Kinematic Analysis Of Hurdles Clearance Techniques And The First Inter-Hurdle Stride Over 110-Metre Hurdles: Comparisons Between Specialists And Decathletes

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Research Article

Keywords: spatial, temporal, support phase, angular parameters, sprinting mechanics.

Posted Date: March 14th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1436060/v1

Abstract

Background: Performances in the 110-metre hurdles sprint differ for Elite Hurdles Specialists (EHS) and Elite Decathletes (ED), possibly resulting in technical differences. This study aims to compare the kinematics of hurdle clearance and the first stride inter-hurdles of EHS and ED.

Methods: This is a cross-sectional study involving twenty male athletes volunteered for the investigation (10 male EHS, and 10 male ED). Each athlete had previously achieved a 110m hurdles in a real competitive practice situation, and the kinematic parameters were determined by using kinematic analysis. The indices of spatial and temporal interaction in the support phase, as well as the angular parameters of motion and height of the body center of mass (CM) for various postures, were determined.

Results: EHS were characterized by faster hurdle crossing ($p < 0.01$), shorter stride length over the hurdle ($p < 0.05$), and a shorter support phase in the first stride post-hurdle ($p < 0.01$). The CM path of ED was higher than that of EHS ($p < 0.01$). EHS attack the hurdle with the lead leg knee significantly more flexed ($p < 0.001$) and after crossing the hurdle, regain contact with the ground with the lead leg more flexed at the hip level ($p < 0.01$), the trunk more inclined forward ($p < 0.01$), and a relatively smaller positioning angle of the supporting leg ($p < 0.05$).

Conclusions: EHS were distinguished by maintaining efficient sprinting mechanics over the hurdles, enabling them to develop optimal velocity between hurdles. This was reflected in both a shorter impulse time and a considerable reduction of braking forces at the touchdown. In addition, EHS showed a more fluid and quicker resumption of optimal speed between hurdles, resulting in minimal loss of speed and superior performance.

Background

Unlike the flat sprint, in which the structure of the stride, in terms of amplitude or frequency, is not subject to important external constraints, the hurdles event is a model of repetitive activity involving important spatiotemporal imperatives [1]. Proper hurdling technique is a complicated combination of various running and jumping kinematics [2]. Among the three outdoor hurdles events currently being run at the international level, the high hurdles sprint is the most demanding [3]. Thus, athletes, coaches, and researchers have sought to improve hurdles performance by placing more emphasis on the kinematic analysis of hurdling techniques. Over the years, there has been a considerable amount of biomechanical literature concerning the kinematic analysis of hurdle clearance at different levels of performance in both male and female athletes [2, 4–7]. However, there has been little information comparing the various characteristics of movements of top-level hurdles specialists to those of high-level combined events athletes. Moreover, analysis of the specialized literature shows that most studies related to the technical aspects of hurdles and sprint observations are performed during training conditions or are derived primarily from simulated events rather than from genuine competitions. It is, however, difficult to effectively simulate competitive race conditions. It is also likely that athletes concentrate more fully and thus run slightly faster at an official event than under practice or other conditions [5]. This may be due to factors such as adrenaline and to the fact that, in a meet, the race has only to be run once. Therefore, the aim of this study is to establish the main factors of hurdle clearance technique efficiency by revealing, based on a comparative kinematics analysis, some important biomechanical parameters involved in the hurdle sprint techniques of elite hurdles specialists and elite decathletes' performances. We hypothesized that elite hurdles specialists will demonstrate a faster crossing technique, and a more fluid and quicker resumption of the speed between hurdles, resulting in minimal loss of speed and superior performance.

Methods

Participants

Data were collected from 20 elite athletes: 10 male elite hurdles specialists [(EHS), (age: 20.9 ± 2.2 years, body mass: 76.9 ± 7.0 kg, height: 1.85 m ± 0.05 m)], and 10 male elite decathletes [(ED), (age: 20.8 ± 2.27 years, body mass: 87.7 ± 6.9 kg, height: 1.91m ± 0.03 m)]. The protocol was conducted in accordance with the latest declaration of Helsinki [8], and approval was obtained from the local ethics committee of the Tunisian Athletics Federation, Tunisia. All athletes were informed about the study protocol and signed an informed consent form before taking part.

Procedures

The protocol was performed on three separate days in randomized order and involved hurdling specialists and decathletes during a training session. Each athlete had previously achieved a 110m hurdles in a real competitive practice situation. Each run was performed by two athletes to simulate the competitive aspect of a race. Each athlete that was the focus of the kinematic analysis was placed on the side closest to the camera range to allow for the capture of various body segments. All stages were carried out in conditions of a warm temperature of around 26–27° and a wind velocity of less than 1.0 m·s-1.

Motion Analysis

Kinematic analysis of the 110m hurdles sprint was performed by using a high-speed camera (Arriflex SR-II, Germany) equipped with a telephoto lens (Angenieux 10–150 mm, France) and operating at 100 Hz. The video camera was placed perpendicularly to the runway axis at 11m from the filmed target of the first hurdle level to obtain a sagittal view of the hurdler as the athletes cleared the obstacle [9]. The appropriate location and height of the camera (1.27m) allowed the capture of a whole phase of hurdle clearance, including the touchdown and the entire cycle of the first stride after the filmed hurdle. Targets were temporarily placed on the runway to calibrate the space volume travelled by the runner, to insure it was sufficiently large to contain the hurdler. To determine our selected kinematic parameters, we adopted the representative model of the human body described by Winter [10]. We considered the various segments of the body of each marker as non-deformable solids interconnected by perfect connections. The landmarks used were the endpoints of the 14th segments into which the body was divided. The segments' inertia was determined based on Hanavan's model [11], which considers the segments as truncated cones (feet, legs, thighs, arms, forearms, and hands) or revolution truncated ellipsoids (pelvis, abdomen, thorax, head, and neck). The two-dimension (2D) coordinate positions were precisely known by the position of targets placed temporarily on the runway to calibrate the volume of the runway evolution surface. Such calibration makes it possible to locate the orthogonal reference system (R) from which the projection coordinates will be carried out. 2D coordinates segmental body joints data were collected using motion analysis software (Regavi, Micrelec, Coulommiers, France). The video sequences were stripped image by image, indicating the successive positions of each segment joint during movement. We reconstituted the body segments considered as rigid to make kinograms of each hurdler. Selected kinematic parameters were calculated using scientific graphing and data analysis software (SigmaPlot 10.0, Systat Software Inc, USA). For smoothing, we used a second-order low-pass filter with an 8-Hz cut-off frequency determined from a residual analysis [10].

Statistical Procedures

All distributions were checked for normality using the Shapiro-Wilk test. Differences between groups (EHS vs ED) were investigated using Student's t-test for normal distributions and using Mann-Whitney U-test for non-normal distributions. Specific correlations between performance over 110 meters hurdles (dependent variable; DV) and spatiotemporal variables (independent variables; IV) were performed using the Pearson correlation coefficient. In addition, the linearity of IV was tested using scatter plots. The normality and homoscedasticity of the residuals were also verified, and IV variables were checked for multicollinearity using the variance inflation factor (VIF). Values were more than 10 indicating the occurrence of high intercorrelations among IV. To deal with multicollinearity, a principal components analysis (PCA) was used, and a sequential multiple regression (SMR) procedure was performed to determine the amount of variance in performance that could be explained throw the components derived from the PCA analysis and the athletic specialty. Threshold values for the interpretation of the adjusted R^2 as an effect size were set at 0.02 (small), 0.13 (medium), 0.26 (large) in accordance with Cohen [12]. Statistical analysis was performed with the SPSS statistical package (version 26 for Windows; SPSS Inc., Chicago, IL, USA), results are presented as mean ± standard deviation (SD), and the statistical significance was set at α = 0.05.

Results

Spatial and temporal data

Performances of the 110m hurdles sprint achieved by elite hurdlers were significantly better than those of elite decathletes ($p < 0.001$). The relative values were 14.78 ± 0.61s and 16.06 ± 0.66s respectively (Table 1). The comparison of kinematic parameters between ED and EHS revealed that the amplitude of the stride over the hurdle was significantly greater in decathletes. This larger hurdle step length coincided with a greater take-off distance. This was clearly expressed in the attack area. The distance from the take-off point to the hurdle was 2.16 ± 0.13m in ED and 1.95 ± 0.19m in EHS ($p < 0.05$). In contrast, the distance from the hedge to the touchdown point, after clearance, was not different between ED and EHS. The average hurdle stride was 3.60 ± 0.17m in EHS and 3.84 ± 0.27m in ED. The take-off distance was 1.95 ± 0.19m and 2.16 ± 0.13m respectively, which represents 54.2% and 56.3% of the total hurdle stride length. The landing distance was 1.65 ± 0.16m for EHS and 1.68 ± 0.23m for ED, which was between 45.8% and 43.8% of the total hurdle stride length (Fig. 1).

Table 1
Spatial and temporal parameters of hurdle clearance and the first stride post-hurdle in Elite Hurdlers Specialists and Elite Decathletes

Parameters	**Elite Hurdlers Specialists (n = 10)**	**Elite Decathletes (n = 10)**
Total stride length (m)	3.60 ± 0.17	3.84 ± 0.27*
Flight phase time (s)	0.373 ± 0.030	0.41 ± 0.047*
Distance, take-off point before the hedge - hedge (m)	1.95 ± 0.19	2.16 ± 013
Distance, hedge - landing point (m)	1.65 ± 0,16	1.68 ± 0.23
Amplitude of the first stride post-hurdle (m)	1.56 ± 0 .10	1.70 ± 0.11*
Support time of the first stride post-hurdle (s)	0.10 ± 0,013	0.128 ± 0.018*
Flight time of the first stride post-hurdle (s)	0.076 ± 0.016	0.073 ± 0.017
Height of the CM before the take-off pre- hurdle. (m)	1.03 ± 0,04	1.04 ± 0.05
Height of the CM at the impulsion (m)	1.15 ± 0,05	1.26 ± 0.07**
CM’s height above the hedge (cm)	23.00 ± 3	39.00 ± 4**
Height of the CM at landing after clearance (m)	1.17 ± 0,03	1.24 ± 0.06*
Height of CM at the impulse of the first stride post-hurdle (m)	1.07 ± 0.02	1.13 ± 0.05*
Performances (s)	14.78 ± 0.61	16.06 ± 0.67**
** p < 0.05; ** p < 0.001 compared to Elite Hurdlers Specialists.*		

As such, EHS were characterized by a less extensive hurdle clearance stride ($p < 0.05$), a shorter flight time over the hurdle ($p < 0.01$), and a smaller support phase of the first step inter-hurdle ($p < 0.01$). Whereas, except for the moment of the supporting leg’s contact with the ground before attacking the hedge, the CM’s path in ED was higher than that in EHS ($p < 0.01$). The position of the CM above the hurdle was also higher in ED (39 ± 4 cm) than in EHS (23 ± 3 cm; (Fig. 2)). The intercorrelations study showed that both groups’ performance in the 110m hurdles was positively correlated with the time of hurdle crossing (EHS: $r = 0.74$, $p < 0.01$; ED: $r = 0.63$, $p < 0.05$) and with the duration of the support phase of the first step post-hurdle (EHS: $r = 0.91$, $p < 0.001$; ED: $r = 0.73$, $p < 0.01$).

Angular Kinematics

At the hurdle attack, no significant differences were observed between the two groups in terms of angular variations of the supporting leg, the hip attack leg, the body tilt, and the leg impulse (Fig. 3. However, at the hurdle-crossing, EHS showed a higher degree of lead leg knee flexion than ED ($p < 0.001$). During this phase, the tilt of the trunk forward significantly influenced the achieved performance (EHS: $r = -0.70$; $p < 0.05$; ED: $r = -0.63$; $p < 0.05$). However, at the landing phase, EHS touched down with the trail leg more flexed at the hip level, the trunk more sloped forward by return to vertical, and a smaller positioning angle of the trail leg ($p < 0.05$). During this phase, the performance of EHS on the 110 m hurdles sprint was positively correlated with the hip opening of the support leg ($r = 0.66$, $p < 0.05$). Nevertheless, the sequence of the first stride inter-hurdle was made with no significant angular variation for all participants, except that of the impulsion, which was significantly more important in EHS ($p < 0.05$).

Associations between performance over 110 meters hurdles and spatiotemporal variables

The partial component analysis was carried out with 1 as the minimum eigenvalue of the factors. After Varimax rotation with Kaiser normalization, a two-factor solution was extracted (Table 2). The components and sport specialty were entered into the equation one at a time to determine the contribution of each to the regression equation. As shown in Table 3, component 1 was not correlated to performance and sport specialty, its effect on performance was not significant ($R^2 = 0.072$). Conversely, component 2 and athletic specialty affected significantly the performance achieved over 110-m hurdles, this effect was large for component 2 ($R^2 = 0.848$) and small for the specialty ($R^2 = 0.03$). A significant correlation was also noted between component 2, sport specialty, and performance ($r = 0.895$ and 0.731, respectively). Component 2 includes stride length; the flight phase time; distance: take-off point - hedge; the amplitude and support time of the first stride after the hedge; the height of CM at the impulsion before the hedge, above the hedge, at landing after clearance and at impulse at the first stride after the hedge; the knee angle of the attacking leg in the attack phase; the hip angle and the positioning angle of the supporting leg at the landing phase; and the inclination of the trunk from the vertical at the landing phase.

Table 2
Factors extracted, eigenvalues and proportion of variance after rotation

Independent Variables	**Component**	
	1	**2**
Total stride length (m)	.222	**.859**
Flight phase time (s)	.379	**.921**
Distance, take-off point before the hedge - hedge (m)	.467	**.831**
Distance, hedge - landing point (m)	**.826**	.510
Amplitude of the first stride post-hurdle (m)	.457	**.865**
Support time of the first stride post-hurdle (s)	.466	**.865**
Flight time of the first stride after the hedge	**.945**	.247
Height of the center of mass at take-off before the hedge (m)	**.846**	.512
Height of the center of mass at the impulse before the hedge (m)	.269	**.955**
Height of the center of mass above the hedge (cm)	− .046	**.977**
Height of the center of mass on landing after clearance (m)	.414	**.892**
Height of the center of mass at the impulse during the first stride after the hurdle (m)	.326	**.919**
Attack phase, angle of the ankle of the supporting leg	**.974**	.064
Attack phase, angle of the knee of the supporting leg	**.886**	.424
Attack phase, hip angle of the supporting leg	**.935**	.269
Attack phase, angle of the supporting leg at the impulsion	**.920**	.270
Attack phase, knee angle of the attacking leg	.177	**.976**
Attack phase, inclination of the trunk from the vertical	**.919**	.368
Landing phase, ankle angle of the supporting leg	**.874**	.357
Landing phase, Knee angle of the supporting leg	**.684**	.662
Landing phase, hip angle of the supporting leg	.407	**.902**
Landing phase, positioning angle of the supporting leg	.439	**.875**
Landing phase, knee angle of attacking leg	**.752**	.629
Landing phase, inclination of the trunk from the vertical	− .032	**− .885**
First inter-hurdle stride, ankle angle of the supporting leg	**.885**	.398

Independent Variables	**Component**	
	1	**2**
First inter-hurdle stride, knee angle of the supporting leg	**.963**	.219
First inter-hurdle stride, hip angle of the supporting leg	**.787**	.486
First inter-hurdle stride, angle of the supporting leg at the impulsion	**.953**	− .205
First inter-hurdle stride, knee angle of the attacking leg	**.782**	.551
First inter-obstacle stride, inclination of the trunk from the vertical	**− .638**	− .628
Extraction Method: Principal Component Analysis.		
Rotation Method: Varimax with Kaiser Normalization.		

Table 3
Sequential multiple regression models for associations between performance over 110 m hurdles and spatiotemporal variables and angular variations during hurdle clearance and the first stride after hurdles.

Model		β (SE)	Pearson Correlation		R^2	R^2 Change	F Change
			Performance	**Specialty**			
1	(Constant)	15.426 (0.195) ***			0.072	0.120	2.464
	REGR factor score 1	0.313 (0.200)	0.347 (NS)	-0.350 (NS)			
2	(Constant)	15.426 (0.057) ***			0.920	0.808	190.814 ***
	REGR factor score 1	0.313 (0.059) ***					
	REGR factor score 2	0.812 (0.059) ***	0.899***	0.895***			
3	(Constant)	13.774 (0.488) ***			0.950	0.030	11.548 **
	REGR factor score 1	0.511 (0.074) ***					
	REGR factor score 2	0.307 (0.156)					
	Specialty	1.101 (0.324) **	0.731 ***				

*Regression β coefficients (unstandardized) represent the degree of change in the performance for every 1-unit of change in the predictor variable. *p < 0.05, ** p < 0.01, ***p < 0.001. SE = standard error.*

Discussion

According to the collected data, performance improvement in the hurdles sprint involves a reduction of spatiotemporal parameters; this result corresponds with Graubner and Nixdorf's study [13], which intends degrees of freedom reduction of system. Contrary to the findings of Tsiokanos et al. [14], the present study demonstrates that improved performance in the 110m hurdles sprint event depends on spatial and temporal parameters. In the support phase, the vertical force components are crucial, especially during the crossing of each hurdle [15]. During the segments' body transition, invariable and common characteristics can be distinguished. These distinctions are essential: both for the determination of universal mechanisms in the organization of hurdlers' temporal and spatial movements and for solving problems related to the presence of the obstacle [16]. This is of particular importance in combined athletics events, since participants are obliged to develop their technical skills in several athletic specialties at the same time. In contrast, the training efforts of hurdlers are focused on improving hurdling skills, refining hurdles sprint mechanics, and establishing general sprint conditioning, as well as on the even distribution of energy throughout the race. The resolution of such tasks can be expected to be even more successful when the general mechanisms constituting the basis of such combined events, or distinct technical elements of the same discipline, have been studied appropriately.

Our results also highlight the importance of increasing the sprint rhythm to improve 110m sprint hurdlers' performance. This means that the velocity of running between and over the hurdles needs to be matched with the technique and agility of the runner. Agility itself depends on several factors, especially those that describe the attacking phase in front of the hurdle, the CM path, and the landing after the flight over the hurdle [15]. Running speed could also be increased by optimizing support and flight time and reducing amortization time [17–19].

The present study confirms that EHS were distinguished from ED by their shorter stride length over the hurdle, lower CM path, and faster crossing technique. Thus, agility and fluency in running over the hedge was significantly higher in EHS. Coh et al. [19] found that elite athletes with shorter hurdle clearance times had faster hurdle running times. According to McDonald and Dapena [20], the criterion of an efficient hurdle clearance technique is the shortest possible time of the flight phase (hurdle clearance time); otherwise, the hurdler loses velocity in the air. According to Bubanj et al. [15], this condition is a very effective way to reduce the vertical oscillations of the CM since it allows the athlete to maintain a stable horizontal velocity and develop a consistent stride pattern. Our results, determined under experimental competitive conditions, were in accordance with the findings of Hanley et al. [21] performed in-competition in eight finalists from the men's 110 m hurdles at the London 2017 World Championships. Our findings further reveal significant differences between ED and EHS in relation to the first stride post-hurdle that are related to the latter's superior performance. This could be explained by the necessity for minimizing the braking forces to maintain a constant horizontal velocity along the race and enable a quick resumption of optimal speed between the hurdles [22]. Indeed, it is widely accepted that one of the most important characteristics of the effectiveness of the hurdles sprint techniques is the ability to maintain a high and constant running rhythm without losing balance, especially after crossing the hurdle at the touchdown moment [23], and that the braking phase must be as short as possible [2]. Moreover, a typical technical fault, particularly among novice runners, is the considerable loss of speed after the touchdown that leads to a substantial reduction of the horizontal velocity and amplitude of the first stride after the hedge [7, 24]. As such, it becomes clear that the optimal flight time in EHS during the recovery stride (post-hurdle) reflects a more efficient running technique [25]. This underlines the finding of Li and Fu [26] that the first stride after the hurdle is a crucial factor that determines whether the hurdle clearance technique is satisfactory.

The comparative analysis of the angular kinematics reveals that EHS are distinguished by a more pronounced forward slope of the trunk at hurdle-crossing, particularly during the landing phase. This body posture at the landing phase creates auspicious conditions for an active landing after hurdle-crossing, minimizing the loss of speed mainly during the amortization phase, ensuring easier forward locomotion [20], and allowing the CM to lower to an optimal level above the hedge [2]. It should also be noted that EHS show more efficient movement of the attack leg at the moment of propulsion and hurdle attack. In fact, the lead leg's smaller knee angle reduces its moment of inertia at the attack of obstacle [15]. According to Coh et al. [2], the leading leg increases the value of the horizontal CM velocity of the athlete at hurdle-crossing.

Conclusions

The comparative kinematic study of the fifth hurdle clearance and the first stride post-hurdle of EHS and ED permitted the determination of common components and specific distinctive technical elements of each group. By examining the kinematic particularities in the phases of launch, flight, and landing, some of the most important parameters have been determined. It was found that EHS were distinguished from ED by a shorter flight time, shorter length stride over the hurdle, lower CM path, more forward tilted trunk at the landing phase after clearance, shorter braking phase at landing, more open propulsion angle at the attack moment in front of the hurdle and at the first stride inter-hurdle, as well as a shorter support time at the recovery stride after clearance. Our results further showed that EHS were distinguished by more rational and efficient hurdling techniques, resulting in better outcomes than those of ED. The data also noted that component 2 largely affected performance over 110m hurdles. The athletic specialty also had a weak but significant influence on performance. Results collected from EHS and ED during the 110m hurdles sprint in official competitions could be useful: first for the estimation of hurdling techniques and second to engender a clearer comprehension of hurdling selected parameters. We consider that aided by this understanding, hurdling techniques could be adapted specifically for each event rather than generally, which could lead to improved performance.

Practical Implications

Within the limitations of our study, the present findings highlight how to minimize the loss of speed. Sprint hurdlers must maintain the efficient sprinting mechanism over the hurdles to develop optimal velocities between them. Moreover, training must be focused on creating shorter impulse time as well as a greater reduction of braking forces at touchdown.

Abbreviations

EHS: Elite hurdles specialists; ED: Elite decathletes; CM: Center of mass; DV: Dependent variable; IV: Independent variable; VIF: Variance inflation factor; PCA: Partial component analysis; SMR: Sequential multiple regression.

Declarations

Acknowledgements

We thank everyone who devoted their time and effort to participate in this study. Special thanks to Professor Mahmoud Ali Attia for his participation in the design of the research proposal and the interpretation of the results.

Authors' contributions

MAS and HM contributed to the conception and the design of the work, interpreted data, and drafted the work. MBC, IA and MMA contributed to the conception and the design of the work, participated in the acquisition and the analysis of data, and revised the manuscript. All authors had read and approved the final version of the manuscript and take full responsibility for the manuscript.

Funding

Not applicable

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Approval was obtained from the local ethics committee of the Tunisian Athletics Federation, Tunisia. All athletes were informed about the study protocol and signed an informed consent form before taking part.

Consent for publication

Not applicable

Competing interests

The authors have no conflicts of interest to declare

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Figures

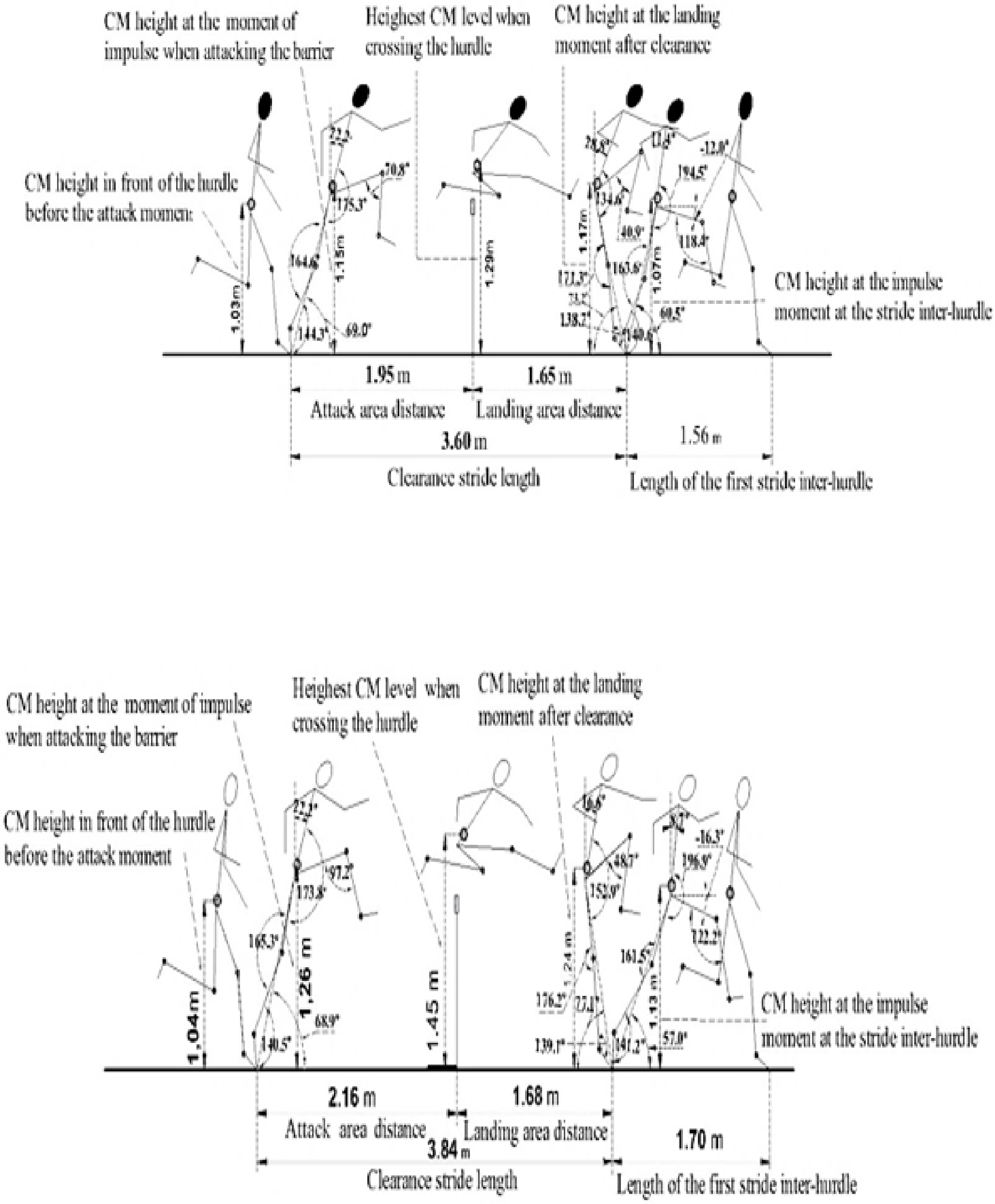


Figure 1

Visual representation of take-off and landing distance, hurdle clearance, length of landing and the first stride after inter-hurdle, and the height of the CM at take-off, obstacle clearance and on landing for Elite Hurdle specialists (upper) and Elite Decathletes (bottom). *Results are presented as means and the hurdle is shown as the athletes would approach it running from left to right.*

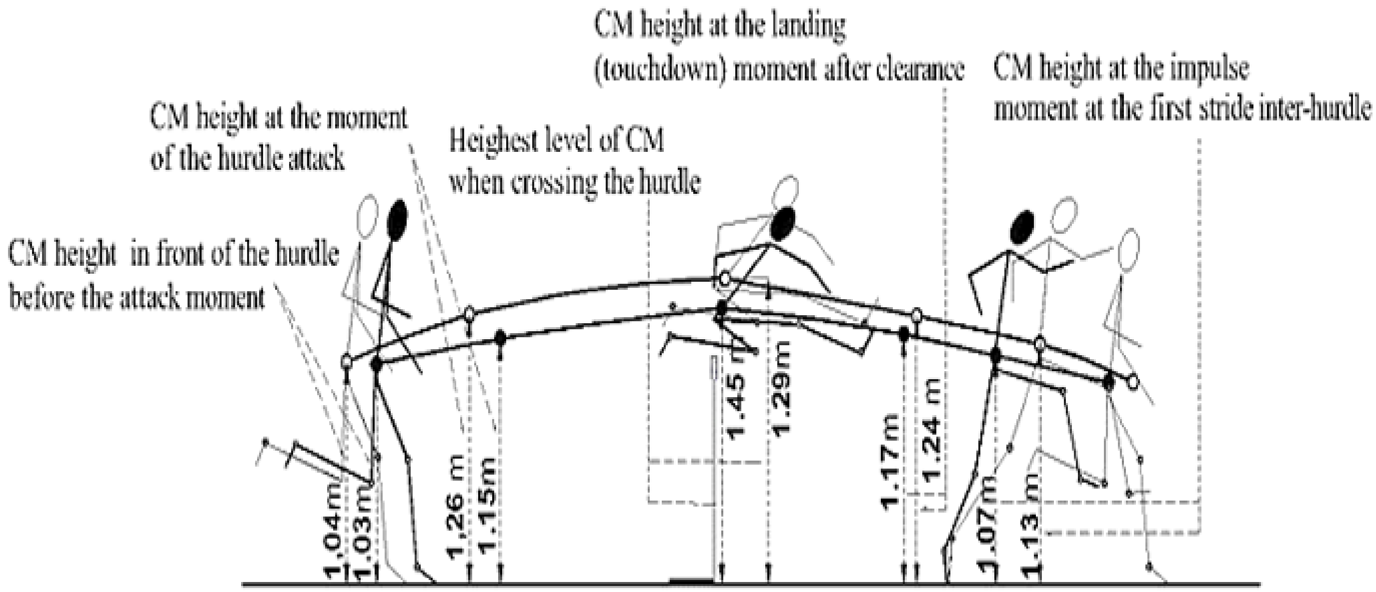
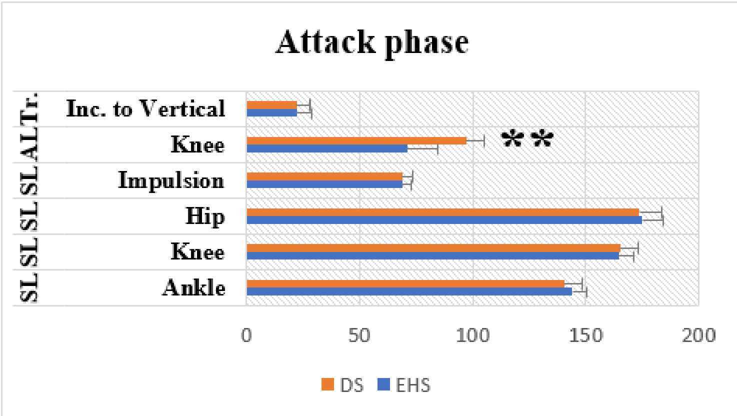
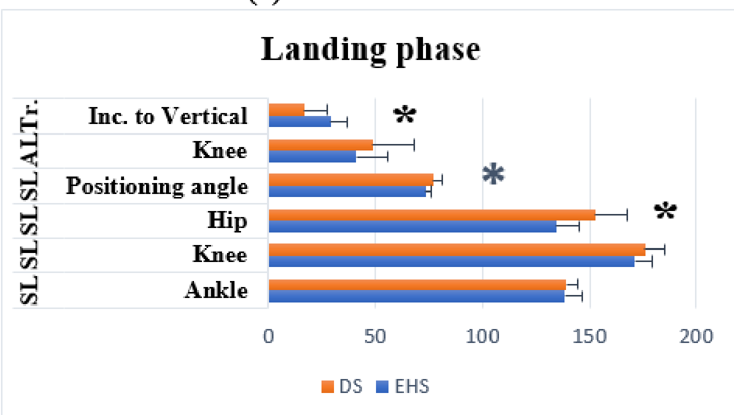


Figure 2

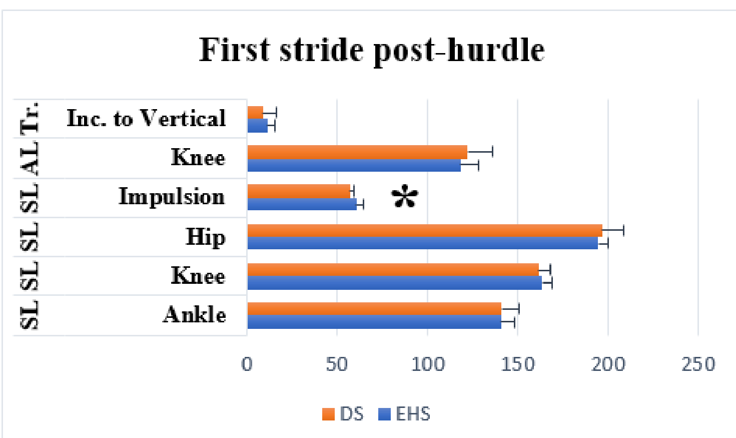
Visual representation of the height of the CM at take-off, obstacle clearance, landing and the first stride post hurdle in Elite Hurdle Specialists (■) and Elite Decathletes (□). *Results are presented as means and the hurdle is shown as the athletes would approach it running from left to right.*



(a)



(b)



(c)

Figure 3

Angular variations in the support leg (SL), the attack leg (AL) and the trunk (Tr.) at the attack (a) and landing phase (b), and at the first stride post-hurdle (c) in Elite Hurdle specialists (EHS) and Elite decathletes (ED). **p < 0.05; **p < 0.001 compared to the other group.*