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Evolution of the Hurdle-Unit Kinematic Parameters in the 60 m Indoor Hurdle Race

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Featured Application: Coaches and athletes should implement their training programs to have an impact on some of these variables according to the specific demands of each hurdle-unit phase and gender.

Abstract: The aims of this study were to compare the five hurdle-unit split times from the deterministic model with the hurdle-to-hurdle model and with the official time, to compare the step kinematics of each hurdle-unit intervals, and to relate these variables to their respective hurdle-unit split times. The temporal and spatial parameters of the 60 m hurdles race were calculated during the 44th Spanish and 12th IAAF World Indoor Championships (men: n = 59; women: n = 51). The hurdle-unit split times from the deterministic model showed a high correlation (r = 0.99; $p < 0.001$) with the split times of the hurdle-to-hurdle model and faster split times were related to shorter step and flight times in hurdle steps for both genders. At the first hurdle, male athletes tended to increase their flight and contact times while the tendency of female athletes was to decrease their contact and flight times. In addition, at the first hurdle, both genders presented shorter take-off distance, shorter landing distance, and greater step width than in the remaining hurdles of the race. Therefore, coaches should implement training programs that have an impact on these key variables according to the specific demands of each hurdle-unit phase and gender.

Keywords: track and field; kinematics; performance analysis; competition; DLT algorithms

1. Introduction

The hurdles events have been analyzed through different approaches such as biomechanics, conditional, teaching and learning, talent identification, psychological, or medical [1,2]. Within biomechanical analyses, two types of studies stand out: temporal and spatial. The ubication of the hurdles serves as a useful reference for the division of the event into the following phases [3]: approach run phase (from the starting line to the first hurdle), hurdle unit phase (race and clearance of the hurdles), and run-in phase (from the last hurdle to the finishing line).

Temporal analyses are commonly focused on the split times between each hurdle clearance (foot landing) [4–7]. The times from the athlete's foot landing after one hurdle to the following hurdle are employed for practical reasons, as it allows an easy visual identification of the splits. Tsionakos et al. [6] showed that the correlation between intermediate times and final performance was decisive from the fifth obstacle onwards in the 110 m obstacle event (r = 0.77 to 0.98), while Panoutsakopoulos et al. [7] found a correlation between split times with the official time in the 60 m indoor event in most of the intervals, both for elite men (r = 0.65 to 0.84) and women (r = 0.55 to 0.87). Similarly, González Frutos et al. [8] found an almost perfect correlation (r = 0.99) between the mean of the hurdle-unit split time and the official time in the 60 m hurdle race. In addition to the split time analysis, it is frequent to refer to the flight time over the hurdle (from take-off to landing) in temporal studies. Panoutsakopoulos et al. [7] found a correlation in not all of the hurdles between the flight time and the official time, while González Frutos et al. [8] found a very large correlation (r = 0.82) between the mean flight time of the five hurdle steps and the official time.

Among the spatial analyses, three-dimensional (3D) studies stand out, even though they are habitually carried out in a single hurdle-unit interval (between the second and fifth hurdle), in a training situation or employing a small sample of subjects due to the costly analysis of the data [9–16]. The organization of the steps that make up the hurdle-unit phase within the studies depends on the selection of the phase of interest: following a deterministic model which comprises the preparatory, hurdle, landing and recovery steps [9,17], only the hurdle and landing steps [10,11,13–15], or from hurdle to hurdle [12]. There is a single precedent of the analysis of all ten hurdles during the 110 m hurdle event [18], who performed a two-dimensional analysis and calculated take-off (2.04 ± 0.07 m) and landing (1.47 ± 0.03 m) distances. Complementarily, González-Frutos et al. [8] analyzed the average of every step of the hurdle-unit phase, in addition to the approach run and run-in phases, finding differences between international and national hurdlers in various parameters during 60 m hurdles event, for both men and women.

Most of these kinematical studies indicate that an efficient hurdle clearance technique is associated with the take-off contact time, take-off and landing distances, take-off angle, and to the hurdle flight time. However, the differences found between some studies may be due to the analysis of different single hurdle intervals, since the kinematic parameters in hurdles and sprint events change as the running speed varies [18,19]. Also, differences could rely on the different criteria when defining the split times of each hurdle-unit [11,13–15] as not many studies consider both the preparatory and recovery steps on it.

Therefore, the aims of the present research were: (1) to compare the five hurdle-unit split times from a deterministic model with the hurdle to hurdle model and with the official time, (2) to compare the step kinematics of each hurdle-unit intervals, and (3) to relate these variables to their respective hurdle-unit split times. Our hypothesis is that both models correlate with each other and with the final result in the race, while there should be differences in the registered values of each hurdle-unit interval. Additionally, we hypothesize that these differences between hurdle-unit phases, and the correlations between variables and their hurdle-unit split times, will be diverse for men and women.

2. Materials and Methods

2.1. Subjects

All the races were filmed during the 60 m hurdle event of the 44th Spanish Indoor Championship and 12th IAAF World Indoor Championship (2008) with the license of both organizing committees. The best performance of each athlete (men, n = 59; women, n = 51) from the heat, semifinal, and final rounds was included in the study. All experimental procedures were carried out in accordance with the Declaration of Helsinki and were approved by the Ethics Committee of the Technical University of Madrid.

2.2. Procedures

The races were filmed with six fixed JVC GY-DV300 video cameras (Japan Victor Company, Yokohama, Japan) located at the main stands and operating at 50 fps (frames per second; shutter speed: 1/1000), similar to that previously used in other studies [5,9,11,12,15]. Four cameras had a predominantly side view: camera one recorded the first 13 m; camera two from 13 to 30 m; camera three from 30 to 47 m; camera four the last 13 m (47 to 60 m) of the race. To avoid visual occlusion of the athletes, cameras five and six were placed to capture the frontal view: camera five recorded the first

30 m (including the referees' starting shot) and camera six the last 30 m. A common event (foot landing or take-off) in the field of view of two different cameras were employed for the camera synchronization.

An experienced observer manually digitized the hurdlers' foot landing and take-off points from the race footage using Photo 23D software (Technical University of Madrid, Spain) [20]. The official lane marks were employed as control points (six in each camera) for calibration purposes and direct lineal transformation algorithms [21] were used to reconstruct the real coordinates (in meters) from the screen coordinates (in pixels). Thirty points of known spatial coordinates (different from those used for calibration purposes) represented by the official lane marks and uniformly distributed in the field of view were used for error estimation. The root mean square error [22] was less than 0.04 m for the step length (x-axis) and less than 0.02 m for the step width (y-axis) on the six cameras, providing a validity of the measurements similar to those of other previous research on race analysis [23]. The step length and step width were calculated by the difference on the x (longitudinal) or y (transverse) axes, respectively, of the most forward point of the foot on the ground during successive contacts on it.

The definition (Figure 1) proposed by McDonald and Dapena [9] was used for the organization of the temporal and spatial parameters of the five hurdle-unit phases of the 60 m hurdles, which integrated the preparatory step, hurdle step (divided into take-off distance and landing distance), landing step, and recovery step. The calculation of the split times used the same sequence, including the time elapsed from the beginning of the preparatory step to the beginning of the next preparatory step. Alternatively, the split times were also calculated from the landing step to the next landing step as done by the temporal studies [4–7], for comparative purposes.

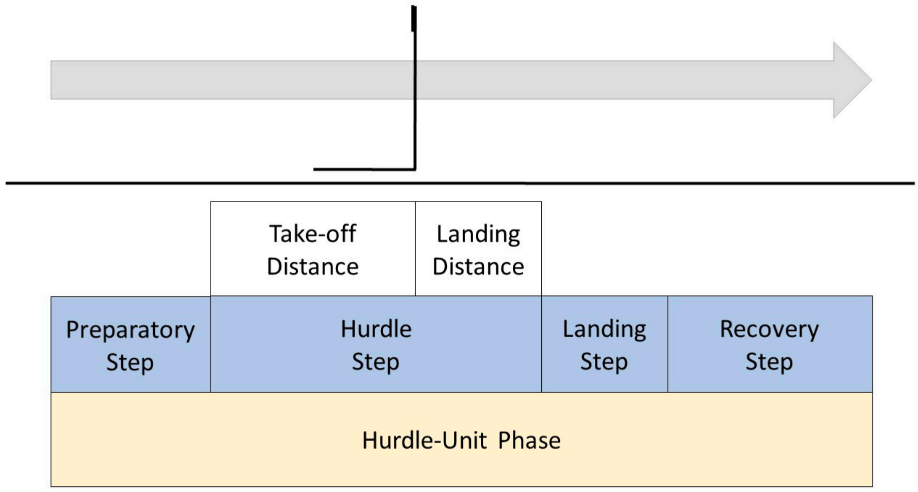

Figure 1. Definitions employed for the hurdle-unit phase analysis according to McDonald and Dapena [9].

2.3. Statistical Analysis

All results are expressed as the mean ± standard deviation (SD). Split times, step times, contact times, flight times, step lengths, and step width of the athletes were compared with a repeated measures analysis of variance according to the hurdle-unit phase (first, second, third, fourth, and fifth hurdle, and mean of the five hurdles) for both genders of athletes (male or female). Planned repeated contrast tests between successive laps were carried out. Post hoc tests were used to determine statistical effects ($p < 0.05$) between factors using Bonferroni corrections and were interpreted using effect sizes (ηp2) with 0.2, 0.5, and 0.8 threshold values for small, medium, and large effects [24]. Cohen d effect sizes between the hurdle-unit phases and mean hurdle-unit phase were calculated to display practical significance. Effect sizes of 0.00 to 0.19, 0.20 to 0.59, 0.60 to 1.19, 1.20 to 1.99, 2.00 to 3.99, and ≥4.00 were interpreted as trivial, small, moderate, large, very large, and nearly perfect, respectively [25]. Pearson correlation coefficients were used to relate all the kinematic race parameters to the hurdle-unit split time or race result, being 0.1, 0.3, 0.5, 0.7, and 0.9, the threshold values that represented small, moderate, large, very large, and nearly perfect correlations [25]. Statistical analyses were performed using the IBM Statistical Package for Social Sciences Statistics, version 22.0 (IBM Inc., Armonk, NY, USA).

3. Results

3.1. Split Times

The mean split times on the hurdle-unit phase (men: 1.10 ± 0.06 s; women: 1.09 ± 0.07 s) measured from preparatory to the next preparatory step showed nearly perfect relationships with the split times measured from landing to the next landing step (r = 0.99; $p < 0.001$), and also with the race results (r = 0.99; $p < 0.001$) both for men and women.

Hurdle-unit split times changed along the 60 m hurdles race (men: $F_{3.718} = 3.28$, $p = 0.014$, $\eta p2 = 0.05$, and women: $F_{3.299} = 6.60$, $p = 0.001$, $\eta p2 = 0.12$) with the greatest differences observed in hurdle one for both gender and hurdle five for men (Table 1). Split times in all the hurdles showed very large to nearly perfect correlations with the race results, with correlation coefficients increasing from the first to the fourth hurdle (Table 1).

Table 1. Evolution of the hurdle-unit split times (s) and relationships (r) with the 60 m hurdle race results during the 44th Spanish Indoor and 12th IAAF World Indoor Championships.

	Hurdle 1	Hurdle 2	Hurdle 3	Hurdle 4	Hurdle 5
Split Time					
Men	1.11 ± 0.06 ^{*4}	1.10 ± 0.06	1.10 ± 0.08	1.09 ± 0.07	1.11 ± 0.07 ^{*4}
Women	1.10 ± 0.06 $^{*34\#5}$	1.09 ± 0.07	1.09 ± 0.08	1.08 ± 0.09	1.08 ± 0.07
Correlation					
Men	0.906 $^{\#}$	0.914 $^{\#}$	0.927 $^{\#}$	0.955 $^{\#}$	0.874 $^{\#}$
Women	0.942 $^{\#}$	0.970 $^{\#}$	0.975 $^{\#}$	0.980 $^{\#}$	0.944 $^{\#}$

Inter-hurdle-unit phase differences and correlations: * $p < 0.05$, # $p < 0.001$. Superscripts numbers indicate the hurdle-unit (1–5) where differences exist.

3.2. Kinematic Differences between Hurdles

In the preparatory step, women showed differences between hurdles in the step ($F_{3.50} = 4.15$, $p = 0.005$, $\eta p2 = 0.08$), contact ($F_{3.77} = 3.23$, $p = 0.015$, $\eta p2 = 0.06$), and flight times ($F_{3.74} = 10.84$, $p = 0.001$, $\eta p2 = 0.18$), whereas men (Table 2) only experienced differences in the flight time ($F_{3.95} = 2.92$, $p = 0.023$, $\eta p2 = 0.05$). Women (Table 3) showed the shortest preparatory step, contact, and flight times on the first hurdle. In the hurdle step, changes were observed through the race in the step (men: $F_{3.53} = 6.35$, $p = 0.001$, $\eta p2 = 0.10$; women: $F_{3.37} = 5.26$, $p = 0.001$, $\eta p2 = 0.10$) and flight (men: $F_{3.33} = 5.92$, $p = 0.001$, $\eta p2 = 0.09$; women: $F_{3.69} = 3.19$, $p = 0.017$, $\eta p2 = 0.06$) times, with the greatest values observed in the first hurdle both for men (Table 2) and women (Table 3). In the landing step, men (Table 2) showed differences along the race in the step ($F_{4.00} = 4.35$, $p = 0.002$, $\eta 2 = 0.07$) and contact times ($F_{3.96} = 3.04$, $p = 0.018$, $\eta p2 = 0.05$), while, in the recovery step, changes were observed for women (Table 3) in step time ($F_{3.69} = 6.20$, $p = 0.001$, $\eta p2 = 0.11$), with maximum step times accounting in the first hurdle.

When compared to the mean race values, the greatest differences for women were observed in the first hurdle for contact (moderate effect, Figure 2D) and flight times (large effect, Figure 2F) of the preparatory step, and in the third hurdle for preparatory flight time (moderate effect, Figure 2F). However, the differences regarding the mean race values for men hurdlers did not show a moderate effect size for the step, contact, and flight times (Figure 2A–C,E).

Step length also changed through the 60 m hurdle race in every step of the hurdle-unit phase, except for the landing step in the women's race. The greatest changes were observed in the landing distance during the men's race ($F_{3.82} = 27.91$, $p = 0.001$, $\eta p2 = 0.33$) and in the take-off distance of the women's race ($F_{3.74} = 62.29$, $p = 0.001$, $\eta p2 = 0.56$). Step width also displayed meaningful differences according to the hurdle order, specifically in the hurdle step for men ($F_{2.99} = 11.97$, $p = 0.001$, $\eta p2 = 0.17$) and women ($F_{3.04} = 11.64$, $p = 0.001$, $\eta p2 = 0.19$).

Table 2. Evolution of the spatial-temporal variables of men hurdlers participating in the 44th Spanish Indoor and 12th IAAF World Indoor Championships.

		Hurdle 1	**Hurdle 2**	**Hurdle 3**	**Hurdle 4**	**Hurdle 5**
Step Time	Preparatory step	0.20 ± 0.00	0.20 ± 0.00	0.20 ± 0.00	0.20 ± 0.00	0.20 ± 0.00
	Hurdle Step	0.51 ± 0.01	0.50 ± 0.01	0.50 ± 0.01	0.49 ± 0.01 $^{\#125}$	0.50 ± 0.01
	Landing Step	0.16 ± 0.00	0.15 ± 0.00	0.15 ± 0.00	0.16 ± 0.00 $^{¥2\#3}$	0.16 ± 0.00
	Recovery Step	0.25 ± 0.00	0.25 ± 0.00	0.24 ± 0.00	0.24 ± 0.00	0.25 ± 0.00
Contact Time	Preparatory step	0.11 ± 0.00	0.11 ± 0.00	0.11 ± 0.00	0.11 ± 0.00	0.11 ± 0.00
	Hurdle Step	0.12 ± 0.00	0.12 ± 0.00	0.12 ± 0.00	0.12 ± 0.00	0.12 ± 0.00
	Landing Step	0.09 ± 0.00 $^{¥3}$	0.08 ± 0.00	0.08 ± 0.00	0.09 ± 0.00	0.09 ± 0.00
	Recovery Step	0.12 ± 0.00	0.12 ± 0.00	0.12 ± 0.00	0.12 ± 0.00	0.12 ± 0.00
Flight Time	Preparatory step	0.09 ± 0.00	0.09 ± 0.00	0.09 ± 0.00	0.09 ± 0.00	0.09 ± 0.00
	Hurdle Step	0.39 ± 0.01 $^{\#4}$	0.38 ± 0.00	0.38 ± 0.01	0.37 ± 0.01	0.38 ± 0.01 $^{¥3}$
	Landing Step	0.07 ± 0.00	0.07 ± 0.00	0.07 ± 0.00	0.08 ± 0.00	0.07 ± 0.00
	Recovery Step	0.12 ± 0.00	0.13 ± 0.00	0.12 ± 0.00	0.12 ± 0.00	0.12 ± 0.00
Step Length	Preparatory step	1.82 ± 0.01$^{*24\#3}$	1.88 ± 0.02	1.91 ± 0.02	1.87 ± 0.02	1.86 ± 0.01 $^{¥3}$
	Hurdle Step	3.76 ± 0.03	3.73 ± 0.02	3.89 ± 0.03 $^{\#1245}$	3.71 ± 0.02	3.72 ± 0.02
	Take-off distance	2.01 ± 0.02 $^{*4\#235}$	2.11 ± 0.02	2.14 ± 0.02	2.08 ± 0.02 $^{¥35}$	2.12 ± 0.02
	Landing distance	1.74 ± 0.03 $^{\#245}$	1.62 ± 0.03	1.75 ± 0.03 $^{\#245}$	1.63 ± 0.03	1.60 ± 0.02
	Landing Step	1.42 ± 0.02 $^{¥5\#4}$	1.46 ± 0.02	1.45 ± 0.02 ^{*4}	1.50 ± 0.02	1.48 ± 0.02
	Recovery Step	1.98 ± 0.01^{*4}	2.01 ± 0.02	1.98 ± 0.01 ^{*4}	2.03 ± 0.01	2.02 ± 0.02
Step Width	Preparatory step	0.13 ± 0.01	0.14 ± 0.01	0.15 ± 0.01 ^{*4}	0.12 ± 0.01	0.13 ± 0.01
	Hurdle Step	0.16 ± 0.01 $^{¥23\#45}$	0.09 ± 0.01	0.10 ± 0.01	0.08 ± 0.01	0.08 ± 0.01
	Landing Step	0.13 ± 0.01	0.12 ± 0.01	0.12 ± 0.01	0.12 ± 0.01	0.16 ± 0.01 $^{*1¥2\#34}$
	Recovery Step	0.21 ± 0.01	0.24 ± 0.01	0.23 ± 0.01	0.24 ± 0.01	0.29 ± 0.01 $^{*2¥34\#1}$

Inter-hurdle difference: $^{*}\ p < 0.05$; $^{¥}\ p < 0.01$; $^{\#}\ p < 0.001$. Superscripts numbers indicate the hurdle-unit (1–5) where differences exist.

Table 3. Evolution of the spatial-temporal variables of women hurdlers participating in the 44th Spanish Indoor and 12th IAAF World Indoor Championships.

		Hurdle 1	**Hurdle 2**	**Hurdle 3**	**Hurdle 4**	**Hurdle 5**
Step Time	Preparatory step	0.20 ± 0.00 $^{¥3}$	0.21 ± 0.00	0.21 ± 0.00	0.21 ± 0.00	0.21 ± 0.00
	Hurdle Step	0.46 ± 0.01	0.46 ± 0.01	0.45 ± 0.01 ^{*12}	0.45 ± 0.01	0.45 ± 0.01
	Landing Step	0.18 ± 0.00	0.17 ± 0.00	0.17 ± 0.00	0.17 ± 0.00	0.17 ± 0.00
	Recovery Step	0.26 ± 0.00 $^{*2\#5}$	0.25 ± 0.00	0.25 ± 0.00	0.25 ± 0.00	0.25 ± 0.00
Contact Time	Preparatory step	0.11 ± 0.00 $^{*4¥5}$	0.11 ± 0.00	0.11 ± 0.00	0.11 ± 0.00	0.11 ± 0.00
	Hurdle Step	0.11 ± 0.00	0.11 ± 0.00	0.11 ± 0.00	0.11 ± 0.00	0.11 ± 0.00
	Landing Step	0.09 ± 0.00	0.09 ± 0.00	0.09 ± 0.00	0.09 ± 0.00	0.09 ± 0.00
	Recovery Step	0.12 ± 0.00	0.11 ± 0.00	0.11 ± 0.00	0.12 ± 0.00	0.11 ± 0.00
Flight Time	Preparatory step	0.09 ± 0.00 $^{\#2345}$	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00	0.10 ± 0.00
	Hurdle Step	0.35 ± 0.01	0.34 ± 0.01	0.34 ± 0.01	0.34 ± 0.01	0.34 ± 0.01
	Landing Step	0.09 ± 0.00	0.09 ± 0.00	0.09 ± 0.00	0.09 ± 0.00	0.09 ± 0.00
	Recovery Step	0.14 ± 0.00	0.14 ± 0.00	0.14 ± 0.00	0.14 ± 0.00	0.13 ± 0.00

Table 3. *Cont.*

		Hurdle 1	Hurdle 2	Hurdle 3	Hurdle 4	Hurdle 5
Step Length	Preparatory step	$1.63 \pm 0.01^{\#2345}$	1.76 ± 0.02	1.78 ± 0.01	1.79 ± 0.01	1.79 ± 0.01
	Hurdle Step	3.18 ± 0.03	3.21 ± 0.02	$3.33 \pm 0.02^{\#1245}$	3.20 ± 0.02	3.22 ± 0.02
	Take-off distance	$1.79 \pm 0.02^{\#2345}$	1.93 ± 0.02	$2.01 \pm 0.02^{\#24}$	1.93 ± 0.02	1.97 ± 0.02
	Landing distance	$1.40 \pm 0.03^{¥3\#245}$	1.28 ± 0.03	$1.32 \pm 0.03^{\#5}$	1.27 ± 0.03	1.25 ± 0.03
	Landing Step	1.48 ± 0.02	1.45 ± 0.02	1.50 ± 0.01	1.49 ± 0.01	1.50 ± 0.02
	Recovery Step	$1.93 \pm 0.01^{¥4}$	1.98 ± 0.01	1.95 ± 0.01	1.98 ± 0.01	$1.91 \pm 0.01^{*2¥4}$
Step Width	Preparatory step	0.10 ± 0.01	0.10 ± 0.01	0.09 ± 0.01	0.10 ± 0.01	0.09 ± 0.01
	Hurdle Step	$0.13 \pm 0.01^{¥5\#234}$	0.07 ± 0.01	0.06 ± 0.01	0.06 ± 0.01	0.07 ± 0.01
	Landing Step	0.12 ± 0.01	0.10 ± 0.01	0.11 ± 0.01	0.11 ± 0.01	0.13 ± 0.01
	Recovery Step	0.20 ± 0.01	0.19 ± 0.01	0.20 ± 0.01	0.20 ± 0.01	$0.23 \pm 0.01^{*2}$

Inter-hurdle difference: * $p < 0.05$; ¥ $p < 0.01$; # $p < 0.001$. Superscripts numbers indicate the hurdle-unit (1–5) where differences exist.

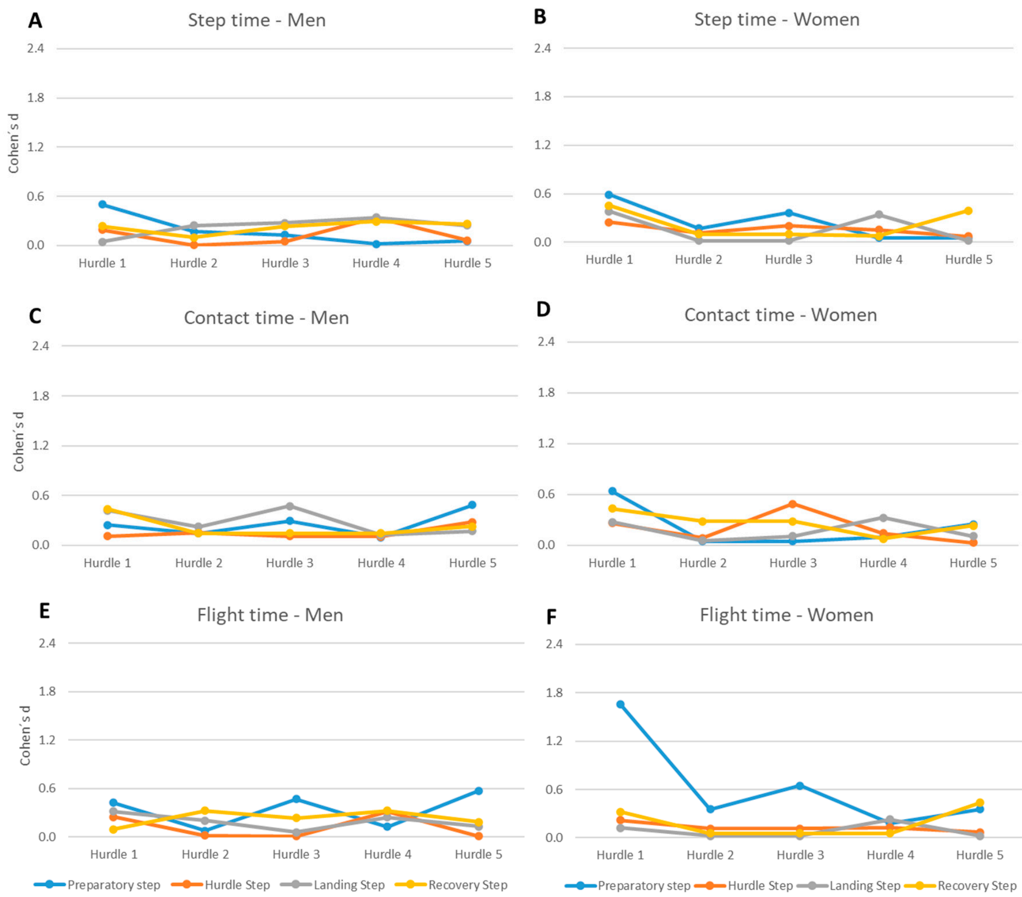

Figure 2. Magnitude of differences (Cohen's d) for the temporal parameters ((**A**,**B**) step time; (**C**,**D**) contact time; and (**E**,**F**) flight time) in relation to mean race values for men and women. An effect size greater than 0.6 or 1.2 was considered as moderate or large, respectively, by Hopkins et al. [25].

The differences in the spatial parameters with respect to the mean race values showing moderate, large, or very large effect sizes on step length in every step, except for the landing step, both for men and women. Moreover, the greatest values were achieved in the first and third hurdle (Figure 3A,B). The step width also showed moderate (men's recovery step), large (men's hurdle step), or very large (women's hurdle step) differences at the first hurdle (Figure 3C,D).

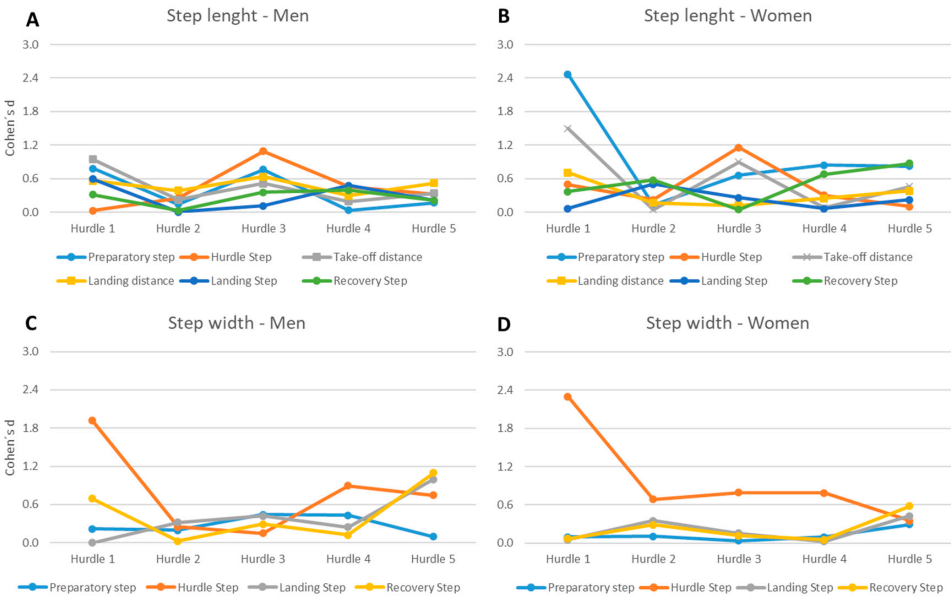

Figure 3. Magnitude of differences (Cohen's d) for the spatial parameters ((**A**,**B**) step length; (**C**,**D**) step width) in relation to mean race values for men and women. An effect size greater than 0.6 or 1.2 was considered as moderate or large, respectively, by Hopkins et al. [25].

3.3. Correlations of Kinematic Parameters with Hurdle-Unit Times

Step and flight times during the hurdle step showed very large relationships with the split times both for men (Figure 4A–E) and women (Figure 4B,F). Additionally, the step time during the recovery step showed a very large correlation with the split times for women (Figure 4B).

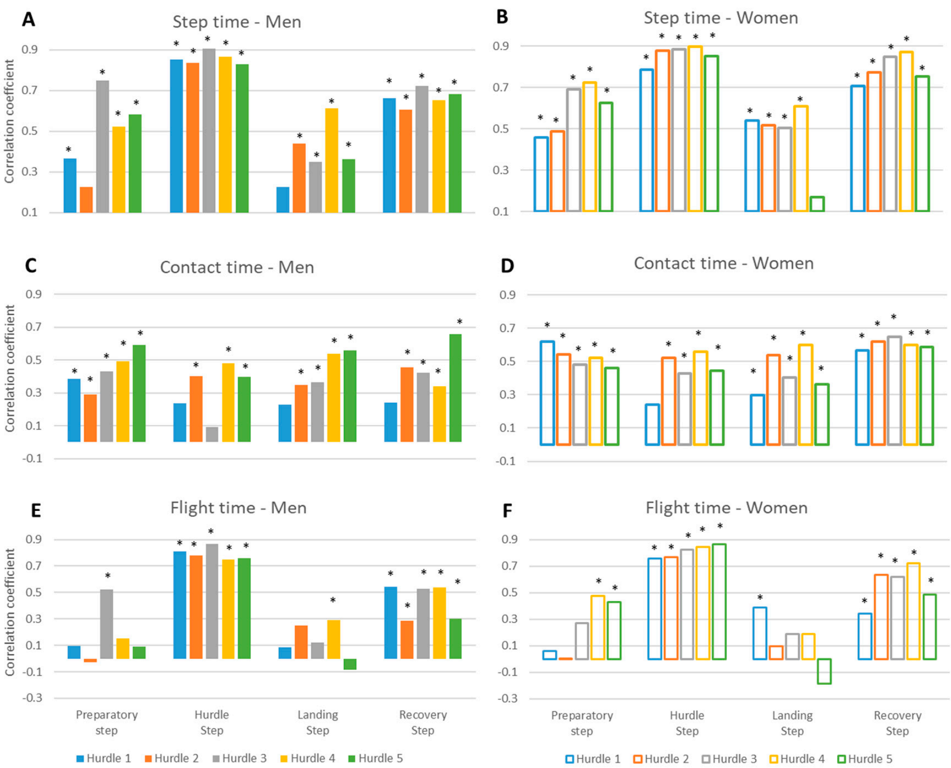

Figure 4. Pearson's correlation coefficient (r) between temporal parameters ((**A**,**B**) step time; (**C**,**D**) contact time; and (**E**,**F**) flight time) and the hurdle-unit splits times during the 44th Spanish Indoor and 12th IAAF World Indoor Championships. Correlations: * $p < 0.05$.

Every landing distance showed moderate to large (first and third hurdle) relationships with their respective split times in the men's race, while take-off distance showed moderate to large (fourth hurdle) correlations from the third to the fifth hurdle (Figure 5A). In the case of women athletes, the highest correlations were observed in the landing and recovery step of the last hurdle (moderate). The hurdle step width of men (Figure 5C) and women (Figure 5D) hurdlers showed moderate relationships with their respective split times in the first hurdle.

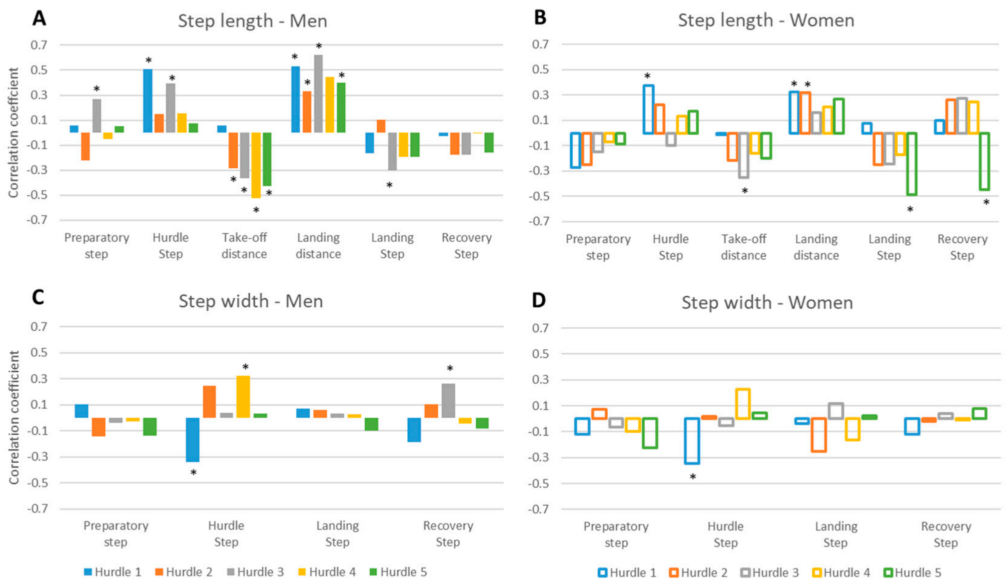

Figure 5. Pearson's correlation coefficient (r) between spatial parameters ((**A**,**B**) step length; and (**C**,**D**) step width) and the hurdle-unit split times during the 44th Spanish Indoor and 12th IAAF World Indoor Championships. Correlations: * $p < 0.05$.

4. Discussion

The present research examined the evolution of the kinematic parameters during the 60 m hurdle races of the 44th Spanish Indoor and 12th IAAF World Indoor Championships. Previous studies have focused on an isolated hurdle-unit analysis during the race, which could presumably have left a big knowledge-gap for coaches and athletes. The results of the present study indicate that each of the hurdle-units of the race presents a high correlation with the race result. Nevertheless, there were differences on some of the temporal and spatial parameters of the hurdle-unit subphases (especially the first and last ones).

4.1. Split Times

For the split times, the present research organized the hurdle-unit subphases from the preparatory to the recovery steps [9]. This hurdle-unit division allowed the inclusion of all performance criteria of the hurdle event in a more rational way following a deterministic model [17]. Split times calculated in the current investigation showed greater correlations with race results than values reported in previous studies [7,26], although, in all the cases, correlations were very large. Interestingly, correlation values increased from the first to the fourth hurdle in line with Tsionakos [6] in the 100/110 m event, whereas the values decreased in the fifth interval of the men's races. This may be due to the shorter distance between the last hurdle and the finish line, which could cause technical modifications (i.e., advance the trunk) in the last hurdle-unit phase to prepare for the run-in phase [27] or by the fatigue created by the greater relative height of the hurdles in men races [8,9,28].

Mean split times were slightly greater than the values of the finalists of international competitions [4–7,29–32], probably because of a greater sample size in the present research as it included both international and national standard level athletes. For both genders, there was a tendency in the first hurdle-unit to be the slowest of the race in line with previous studies [6]. However, in the case of men, the fifth (last) hurdle-unit was slower than the previous ones. This gender-dependent evolution in the split times coincides with that observed by Panoutsakopoulos et al. [7] and Kuitunen and Poon [26] and could be explained by the highest hurdle height of men. According to McDonald and Dapena [9], Salo et al. [11], and González-Frutos et al. [8], this height difference would represent a greater effort for men and would cause a loss of speed from the fourth hurdle on, whereas women can fasten up to the last hurdle.

4.2. Kinematic Differences between Hurdles

The first hurdle presented most of the kinematic differences throughout the race, even though the pattern was different from men to women. Male athletes presented a greater flight time in the hurdle step and a greater contact time on the landing step of the first hurdle, whereas female athletes presented a shorter step, contact, and flight times on the preparatory step. These differences could be explained by the relative differences in height and distance between hurdles in men and women hurdlers [9,28]. Indeed, the greater height of the hurdle in the male event could hinder the adjustments to the first hurdle with a possible greater take-off angle to avoid falling and its subsequent landing from a greater height [8,9,11]. For both genders, the take-off distance was the shortest and the step width was the greatest in the first hurdle step, which could be related to the need to avoid contact with the lead leg [29,30] by means of a lateral displacement. This could represent an important finding of the present research, as previous studies [9–12,15] have only focused on the study from the second to the fifth hurdle without providing information about the step width.

For the remaining hurdles, the longest take-off distance was observed in the third hurdle, which seems to be one of the most important performance indicators [8,9,11,15]. In the last (fifth) hurdle, male athletes increased their landing and recovery step length while female athletes presented a shorter recovery step length. These spatial differences in the last hurdle are in line with the temporal modifications mentioned above and suggest that gender differences, due to different distance and number of steps to the finish line, should be acknowledged by coaches when addressing this hurdle unit. Since previous studies have analyzed the second [10], third [11], fourth [9,12,15], or fifth hurdle [9,12] in isolation, our data clearly show that kinematics differences exist between hurdle units in a single race.

4.3. Correlations of Kinematic Parameters with Hurdle-Unit Times

The very large correlations of the step and flight times during the hurdle step with the hurdle-unit performance were in line with the very large correlations of these parameters with the race result [8]. These data reinforce the idea that shorter hurdle clearance times favor the maintenance of the horizontal velocity of the athletes [11]. Previous studies have not reported such large correlations [6] or have only observed high correlations in the men's race [26] or in some specific hurdle-units [7]. The differences with the current study might be due to a wider sample of athletes who were examined during the present research. For the female hurdlers, and as a difference to their male counterparts, very large correlations were observed between the recovery step and the split times. It is probable that the lower parabola observed for women [9] in the hurdle step, required the lengthening of the three inter-hurdle steps and highlighted the role of the recovery step. These gender differences somehow support the idea proposed by Mann [28] of increasing the distance between hurdles in the men's races and the hurdle height in the women's races. In the case of women, this would increase the importance of the technical ability [33], contributing to an upgrading of this event [34].

Regarding spatial variables, the correlations found between the take-off and landing distances with the split times of male hurdlers support the influence of the hurdle height on kinematics [8,9,11,34]. The fastest male hurdlers showed a clear ability to produce a longer take-off but shorter landing distances throughout the race. Furthermore, landing distances obtained greater correlations with the split times on the first half of the race, while take-off distances showed greater correlations with the split times in the second half of the race. Therefore, it could be understood that the lack of technical control in the landing distance during the first part of the race leads to fatigue in the second part, which might have a technical impact translating into a shorter take-off distance. Women hurdlers, on the other hand, presented the largest correlations between the split times in the landing and recovery step of the last hurdle. That is, a longer length of the landing and recovery after the last hurdle was related to a better split indicating the importance of the sprint ability [35]. Interestingly, for both genders, a greater step width over the first hurdle was related to a better split time. This had not been previously measured in competition, even though other studies focused on the approach run phase [36–38] and provides clear information on how the best hurdlers perform at the beginning of the race and negotiate the short take-off distance to the first hurdle.

4.4. Practical Applications and Research Limitations

According to the present results, coaches and practitioners should consider the key role of the first hurdle-unit and its technical demands with a greater step width and changes on the flight-contact times depending on gender. Also, the technical evolution throughout the race should be considered by maximizing the take-off distances at the beginning and minimizing the landing distances as the race progresses. Split times both in a training and competition setup should be recorded comprising the entire hurdle-unit structure (from preparatory to recovery steps).

Future research on the 60 m hurdle events could also consider the effect of contacting the hurdle during the flight phase on the kinematic parameters [39] or the differences in the race evolution according to the athletes' competitive level. Also, studies employing data recordings with a greater temporal resolution would be advisable to increase the uncertainty related to contact and flight times.

5. Conclusions

The results of this study provide solid evidence on the kinematic differences that competitive hurdlers present through the race. Split times improve from the first hurdle onwards and present gender-specific differences on the last (fifth) hurdle. In the first hurdle, men tend to increase their flight and contact times and women tend to decrease their contact and flight times. Also, both genders present shorter take-off distance, shorter landing distance, and greater step width than in the remainder of the race.

Faster split times were related to shorter step and flight times of the five hurdle steps for both genders. However, greater take-off distances for men in the first half of the race and shorter landing distances in the second half were related to faster performers. For women, longer recovery steps on the last hurdle were related to faster performers. The hurdle-unit split times from the preparatory to the recovery step present a more rational race division (according to a deterministic model) and can be compared with the split times of temporal studies.

From all of the above, coaches and athletes should implement their training programs considering the differences between men and women, to have an impact on the key variables according to the specific demands of each hurdle-unit phase.

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