Baltic Journal of Health and Physical Activity

Volume 16 | Issue 1 Article 4

2024

The impact of physique on strategy and performance in the 400 m hurdles race among elite male athletes

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Recommended Citation

Iskra J, Gupta S, Przednowek K, Best RV, Stanula A. The impact of physique on strategy and performance in the 400 m hurdles race among elite male athletes. Balt J Health Phys Act. 2024;16(1):Article4. https://doi.org/10.29359/BJHPA.16.1.04

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Abstract

Introduction: the objective of this study was to assess the impact of physique on the stride pattern and performance of elite male 400-m hurdles runners. Materials and Methods: this study is based on the analysis of the performance of 297 male 400-m hurdlers in 13 Olympic games, 16 world championships, and 15 European championships. The hurdlers were divided into 4 groups, based on their height and body mass index (BMI) – taller and heavier (TH), taller and lighter (TL), shorter and heavier (SH), and shorter and lighter (SL). Times taken to complete various phases of the 400-m hurdles race – H0-1 (from starting line to hurdle 1), H1-3 (from hurdle 1 to hurdle 3), H3-5, H6-8, H8-10, and H10-F (from hurdle 10 to the finishing line) – were noted. Similarly, the number of strides to complete 3 inter-hurdle phases (H1-4, H4-7, and H7-10) was recorded. Results: The technical index (TI = time for 400m hurdles run – time for 400m flat run) was the lowest in TH, followed by TL, SL, and SH. The stride number increased from H1-4 to H7-10. Taller hurdlers took fewer strides than shorter ones. Only 8.5% of the hurdlers followed a uniform stride number (13 or 15). Conclusions: the physique of elite 400-m men hurdlers can vary widely. Taller hurdlers fly over hurdles more efficiently; a uniform stride pattern is independent of height and BMI, and is followed by a few hurdlers only, and physique has a significant impact on running performance at a few phases of the 400-m hurdles run.

Keywords

stride pattern, stride number, technical index, inter-hurdle phase, mixed stride

Baltic Journal of Health and Physical Activity
e-ISSN 2080-9999

Article

The impact of physique on strategy and performance in the 400 m hurdles race among elite male athletes

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Academic Editor: Agnieszka Maciejewska-Skrendo

Received: July 2023
Accepted: February 2024
Published: March 2024

1. Introduction

The 400-m hurdles race is one of the most demanding track events where performance depends on motor conditioning, speed, and the technique of overcoming the hurdles at a regular interval [1–4]. In the 400-m men's hurdles race, there are 10 hurdles, each 91 cm high and placed 35-m apart. Success in the 400-m hurdles demands an ideal physique and appropriate technical training besides other physiological factors [2, 5–7]. Time required by elite hurdlers to complete the 400-m hurdles race ranges between 46 s and 50 s and depends on an ideal combination of both anaerobic and aerobic energy systems. Compared to the 400-m (flat) run, the aerobic contribution is greater during the 400-m hurdles run [8]. Elite hurdlers commonly use 13 to 15 steps to complete the 35-m distance between two hurdles. However, in the later part of the race, fatigue forces gradual reduction of speed and increases step frequency in many, including elite hurdlers.

The 400-m hurdles strategy is based on two basic elements: the temporal one ("split times") and the spatial one ("step pattern") [9–11]. In the history of the 400-m hurdles, athletes with a wide range of physiques have been very successful. The first 400-m hurdles Olympic medalists in 1900 were relatively shorter (Tewskbury 170 cm, Tauzin and Orton 169 cm each). Successful hurdlers in the next Olympics showed a wide range of body height and mass, 173–196 cm, and 70–85 kg, respectively [12–14]. The effects of hurdlers' height and mass on 400-m hurdles performance have not been clearly established up to this point. Studies related to the impact of the hurdlers' physique on their 400-m hurdles performance do not unanimously conclude any significant findings that are important from the training and strategy point of view [15, 16]. However, it is widely accepted that physique is an important component in determining 400-m hurdles race strategy and success [6, 13, 17–19]. An important component of 400-m hurdles race strategy is the "step pattern", which not only determines the step frequency and step length but dictates the leading leg flying over the hurdles as well. Unfortunately, despite dependence of 400 m hurdles performance on the hurdlers' BMI and physique, scientific studies describing the hurdles race strategy based on the physique and BMI are lacking. The aim of the study was to assess the influence of body height and body mass index (BMI) of elite male hurdlers on the 400-m hurdles race strategy and performance.

2. Materials and methods

2.1. Procedure

This study is based on an analysis of the performance of 297 male 400-m hurdlers participating at some of the highest levels of competition from 1968 to 2017. Only the final runs at the Olympic Games (13 editions, 1968 to 2016), World Championships (16 editions, 1983 to 2017) and the European Championships (15 editions, 1969 to 2016) were considered. Race times below 50.00 s were included for the final analysis.

The hurdlers mean age, height, body mass, and body mass index (BMI) were 25.96 ± 3.69 years (ranging 19 to 36 years), 185.51 ± 5.85 cm, 76.53 ± 5.71 kg, and 22.23 ± 1.11, respectively. The athletes' BMIs were calculated using their heights and weights from online broadcasts. Average timing of the participants for the 400-m hurdles was 48.65 ± 0.74 s (ranging from 46.78 to 50.00 s), whereas their average timing for the 400-m (flat) run was 45.94 ± 0.84 s. The hurdlers' height and body mass were obtained from "The Association of Track and Field Statisticians" Athletics annual entries [27]. No informed consent was required because all the data was obtained from publicly available internet broadcasts.

This study utilized an observational research design. Hurdlers were divided into 4 groups according to their physique, based on their height and BMI, as follows:

1) taller and heavier hurdlers (TH) (n = 71): height ≥ 185 cm; BMI ≥ 23.09;
2) taller and lighter hurdlers (TL) (n = 84): (height ≥ 185 cm; BMI < 23.09;
3) shorter and heavier hurdlers (SH) (n = 70): height < 185 cm; BMI ≥ 23.09;
4) shorter and lighter hurdlers (SL) (n = 72): height < 185 cm; BMI < 23.09.

The study used the following 4 temporal and spatial variables related to 400-m hurdles and 400-m flat races:

1. 400-m hurdles and 400-m flat run times: 400-m hurdles run time (t400mH), 400-m flat run time (t400m), and technical index (TI = t400mH – t400m) of the athletes were noted;

2. phase timings: times taken to complete various phases of the 400-m hurdles race, based on the inter-hurdle interval, were noted. Six phases were highlighted – $H_{0\text{-}1}$, $H_{1\text{-}3}$, $H_{3\text{-}5}$, $H_{6\text{-}8}$, $H_{8\text{-}10}$, and $H_{10\text{-}F}$. The first phase ($H_{0\text{-}1}$) indicates the distance from the starting line to the 1st hurdle, $H_{1\text{-}3}$ indicates the distance from the 1st hurdle to the 3rd one, and $H_{10\text{-}F}$ represents the distance from the 10th hurdle to the finishing line. All these data were obtained from other studies [3, 20–25];

3. phase step number – this is the number of steps to complete 3 phases of the hurdles race: $H_{1\text{-}4}$ (i.e., hurdle 1 to hurdle 4), $H_{4\text{-}7}$ (hurdle 4 to hurdle 7), and $H_{7\text{-}10}$ (hurdle 7 to hurdle

10). The percentage share of even and odd step numbers per "hurdle unit" are also presented (= 9 distances between the hurdles). Step number is important in the planning and implementation of the hurdles race [10, 19, 22];

4. inter-hurdle step number– this shows the number of steps taken between two consecutive hurdles (e.g., between H_1 and H_2, H_2 and H_3, H_9 and H_{10}).

2.2. Statistical analysis

Microsoft Excel 365 was used for data entry and processing. The normality of the distribution was confirmed by the Shapiro-Wilk test, and the homogeneity of variance by the Levene test. In order to compare individual groups of hurdles (TH, TL, SH, and SL), one-way analysis of variance (ANOVA) was used, and when the F test reached the assumed significance level, at a later stage of the analysis, Tukey's honestly significant difference (HSD) post-hoc tests were used to identify differences between individual pairs of hurdler groups. Statistical significance was set at $p < 0.05$. All statistical analyses were conducted using Statistica 13.3 (TIBCO Software Inc., Palo Alto, CA, USA).

3. Results

The hurdlers' physique, based on their height and BMI, as well as their performance in 400-m hurdles and 400-m (flat) runs are presented in Table 1. The SH were the best performers in the 400-m hurdles race, followed by TH, TL, and SL, although the difference was significant only between TL and SH ($p < 0.05$) and SH and SL ($p < 0.01$). TH had the best (least) TI, followed by TL, SL, and SH. However, significant differences ($p < 0.01$) were found only between TH and SH and between TL and SH. In most of the instances, the BMI significantly varied ($p < 0.001$) between the groups.

Table 1. The athletes' physical characteristics and their performance in 400-m hurdles and 400-m flat runs.

Variable	Group of hurdlers				All Hurdlers (n = 297)	ANOVA	Post-hoc comparison
	TH (n = 71)	TL (n = 84)	SH (n = 70)	SL (n = 72)			
Body height (cm)	190.2 ± 3.65	189.5 ± 3.08	180.7 ± 4.13	181.0 ± 4.19	185.5 ± 5.85	F = 140.10 $p < 0.001$	TH-SH*** TH-SL*** TL-SH*** TL-SL***
Body mass (kg)	83.6 ± 3.36	76.1 ± 2.67	75.7 ± 4.24	70.9 ± 4.01	76.5 ± 5.71	F = 150.53 $p < 0.001$	TH-TL*** TH-SH*** TH-SL*** TL-SL*** SH-SL***
Body mass index	23.1 ± 0.60	21.2 ± 0.78	23.2 ± 0.67	21.6 ± 0.62	22.2±1.11	F = 165.24 $p < 0.001$	TH-TL*** TH-SL*** TL-SH*** TL-SL*** SH-SL***
t400mH (s)	48.62 ± 0.68	48.72 ± 0.78	48.43 ± 0.72	48.84 ± 0.71	48.65 ± 0.74	F = 4.12 $p = 0.007$	TL-SH* SH-SL**
t400m (s)	46.01 ± 1.06	45.98 ± 0.85	45.57 ± 0.62	46.21 ± 0.63	45.94 ± 0.84	F = 7.63 $p < 0.001$	TH-SH* TL-SH** SH-SL***
TI	1.97 ± 0.95	2.03 ± 0.73	2.29 ± 0.50	2.09 ± 0.45	2.09 ± 0.70	F = 2.85 $p = 0.038$	TH-SH** TL-SH**

Note: TH – taller and heavier; TL – taller and lighter; SH – shorter and heavier; SL – shorter and lighter; $*p \le 0.05$; $**p \le 0.01$; $***p \le 0.001$.

Table 2 shows the time taken by the hurdlers to run various phases of the 400-m hurdles. Time taken by all the groups of hurdlers gradually increases from H_{1-3} (known as "the speed zone") to H_{8-10} (called "the endurance zone"). No significant difference

($p < 0.05$) in time between the groups of hurdlers was noted at the initial (H_{0-1}), H_{3-5}, H_{6-8}, and the final (H_{10-F}) phases. H_{8-10} was the only phase where the difference between the 4 groups of hurdlers (TH vs SH, TL vs SH, and SH vs SL) was significant ($p < 0.05$ in all the cases). SL were significantly slower than both TH and SH at the H_{1-3} phase. Times taken by the hurdlers to run the 4 phases of the 400-m hurdles race (H_{1-3}, H_{3-5}, H_{6-8}, and H_{8-10}) are presented in Figure 1.

Table 2. Time taken by hurdlers to run various phases of the 400-m hurdles race.

Phases of the 400-m hurdles race	Time taken to run various phases of 400-m hurdles race (seconds)					ANOVA	Post-hoc comparison
	TH (n = 71)	TL (n = 84)	SH (n = 70)	SL (n = 72)	All hurdlers (n = 297)		
H_{0-1}	5.99 ± 0.10	5.99 ± 0.12	5.96 ± 0.13	6.04 ± 0.12	6.00 ± 0,13	NS	NS
H_{1-3}	7.52 ± 0.19	7.55 ± 0.20	7.53 ± 0,20	7.62 ± 0,23	7.56 ± 0.21	F = 2.97 $p = 0.032$	TH-SL* SH-SL*
H_{3-5}	7.85 ± 0.16	7.85 ± 0.22	7.83 ± 0.21	7.81 ± 0.16	7.86 ± 0.21	NS	NS
H_{6-8}	8.60 ± 0.19	8.61 ± 0.20	8.55 ± 0.17	8.63 ± 0.18	8.60 ± 0.19	NS	NS
H_{8-10}	9.20 ± 0.26	9.22 ± 0.26	9.07 ± 0.22	9.18 ± 0.22	9.17 ± 0.24	F = 5.09 $p = 0.002$	TH-SH* TL-SH* SH-SL*
H_{10-F}	5.32 ± 0.28	5.36 ± 0.29	5.37 ± 0.28	5.35 ± 0.29	5.35 ± 0.28	NS	NS

Note: NS – not significant; *$p \leq 0.05$.

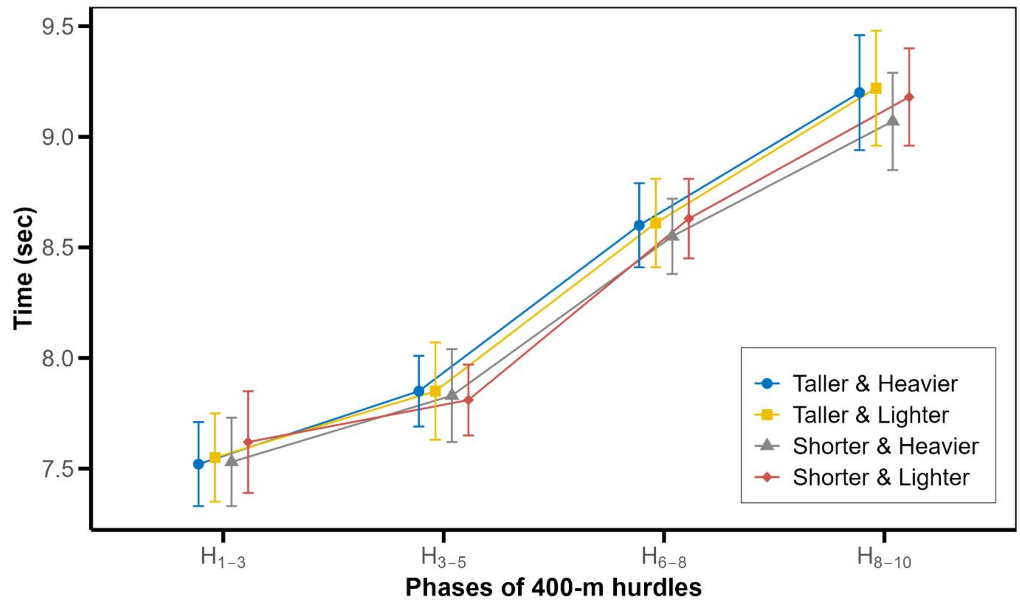

Figure 1. Time required by hurdlers to run the 4 phases (H_{1-3}, H_{3-5}, H_{6-8}, and H_{8-10}) of the 400-m hurdles race.

The number of steps taken by the hurdlers at various stages of the 400-m hurdles race is presented in Table 3. The step number increases from H_{1-4} and attains maximum at H_{7-10} in all the groups. Shorter hurdlers used more steps than taller hurdlers at each corresponding phase of the race ($p < 0.01$ to < 0.001). No difference in the step number was found between TH and TL, and between SH and SL.

Table 3. The number of steps taken by the hurdlers at various stages of the 400-m hurdles race.

Variable	Step number				All hurdlers (n = 297)	ANOVA	Post-hoc comparison
	TH (n = 71)	TL (n = 84)	SH (n = 70)	SL (n = 72)			
Phases of 400-m hurdles							
H_{1-4}	39.13 ± 1.23	39.28 ± 1.29	40.62 ± 2.21	40.43 ± 1.88	39.84 ± 1.84	F = 15.07 *p* < 0.001	TH-SH*** TH-SL*** TL-SH*** TL-SL**
H_{4-7}	39.91 ± 1.46	40.25 ± 1.41	41.70 ± 1.98	41.55 ± 1.64	40.83 ± 1.81	F = 22.35 *p* < 0.001	TH-SH*** TH-SL*** TL-SH*** TL-SL***
H_{7-10}	42.47 ± 1.83	42.71 ± 2.04	44.31 ± 1.24	44.35 ± 1.14	43.43 ± 1.84	F = 28.04 *p* < 0.001	TH-SH*** TH-SL*** TL-SH*** TL-SL***
% of odd and even steps							
%odd	23.63±18.86	28.73 ± 21.87	28.48 ± 21.22	36.93 ± 23.96	29.42 ± 21.96	F = 4.65 *p* = 0.003	TH-SL* TL-SL* SH-SL*
%even	76.37±18.86	71.27 ± 21.87	71.52 ± 21.22	63.07 ± 23.96	70.58 ± 21.96	NS	NS

Note: NS – not significant; **p* ≤ 0.05; ***p* ≤ 0.01; ****p* ≤ 0.001.

Table 4 presents the hurdlers' step pattern. It shows that only 8 TL and 2 TH (or 3.4% of the total) used a uniform (or fixed) step pattern of 13 between 2 consecutive hurdles throughout the race. On the other hand, a uniform step number of 15 was found in only 15 (5.1% of the total) hurdlers, mainly in shorter participants (14 of 15). Many tall hurdlers (68 of 155) preferred to use a 13 + 14 step pattern, whereas many short hurdlers (54 of 142) liked to use a mixed step pattern of 14 + 15 + 16 to complete the race. Some tall hurdlers (13 of 155) chose a 12+13 step pattern, which was not found in short hurdlers at all.

Table 4. The hurdlers' step pattern in the 400-m hurdles race.

Step pattern between hurdles		Number of hurdlers who ran the race with a specific step pattern				
Uniform step	Mixed step	TH (n = 71)	TL (n = 84)	SH (n = 70)	SL (n = 72)	All hurdlers (n = 2 97)
13	—	2 (2.8%)	8 (9.5%)	—	—	10 (3.4%)
15	—	1 (1.4%)	—	9 (12.9%)	5 (6.9%)	15 (5.1%)
—	13 + 14	35 (49.3%)	33 (39.3%)	7 (10.0%)	5 (6.9%)	80 (26.9%)
—	14 + 15	1 (1.4%)	7 (8.3%)	13 (18.6%)	23 (31.9%)	44 (14.8%)
—	13 + 14 + 15	16 (22.5%)	14 (16.7%)	8 (11.4%)	8 (11.1%)	46 (15.5%)
—	14 + 15 + 16	10 (14.1%)	14 (16.7%)	28 (40.0%)	26 (36.1%)	82 (27.6%)
—	13 + 15	—	1 (1.2%)	2 (2.9%)	—	3 (1.0%)
—	14 + 16	—	—	3 (4.3%)	5 (6.9%)	8 (2.7%)
—	12 + 13	6 (8.5%)	7 (8.3%)	—	—	13 (4.4%)
Sum	—	71 (100%)	84 (100%)	70 (100%)	72 (100%)	297 (100%)

4. Discussion

The key findings of this study are that male 400 m hurdle runners having a wide range of body height and physique can compete 400 m hurdles successfully, hurdlers of tall stature can run more smoothly over the hurdles than their shorter counterparts, only a few elite hurdlers make an equal number of steps between hurdles, and total number of steps taken by a hurdler is largely determined his height but not by the BMI. Findings also indicate that only a few phases of the 400 m hurdles run are influenced by the hurdlers' height and BMI.

Anerobic endurance is an important requirement to complete a 400-m hurdles race successfully. The hurdles run is a form of repetitive activity that involves spatio-temporal constraints. The step pattern of elite hurdlers during the hurdles race is very stable [26]. The 400-m hurdles run is certainly a race that demands extensive racing experience as a prerequisite for success. The more times the athletes run hurdles in a competitive environment, the more programmed and effective the step pattern is likely to be, which finally leads to improved performance [1].

The data shows that the physique of successful 400-m men hurdlers considerably varies. Record timings were broken and Olympic medals were won by hurdlers with body heights of 169–198 cm and body mass of 62–90 kg [12, 13, 27]. Most authors agree that physique (body height, in particular) is related to the adopted running strategy [18, 28, 29]. The hurdlers in this study are taller but have similar body mass when compared to early studies [15, 16, 30–32]. Tanner [32: 126] and Hirata [30] investigated the body structure of elite runners, including sprinters and hurdlers. They analyzed the height and mass of the participants in the 1964 Tokyo Olympics and determined the average body height of 183.04 ± 6.7 cm. Khosla [31] analyzed finalist runners from the Munich Olympics (1972) and found body height of 182.5 ± 7.3 cm and body mass of 77.14 ± 7.04 kg. Ivan and Gheorghe [16] reported the body height and body weight of elite 400-m hurdlers as 184.79 ± 5.50 cm and 77.74 ± 5.15 kg, respectively. The analysis over the course of the competition at the World Championships in Daegu (2009) determined the mean body height at 183.04 ± 6.7 cm

[33]. Sedeaud et al. [34] analyzed the body structure of a large group (n = 160) of elite 400-m runners and presented their body weight, height, and BMI as 74 ± 6.38 kg, 182.75 ± 6.24 cm and 22–23 respectively. The study conducted by Kostial, Matousek, and Zahorec [18] showed that the adoption of step frequency largely depends on the length of the limbs (r = -0.80), body height (r = -0.487) and body mass (r = 0.359). In a study conducted by Iskra and Walaszczyk [15], the best hurdlers in Poland were 183.5 ± 4.8 cm in height and with the body mass of 74.4 ± 4.9 kg.

The issue of the 400-m hurdles performance in the context of the technique is often analyzed by trainers and scientists, especially biomechanists [35]. The technical index is one of the basic parameters assessing the level of technical aspects of the hurdles race [4]. A low technical index, around 2 s, in leading 400-m hurdlers, confirms its importance in achieving success in this event [4, 28, 36]. A lower (better) technical index in taller hurdlers indicates their superior skills of “flying over” the hurdles.

Changes in the speed of different 35-m inter-hurdle intervals is one of the most frequently used methods of assessing another important technical parameter of a successful 400-m hurdler [10, 11, 19–22, 25]. Changes in speed result from many factors, e.g., the curvature of the track, and biomechanical and physiological limitations due to fatigue [7–9, 35, 37]. A reduction of speed from the initial phase, or H0-1 (45-m), to the final phase, or H10-F (40 m), is an important characteristic feature of the 400-m hurdles race, although this drop of speed is low in elite hurdlers. The average speed at the first phase (H0-1) decreased from 7.5 m/s to ~7.477 m/s at the last phase (H10-F) of the race. Large involvement of the anaerobic glycolytic system causes a large rise in blood lactate and fatigue [38]. Hurdlers start to feel as if hurdles in the latter part of the run are increasingly higher. This leads to an unavoidable gradual reduction of speed in the latter part of the race. An ideal combination of anaerobic and aerobic training (plus motor conditioning) can reduce fatigue and improve performance. The times taken to run phase H0-1 by all groups of hurdlers were close to one another, and no significant difference existed among the groups. This was al-so true for phases like H3-5, H6-8, and H10-F. However, TH ran significantly faster than SL ($p < 0.05$) at H1-3, and the same is true in the case of SH relative to SL. Similarly, at phase H8-10, the average speed varied ($p < 0.05$) among the groups of hurdlers.

The step number used to cover different phases of the race significantly varies among the groups of hurdlers. Taller hurdlers have longer lower limbs that favor longer and fewer step [15, 39]. Running with 13 steps between hurdles makes it possible to use only one leg as the leading leg. Over 75% of TL use the left leg as the lead leg, and this is important in developing a spatial strategy for the "rhythm" of the steps [1, 4, 6, 19, 24, 28]. However, even most of the taller hurdlers are not comfortable with fewer and longer steps (as in 9 × 13) probably because longer steps are inconvenient and not economical for them [40]. The total number of steps taken by elite hurdlers mainly depends on their height; the BMI within a given range plays no role in it. The step length is self-optimized by runners and has minimal oxygen uptake at the preferred step length. Thus, it is illogical to manipulate the step pattern too much by coaches as this can result in a greater metabolic cost and deteriorate performance [40,41]. Runners can optimize step length for economy when change is required because of fatigue [40].

The efficiency of hurdle clearance is well reflected by the hurdle-clearance step. A higher level of performance is correlated to a shorter clearance step with a greater percentage of the step in front of the hurdle. A consistent pattern of an odd number of steps between all hurdles is one of the prerequisites of performance in the hurdles race. Only an odd number of steps (13, 15, 17, etc.) allows a hurdler to take all hurdles with the same lead leg. An even number of steps between the hurdles, on the other hand, forces hurdlers to alternate their lead-leg for the next hurdle. Yet, this study confirms that an even number of steps is predominant over an odd number of steps in elite hurdlers (Table 3). Probably many top-class 400-m hurdlers are well-trained in swapping their lead-leg without affecting their speed.

Findings of this study indicate that top-class hurdlers mainly follow three step patterns – a) consistent odd number of step (13, 15) between the hurdles; b) single alternate pattern, where the left lead-legged hurdlers transit from 13 to 14 steps; c) double alternate pattern, where the hurdler changes the step frequency twice (13+14+15 and 14+15+16) (Table 4). Elite hurdlers very rarely follow the double countdown (13+15 or 14+16) step pattern, where they avoid changing the lead leg at any cost. Male physique is not the only decisive factor but plays an important role in planning and implementing step patterns in the 400-m hurdles race. A step pattern is largely an inherent property of a runner, including 400-m hurdlers. Physical training, motor conditioning, and experience are likely to have a strong influence on the determination of step pattern and its implementation for a successful 400-m hurdles race.

The track athletes included in this study were highly specialized 400 m hurdlers; therefore, many of them might not have competed frequently in 400 m (flat) event unlike specialized 400 m (flat) runners. Thus, their 400 m flat run performance may not be truly representative, and it may be reasonable to assume that their 400 m flat run performance and TI were underestimated.

The force and power of the lower limb muscles, coupled with the hurdlers' height and BMI, play a significant role in their performance [42]. Factors such as a wide range of physical builds, proficiency in chosen motor skills, hurdles technique, and the spacing between steps during the hurdles race likely play a pivotal role in achieving success in elite 400 m hurdles races. However, this study did not conclusively link the overall performance in the 400m hurdles to the specified height and BMI ranges of top-tier hurdlers.

5. Conclusions

The findings of this study could be beneficial for athletes and coaches in several ways. Within a given range, body height and BMI may not play a key role in planning and implementing step patterns in a 400-m hurdles race. A uniform step pattern is not necessarily required for top-level performance. Shorter hurdlers should focus more on the technical index that helps them jump over the hurdles more easily. We can also conclude that: (1) a wide range of body heights and physiques can allow athletes to compete at the high-est level; (2) taller hurdlers have superior TI that allows them to run over the hurdles more smoothly than their shorter counterparts; (3) a uniform step number (9×13 or 9×15) is followed by only a few (8.4%) elite hurdlers from all the groups. About half (49.8%) of the hurdlers maintain a single alternate step pattern (13+14 or 14+15 or13+15 or 14+16 or 12+13), whereas 42.1% follow a double alternate step pattern (13+14+15 or 14+15+16); (5) body height and BMI of the elite 400-m hurdlers have a significant impact on the running performance only at a few phases (H1-3 and H8-10) of the 400-m hurdles run.

References

1. Lindeman R. 400-meter hurdle theory. Track Coach. 1995 Spring;131:4169–96.
2. McFarlane B. The science of hurdling and speed. 5th ed. Ottawa: Athletics Canada, Minuteman Press; 2004.
3. Iskra J. Athlete typology and training strategy in the 400m hurdles. New Stud Athl. 2012;27(1–2):27–37.
4. Iskra J. Advanced training in the hurdles. Polish Athletic Association, Opole University of Technology; 2013.
5. Ozaki Y, Ueda T, Fukuda T, Inai T, Kido E, Narisako D. Regulation of stride length during the approach run in the 400-m hurdles. J Hum Kinet. 2019 Oct;69:59–67. DOI: 10.2478/hukin-2019-0019
6. McGill S. The art of hurdling: A manual for hurdle coaches. Kindle Edi; 2020.
7. Gupta S, Goswami A, Mukhopodhayay S. Heart rate and blond lactate in 400m flat and 400m hurdles running. A comparative study. Indian J Physiol Pharmacol. 1999;43:361–6.

8. Zouhal H, Jabbour G, Jacob C, Duvigneau D, Botcazou M, Ben Abderrahaman A, Prioux J, Moussa E. Anaerobic and aerobic energy system contribution to 400-m Flat and 400-m hurdles track running. J Strength Cond Res. 2010;24(9):2309–15. DOI: 10.1519/JSC.0b013e3181e31287
9. Iskra J, Coh M. Biomechanical Studies on Running the 400 M Hurdles. Hum Mov. 2011 Jan 1;12(4). DOI: 10.2478/v10038-011-0035-5
10. Guex K. Kinematic analysis of the women's 400m hurdles. New Stud Athl. 2012;29(1–2):41–51.
11. Iskra J, Pietrzak M, Paruzel-Dyja M. The 400 meters hurdles event and the changes in the tactical race strategies in men prior and after the 2000. Česká kinantropologie. 2015;19(3):75–84.
12. Quercetani R. World history of hurdle and steeplechase racing: Men and women. Edit Vallardi, editor. Milan; 2009.
13. Iskra J. Track and field olympic tables. Opole: Politechnika Opolska; 2012.
14. Wallechinsky D, Loucky J. The complete book of the Olympics: 2012 Edition. London: Aurum Press; 2012.
15. Iskra J, Walaszczyk A. Anthropometric characteristics and performance of 110m and 400m male hurdlers. Kinesiology. 2003;35(1):36–47.
16. Ivan P, Gheorghe D. Study On Top Athletes At 400 M Hurdles. In: The European Proceedings of Social & Behavioural Sciences. 2019, 582–8. DOI: 10.15405/epsbs.2019.08.03.69
17. Nie Y, Zhang Z. The relationship between the rhythm of stride pattern and the performance in male 400m hurdles. J Wuhan Inst Phys Educ. 1998;1:34–7.
18. Kostial J, Matousek R, Zahorec J. Limitujuce faktory vykonnosti v behu na 400 m prekazok (In Czech). Teor a Praxe Teles Vych. 1978;4:220–8.
19. Iskra J, Matusiński A, Otsuka M, Guex KJ. Pacing strategy in men's 400 m hurdles accounting for temporal and spatial characteristics of elite athletes. J Hum Kinet; 2021;79:175–86. DOI: 10.2478/hukin-2021-0059
20. Canova R. Distribuzione ritmica della sforzo nei 400 ostacoli. Atlet Leggera. 1979;6:58–62.
21. Glad B, Brüggemann G-P. Time analysis of 400 meters hurdles events. In: Scientific research project at the Games of the XXIVth Olympiad – Seoul 1988 Biomechanical studies of the sprint, hurdle and jumping events. Monaco: International Athletic Foundation; 1990, 132–75.
22. Ditroilo M, Marini M. Analysis of the race distribution for male 400m hurdles at the Sydney Olympics. New Stud Athl. 2001;16(3):15–30.
23. Guo J, Zhang K. Study on relationship between the rhythm and performance of 400m hurdles. J Hubei Sport Sci. 2007;3:285–7.
24. Greene D, Leyshon W, O'Donoghue P. Elite male 400m hurdle tactics are influenced by r... In: O'Donoghue P, Hökelmann A, editors. World Congress of Performance Analysis of Sport VIII. Magdeburg; 2008, 730–6.
25. Graubner R, Nixdorf E. Biomechanical analysis of the discus at the 2009 IAAF World Championships in athletics. New Stud Athl. 2011;26(1/2):19–53. DOI: 10.1097/JSM.0b013e318191c8e7
26. Hay L, Schoebel P. Spatio-temporal invariants in hurdle racing patterns. Hum Mov Sci. 1990 Feb 1;9(1):37–54. DOI: 10.1016/0167-9457(90)90034-B
27. Matthews P. Athletics 2019: The International Track & Field Annual. Sportsbooks; 2019, 592.
28. Boyd R. Some fact about the 400 m hurdles. In: Jarver J, editor. The hurdles: contemporary theory, technique and training. (4th ed.). Tafnews Press; 2004, 115–8.
29. Geller S, Harris L, Sangeetha R. The kinematic and kinetic differences between the first and the final hurdle in a women's 400m hurdle race. South African Athletics Coach; 2012.
30. Hirata KI. Physique and age of Tokyo Olympic champions. J Sports Med Phys Fitness. 1966 Dec;6(4):207–22.
31. Khosla T. Standards on age, height and weight in Olympic running events for men. Br J Sports Med. 1978 Jun;12(2):97–101. DOI: 10.1136/bjsm.12.2.97
32. Tanner J. Physique of the Olympic Athlete. London: George Allen & Unwin, Ltd.; 1964.
33. López JL, García A, Cordente CA, Montoya A, González P, López JL, Amo D, Alberto C, Martínez C, Montoya A, Pablo V, Miguel G, Luis López Del Amo J. Anàlisi de l'elecció de la cama d'atac predominant en la prova de 400 metres tanques dels XIII Campionats del Món d'Atletisme Daegu 2011. Educ Fis i Esports. 2012;4:70–7. DOI: 10.5672/apunts.2014-0983.cat.(2012/4).110.08
34. Sedeaud A, Marc A, Marck A, Dor F, Schipman J, Dorsey M, Haida A, Berthelot G, Toussaint J-F. BMI, a performance parameter for speed improvement. PLoS One. 2014;9(2):e90183. DOI: 10.1371/journal.pone.0090183
35. Mann R, Murphy A. The Mechanics of Sprinting and Hurdling. 2018 Edition. In: Create Space. Create Space Independent Publishing Platform; Amber Murphy's Books; 2018, 338.
36. Hiserman J. The art of long hurdling. Coil Bound; 2012.

37. Schwartz A, Baumann W, Gross V, Vonstein W. Fatigue effects in the 400 m hurdles technique. In: Brüggemenn GP, Rühl JK, editors. Techniques in Athletics. Koln: Deutsche Sporthochschule; 1990, 440–6.
38. Gupta S, Stanula A, Goswami A. Peak blood lactate concentration and its arrival time following different track running events in under-20 male track athletes. Int J Sports Physiol Perform. 2021;16(11):1625–33. DOI: 10.1123/ijspp.2020-0685
39. Uth N. Anthropometric comparison of world-class sprinters and normal populations. J Sports Sci Med. 2005 Dec;4(4):608–16.
40. Hunter I, Lee K, Ward J, Tracy J. Self-optimization of stride length among experienced and inexperienced runners. Int J Exerc Sci. 2017;10(3):446–53.
41. Hunter I, Smith GA. Preferred and optimal stride frequency, stiffness and economy: changes with fatigue during a 1-h high-intensity run. Eur J Appl Physiol. 2007 Aug;100(6):653–61. DOI: 10.1007/s00421-007-0456-1
42. Balsalobre-Fernández C, Tejero-González CM, Del Campo-Vecino J, Alonso-Curiel D. The effects of a maximal power training cycle on the strength, maximum power, vertical jump height and acceleration of high-level 400-meter hurdlers. J Hum Kinet. 2013 Mar;36(1):119–26. DOI: 10.2478/hukin-2013-0012

Author Contributions: Study Design, J.I., K.P. and S.G.; Data Collection, J.I.; Statistical Analysis, K.P. and S.A.; Data Interpretation, J.I., S.G., K.P, R.B., and S.A.; Manuscript Preparation, J.I., S.G., K.P, R.B., and A.S.; Literature Search, J.I., S.G., and A.S.; Funding Acquisition, J.I., S.A. All authors have read and agreed to the published version of the manuscript.

Funding: The research obtained no external funding.

Institutional Review Board Statement: Not applicable

Informed Consent Statement: Not applicable

Data Availability Statement: Data available from the corresponding author on request.

Conflicts of Interest: The authors declare no conflict of interest.