high jumpers. *Frontiers in Sports and Active Living*, *4*, 873526.doi: 10.3389/fspor.2022.873526.

Kim, Y. S., Ryu, J. K., & Jang, J. K.(2015).The Kinetic Analysis of the Approach and Take-off Motion between Performance in Woman's High Jump, *Korean Journal of Sport Biomechanics*, *25*(1), 1-10. *https://doi.org/10.5103/KJSB.2015.25.1.001*.

Goldmann, J. P., Braunstein, B., Heinrich, K., Sanno, M., Stäudle, B., Ritzdorf, W., ... & Albracht, K.(2015).Joint work of the take-off leg during elite high jump,*33rd International Conference on Biomechanics in Sports, Poitiers, France, June 29 - July 3. doi: http://dx.doi.org/10.13140/RG.2.1.1547.0163*

Rao, C. R., Kishore, Y., & Rao, J. R.(2014).Biomechanical Analysis of Centre of Mass Height during the Takeoff Phase In Fosbury Flop High Jump of National Level Participants. *International Journal of Modern Communication Technologies and Research*, (IJMCTR),*2*(10), 265758.

Sado, N., Yoshioka, S., & Fukashiro, S.(2022).Curved Approach in High Jump Induces Greater Jumping Height without Greater Joint Kinetic Exertions than Straight Approach. *Medicine and Science in Sports and Exercise*, *54*(1), 120-128. DOI: 10.1249/MSS.0000000000002761

Becker J, Will F.W.(2015).Integrating biomechanical and motor control principles in elite high jumpers: A transdisciplinary approach to enhancing sport performance, *Journal of Sport and Health Science, 4(4), 341-346. https://doi.org/10.1016/j.jshs.2015.09.004.*

Johnston, L. A., Butler, R. J., Sparling, T. L., & Queen, R. M.(2015).A single set of biomechanical variables cannot predict jump performance across various jumping tasks. *The Journal of Strength & Conditioning Research*, *29*(2), 396-407. *https://doi.org/10.1519/jsc.0000000000000779* .

Sattler, T., Sekulić, D., Spasić, M., Perić, M., Krolo, A., Uljević, O., & Kondrič, M.(2015).Analysis of the association between motor and anthropometric variables with change of direction speed and reactive agility performance. *Journal of human kinetics*, *47*, 137. doi: 10.1515/hukin-2015-0069. PMID: 26557198; PMCID: PMC4633249

Coh, M., & Supej, M.(2008).Biomechanical model of the take-off action in the high jump: a case study. *New Stud in Athletics, IAAF*, *23*(4), 63-73.

Ae, M., Nagahara, R., Ohshima, Y., Koyama, H., Takamoto, M., & Shibayama, K.(2008). Biomechanical analysis of the top three male high jumpers at the 2007 world championships in athletics. *New Studies in Athletics*, *23*(2), 45-52.

Nicholson, G., Bissas, A., & Merlino, S.(2018).Biomechanical report for the IAAF world championships 2017: high Jump Men's,in 2017 *IAAF World Championships Biomechanics Research Project, July, UK* (International Association of Association of Athletics Federations). Available online at: https://www.iaaf.org/about-iaaf/documents/research (accessed July 2018).

Pleša, J., Kozinc, Ž., & Šarabon, N.(2022).A brief review of selected biomechanical variables for sport performance monitoring and training optimization. *Applied Mechanics*, *3*(1), 144-159. https://doi.org/10.3390/applmech3010011.

Kim, E. H., Bae, Y. S., Kim, S. S., Kwon, M. S., Wi, U. R., KIm, K. M., & Lee, J. M.(2011). Biomechanical analysis of men's high jump medalists in iaaf world championships, daegu 2011. *Korean Journal of Sport Biomechanics*, *21*(5), 573-584. *http://dx.doi.org/10.5103/KJSB.2011.21.5.573*.

Bermejo, J., Palao, J. M., & Elvira, J. L.(2011).Effect of age on high jump take off biomechanics. In *ISBS-Conference Proceedings Archive*.

Sado, N., Yoshioka, S., & Fukashiro, S.(2018).Hip abductors and lumbar lateral flexors act as energy generators in running single-leg jumps. *International journal of sports medicine*, *39*(13), 1001-1008. doi:10.1055/a-0749-8846.

Mariano, A. S., Tomazini, F., Rodacki, C., Bertuzzi, R., De-Oliveira, F., & Lima-Silva, A. E.(2021). Effects of caffeine on performance during high-and long-jump competitions. *International Journal of Sports Physiology and Performance*, *16*(10), 1516-1521. *doi: 10.1123/ijspp.2020-0755*.

Pavlovic, R.(2017).The differences of kinematic parameters high jump between male and female finalists World Championship Daegu, 2011. *Turkish Journal of Kinesiology*, *3*(4), 60-69.

solehto, J., Virmavirta, M., Kyrolainen, H., & Komi, P.(2007).Biomechanical analysis of the high jump at the 2005 IAAF World Championships in Athletics. *New Studies in Athletics,**22**(2)17-27.*