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Section III – Sports Training

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Pacing Strategy in Men's 400 m Hurdles Accounting for Temporal and Spatial Characteristics of Elite Athletes

by

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The final result in a 400 m hurdles race (400mH) is relative to the motor preparation, technique of clearing hurdles as well as the adopted strategy of the race, including temporal aspects (split times in particular parts of the race) and spatial elements (the number of strides taken between subsequent hurdles). The objective of the study was to identify an optimal strategy for the 400mH race, including the stride pattern and split times. Data employed for this study were derived from results of 273 races held during the men's finals of international events (Olympic Games, World and European Championships) held from 1968 to 2015. To determine the strategies in the race, three main hurdle sections were identified – 1-4H, 4-7H and 7-10H. In each part, the fast (best results), average and slow (worst results) performing groups of hurdlers were distinguished. The analysis of adopted strategies was carried out taking into account 26 variables (main, basic, temporal and spatial). Basic statistical data, correlations and analysis of variance (ANOVA) were used. Results highlight the use of a variety of strategies, of which selection depends, among others, on body composition and the level of motor abilities (speed, speed endurance and explosive strength), as well as hurdling technique. Especially, the endurance strategy appears to be the most effective one, as it is a characteristic of best performances of many hurdlers. The analysis demonstrates that at the highest sports level the strategy of 400 m hurdles should be analyzed individually.

***Key words**: 400 m hurdle strategy, typology of hurdlers, athletics, pace.*

Introduction

The 400mH race is one of the toughest track events and is referred to as the man-killer event (Quercetani, 2009). The final result in this hurdling race is determined by motor abilities (speed, strength and endurance) and the technique of clearing hurdles. The specific ability, referred to as *hurdle rhythm*, also plays a significant role and relies on a pacing rhythm that includes a specific number of strides between hurdles (12-16) taking into account time variables (Hiserman, 2011; Iskra, 1991, 2012). The basic skill in the 400mH race is associated with maintaining a minimal loss of speed in the race despite significant fatigue resulting from the glycolytic effort (Goupta et al., 1999; Zouhal et al., 2010). Besides speed and endurance, preparation for the 400mH demands strength training with various resistance exercises (Guex, 2012; Reis et al., 2011). The basic training task for the athlete involves the ability to maintain an adequate step pattern, i.e., the number of strides offering minimal pace losses when subsequent sections are cleared between hurdles. This approach to the selection of abilities in athletics mainly applies to anthropometric

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characteristics, which determine results in the flat 400m race (Iskra and Coh, 2011).

To this date, several analyses of strategies in track races involving distances from 400m to the marathon were performed (Hanley and Hettinga, 2018; Hannon and Thomas, 2011; Renfree et al., 2014). The analysis of this issue was limited to the search for spilt times measured between subsequent race sections and their relevance to the final result. However, temporal characteristics in 400mH are still to be examined. Attempts to explain the 400mH strategy have so far been focused on the pace (split times, touchdown times) and the number of steps (stride pattern). This type of research has been conducted since the 1960s and includes mainly groups of hurdlers taking part in championship events (Behm, 2016; Ditroilo and Marini, 2000; Glad and Brüggemann, 1990).

Therefore, the aim of this study was to identify different types of men's 400mH pacing strategies and to determine the best anthropometric, spatial and temporal characteristics of elite athletes.

Methods

Two hundred seventy-three (273) individual men's 400mH results were considered including the finals of the largest athletics competitions in the period from 1968 to 2015. The following were considered: 12 Olympic finals (1968–2012), 14 world championship finals (1983–2015), 12 European championship finals (1971–2014), as well as Olympic Trials held in 2008. All competitions were held on synthetic tracks and the final results were recorded with electronic timing, with accuracy of 0.01 s. In total, split times from 39 events were subjected to the analysis from a period lasting a total of 48 years. The data included final runs with the participation of eight athletes.

The results of hurdlers who (not seeing any chance of success) gave up at the finish (= the result deviated from the 2SD value) were not considered (the exclusion criterion). Due to the lack of data, in some cases only results of medal winners (i.e., places 1–3) were used in the analysis.

Details of the performance level, body composition and technical preparation of the considered hurdlers are presented in Table 1.

Methods applied in the assessment of spatio-temporal variables

Data used in the spatio-temporal analysis originate from a variety of sources published between 1968 and 2017 (including Behm, 2016; Ditroilo and Marini, 2000; Glad and Brüggemann, 1990; Hommel and Koszewski, 1999; Lopez del Amo et al., 2012; Morita and Igarashi, 1992; Moriorka, 1997).

A significant amount of data was obtained from Behm's compilation work (2016), in which the author summed up a dozen papers published between 1995–2011 in the *Revue de l'Amicale des Entraîneurs Français d'Athlétisme*. Baseline body variables (BH, BW) were obtained from data presented in the annual publications "*The Association of Track and Field Statisticians*" (ATFS) – "*The International Track and Field Annual"* from 1968–2019. The analysis of time variables was made following various methods – some of them were described in by Iskra and Coh (2011). The most commonly used methods for measuring "touchdown times" in the 400mH race at championship events applied motion analysis using video software (including Dartfish Software). The reliability of such data sources was confirmed by Greene et al. (2008) and O'Donoghue (2015). The analysis of the so-called "pacing rhythm" (= stride pattern) was performed using the cinematographic method.

Selection of variables

Selected time variables related to "split times" applied to determine the times of particular parts of the race: run-in, times between particular hurdles, and the time of the final phase of the race. Basic data on spatial variables ("stride pattern") referred to data regarding the same sections of the 400mH race.

The identification of chosen sections in the 400mH distance takes into account its various aspects. For some researchers, the "mathematical and geometric" specificity which includes identification of split times in terms of the first and the second part of the race or four 100 m sections in the race with two straightaways and two curves, proves the most significant source of information. For others, the most important aspects include physiological (variations in speed due to fatigue) and biomechanical aspects (variations in hurdling rhythm taking into account the number of steps and changes in the

lead leg) (Iskra and Coh, 2011). The identification of three parts of the race for the purpose of this analysis was based on previous studies related to the hurdle strategy and physiological (Gupta et al., 1999; Zauhal et al., 2010) as well as training aspects (Iskra 1991, 2012; Hiserman 2011; McFarlane 2004) of 400mH races.

From the scientific and practical point of view, the most rational approach assumes the identification of three equal (105 m) sections of the race between hurdles (1–4, 4–7, 7–10) coupled with individual consideration of the run-in (45 m) and the finish (40 m). This classification provided grounds for the subsequent comparison of the specific sections of the race as well as the use of information derived from empirical analysis in the process of developing hurdle technique (Iskra, 2012). Division of the distance into specific parts is presented in Table 2.

The analysis of the 400mH running strategy involved the ratio of the split times recorded in three identified sections of the whole race - T1–4, %T4–7 and %T7–10, expressed in a percentage scale. Separate areas of analysis were identified in each section of the race, taking into account the strategies applied in the race, including a "fast" – i.e. the characteristic marked by an athlete reaching high running speed in the specific sections of the race ("speed" hurdler), "average" – the ability to maintain moderate running speed ("technique" hurdler) and "slow" – characterized by slow running speed in the specific sections of the distance – "endurance" hurdler (Table 3). An equal number (n = 91) of hurdlers was assigned to the fast, average and slow groups in each section of the race.

The search for factors determining sports success in hurdling can be based on the selection of different variables (Guex, 2012; Iskra and Coh, 2011). In total, 26 variables, divided into main (2), basic (6), temporal (11) and spatial (7) were applied with the purpose of searching for details regarding the types of strategies followed in the 400mH races.

The "stride pattern" (according to previous papers) has been identified as the number of strides, without hurdle clearance. Its characteristics are given in the Appendix.

Statistical analysis

Microsoft Excel 2010 was used for data collection and processing. The statistical analysis (Statistica 2010) was used to calculate the absolute and relative values of the variables (mean, SD, min-max and, occasionally, skewness and kurtosis). The Pearson correlation analysis was applied to establish relationships between variables. The analysis of variance (ANOVA) was employed to compare the three different running strategies (in three parts of the distance). Statistically significant effects were further examined with the post-hoc Tuckey's HSD test. The levels of statistical significance for all analyses were set at $p < 0.05$, $p < 0.01$ and $p < 0.001$.

Results

The results of the correlation analysis are presented in Table 4. The differences between the hurdlers in the three parts of the race are presented in Tables 5-7.

First part of the run (%T1-4)

The results of the analysis of correlation (Table 6) demonstrate a faster initial section of the race in older hurdlers ($p < 0.05$), as well as taller and heavier ones ($p < 0.01$) and technically less advanced (IT – $p < 0.05$); these results correlate significantly with the personal record in the 400 m hurdle race ($p < 0.01$). A faster initial section of the race resulted in a significant decrease of speed at the 7th hurdle (r(T7-10) = 0.50, r (10-F) = 0.51; $p < 0.001$). Running speed losses were significant in its final part (r (T7-10-T1-4) = 0.92; $p < 0.001$). Hurdlers who performed well in terms of the fast initial section of the race (= "speed" hurdlers) applied a 13-step rhythm at the start of the race, and then changed to 15 strides later in the distance. The greatest changes in the stride pattern (N7-10-N1-4) were found in this group. Use of the "speed" strategy lengthened the split time in the section of the final race (from the 7th hurdle) (Table 5).

Second part of the run (%T4-7)

Body composition and the stride pattern did not distinguish this group from other types of hurdlers. The best performance in terms of "going into the curve" (T4-7) was a manifestation of good technical preparation, including the ability to change the step rhythm in successive parts of the race. For athletes in this group, the first section of the race was more significant (r(T1-4) = -0.22; r(%T1-4) = -0.28; $p < 0.001$). In the last section of the race (T7-10), speed decreased significantly (Table 6). Adverse changes mainly concerned the

third section of the race (T7-10, %T7-10 and T7-10-T4-7) (Table 6). In the group of "technique" hurdlers, the adopted stride pattern did not play a significant role.

Third part of the run (%T7-10)

The best performance (also relatively) evaluated by the time of the section between the 7th and 10th hurdles applied to elite athletes (time: 48.49 ± 0.77 s, r(400H) = -0.12; $p < 0.05$). Body height of hurdlers who adopted the "endurance" strategy was shorter (r(BH) = 0.23; $p < 0.001$). In comparison to other groups (i.e. ones that followed the "speed" and "technique" strategies), athletes in this group did not demonstrate the same split time in the initial section of the race ($p < 0.01 – 0.001$), but reached the shortest split in the final section (T10-F). In all parts of the race, "endurance" hurdlers had the lowest decreases in terms of the racing speed (r(%T7-10-T1-4) = -0.90; $p < 0.001$) (Table 4). Differences between successive parts of the race did not exceed 1.70 ± 0.29 s (Table 7). Top hurdlers preferred slight changes in the stride pattern until the end of the distance. Despite using a greater number of steps taken at the start (N1-4 and N4-7), athletes in this group used the same number of steps as other groups of athletes to clear the final section between hurdles (N7-10; p = NS) (Table 7).

Table 1

Characteristics of hurdlers (n = 273)

Variable	Unit	Mean	SD	Min-max	Skewness	Kurtosis
T400H	s	48.64	0.75	46.78-50.46	0.26	-0.50
T1-10	s	37.29	0.62	35.66-39.17	0.21	-0.34
Age	years	26.13	3.72	18-37	0.48	-0.30
BH	cm	185.28	5.94	170-198	-0.24	-0.04
BW	kg	76.34	5.71	60-93	0.10	0.16
BMI	kg/m²	22.22	1.10	19.33-25.31	-0.12	-0.14
PB400	s	45.94	0.82	44.05-48.04	-0.04	-0.23
TI	s	2.67	0.82	0.18-5.26	0.03	0.40
T0-1	s	6.00	0.13	5.60-6.42	-0.16	0.25
T1-4	s	11.44	0.29	10.76-12.70	0.50	0.89
T4-7	s	12.32	0.25	11.61-13.18	0.18	0.35
T7-10	s	13.54	0.31	12.84-14.40	0.27	-0.16
T10-F	s	5.34	0.29	4.70-6.80	1.20	3.14
%T1-4	%	23.52	0.50	22.02-25.26	0.15	0.71
%T4-7	%	25.30	0.37	24.14-26.60	0.05	0.29
%T7-10	%	27.82	0.43	26.69-29.53	0.20	0.32

Table 2

Sections of the 400 m hurdle race (according to the aim of the study).

Part of the race	Distance (m)	Distance identification	Type of hurdler
S-1	0-45 (45)	Running acceleration	
1-4	45-150 (105)	Hurdle speed (= "speed" part of the run) - Following the clearing of the first hurdle, the racing speed is constant over the first straight (hurdles 2 and 3), and then it decreases	"Speed" hurdler
4-7	150-255 (105)	Hurdle technique (rhythm) (= "technique" part of the run). Most of hurdlers are inclined to change the lead leg, which is treacherous during a race on a curve	"Technique" hurdler
7-10	255-360 (105)	Hurdle endurance (= "endurance" part of the run). In the conditions of significant glycolytic fatigue, three hurdles are cleared in the preparation for the finish part.	"Endurance" hurdler
10-F	360-400 (40)	Finish - running endurance	

Table. 3

Hurdling strategies in three specific sections of the race.

Section of the race	Total group (n = 273)		Various hurdling strategies		
			"Speed" (n = 91)	"Technique" (n = 91)	"Endurance" (n = 91)
	Split time (s)	%	%	%	%
1-4H	11.44 (0.13)	23.52 (0.50)	22.02 – 23.31[1]	23.32 – 23.72	23.73 – 25.26
4-7H	12.32 (0.25)	25.30 (0.37)	24.14 – 25.16[2]	25.16 – 25.45	25.46 – 26.60
7-10H	13.54 (0.31)	27.82 (0.43)	26.69 – 27.62[3]	27.63 – 27.97	27.97 – 29.53

Table 4

Correlation analysis of three running strategies with selected 400 m hurdle variables.

Variable	Strategy		
	%T1-4	%T4-7	%T7-10
T400H	NS	NS	-.12*
T1-10	NS	-.23***	NS
Age	.15*	NS	NS
BH	.18**	NS	-.23***
BW	.17**	NS	-.17**
BMI	NS	NS	NS
PB400	-.18**	NS	.13*
TI	.26***	NS	-.24***
T0-1	-.14*	NS	.21***
T1-4	-.79***	-.22***	.48***
T4-7	-.13*	-.67***	.18**
T7-10	.50***	.28***	-.75***
T10-F	.51***	.54***	-.28***
T4-7-T1-4	.76***	-.41***	-.36***
T7-10-T4-7	.58***	.80***	-.87***
T7-10-T1-4	.92***	.36***	-.90***
%T1-4	-	-.28***	.66***
%T4-7	-.27***	-	.39***
%T7-10	.66***	.39***	-
N1-4	-.37***	NS	.33***
N4-7	-.24***	NS	.27***
N7-10	NS	NS	NS
N4-7-N1-4	.24***	NS	NS
N7-10-N4-7	.26***	.14*	-.29***
N7-10-N1-4	.34***	NS	-.29***
Type of hurdler	„Speed" hurdler	„Technique" hurdler	„Endurance" Hurdler

* $p \leq 0.05$, ** $p \leq 0.01$

Table 5

Analysis of variance (ANOVA) of the strategy of the first (%T1-4, „speed") part of the 400 m hurdle race.

Variable	Group (x±SD) A „Fast"	B „Average"	C „Slow"	F value	Post-hoc test A-B	B-C	A-C
1. Main variables							
T400H (s)	48.69 (0.74)	48.67 (0.78)	48.55 (0.72)	1.73^{NS}			
T1-10 (s)	37.20 (0.55)	37.34 (0.66)	37.34 (0.65)	1.37^{NS}			
2. Basic variables							
Age (year)	26.50(3.85)	26.72 (3.85)	25.20 (3.31)	4.26*			*
BH (cm)	185.42 (6.11)	185.92(5.62)	184.51 (6.07)	1.83^{NS}			
BW (kg)	76.82 (5.68)	76.84 (5.59)	75.36 (5.81)	1.67^{NS}			
BMI (kg/m^2)	22.33 (1.09)	22.22 (1.16)	22.12 (1.03)	0.43^{NS}			
PB400m (s)	45.76 (0.83)	45.95 (0.85)	46.13 (0.75)	4.37*			*
TI (s)	2.93 (0.78)	2.72 (0.85)	2.42 (0.75)	10.21***		**	***
3. Temporal variables (s)							
T0-1	5.97 (0.12)	6.01 (0.13)	6.00 (0.13)	5.155**	**	*	
T1-4	11.21 (0.20)	11.44 (0.19)	11.68 (0.25)	101.04***	***	***	***
T4-7	12.26 (0.20)	12.36 (0.27)	12.33 (0.27)	3.249*	*		
T7-10	13.71 (0.27)	13.53 (0.28)	13.36 (0.28)	34.209***	***	***	***
T10-F	5.54 (0.29)	5.33 (0.24)	5.20 (0.22)	38.671***	***	**	***
T4-7-T1-4	1.05 (0.18)	0.92 (0.17)	0.65 (0.23)	99.294***	***	***	***
T7-10-T4-7	1.45 (0.28)	1.17 (0.28)	1.03 (0.29)	47.599***	***	**	***
T7-10-T1-4	2.50 (0.28)	2.09 (0.19)	1.68 (0.27)	231.77***	***	***	***
%T1-4	23.00 (0.29)	23.50 (0.12)	24.05 (0.32)	365.65***	***	***	***
%T4-7	25.15 (0.33)	25.38 (0.37)	25.36 (0.37)	9.576***	***	***	
%T7-10	28.13 (0.39)	27.80 (0.32)	27.53 (0.36)	68.322***	***	***	
4. Spatial variables (number of strides)							
N1-10	123.77 (4.24)	123.12 (4.3)	125.43 (5.44)	5.870**		*	**
N1-4	39.33 (1.38)	39.65 (1.52)	40.50 (2.14)	12.167***		**	***
N4-7	40.71 (1.56)	40.48 (1.57)	41.29 (2.01)	5.850**			**
N7-10	43.73 (1.80)	43.07 (1.73)	43.64 (1.83)	2.756NS			
N4-7-N1-4	1.38 (1.04)	0.83 (0.96)	0.79 (0.92)	10.789***	***		***
N7-10–N4-7	3.02 (1.18)	2.59 (1.26)	2.35 (1.49)	5.810**			**
N7-10–N1-4	4.40 (1.49)	3.42 (1.64)	3.14 (1.84)	13.830***	***		***

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

Table 6

Analysis of variance (ANOVA) of the strategy of the second (%T4-7, „technique") part of the 400 m hurdle race.

Variable	Group (x±SD)			F value	Post-hoc test		
	A „Fast"	B „Average"	C „Slow"		A-B	B-C	A-C
			1. Main variables				
T400H (s)	48.70 (0.74)	48.61 (0.73)	48.61 (0.76)	0.110^{NS}			
T1-10 (s)	37.16 (0.60)	37.28 (0.59)	37.44 (0.64)	6.437**			**
			2. Basic variables				
Age (year)	26.26 (3.21)	26.35 (4.01)	25.79 (3.90)	0.808^{NS}			
BH (cm)	186.00 (3.21)	184.48 (6.3)	185.36 (5.86)	0.969 ^{NS}			
BW (kg)	76.37 (5.21)	75.91 (6.05)	76.71 (5.86)	0.260 ^{NS}			
BMI (kg/m^2)	22.07 (1.20)	22.28 (1.01)	22.31 (1.06)	1.102 ^{NS}			
PB400m (s)	45.88 (0.84)	46.03 (0.78)	45.91 (0.85)	0.711 ^{NS}			
TI (s)	2.78 (0.82)	2.58 (0.79)	2.70 (0.84)	1.305 ^{NS}			
			3. Temporal variables (s)				
T0-1	6.02 (0.12)	5.98 (0.13)	5.99 (0.13)	1.618 ^{NS}			
T1-4	11.37 (0.26)	11.43 (0.30)	11.53 (0.29)	8.041***			***
T4-7	12.14 (0.20)	12.31 (0.20)	12.50 (0.21)	69.336***	***	***	***
T7-10	13.65 (0.31)	13.54 (0.31)	13.42 (0.28)	10.296***		*	***
T10-F	5.52 (0.34)	5.35 (0.20)	5.17 (0.18)	41.376***	***	***	***
T4-7-T1-4	0.77 (0.26)	0.91 (0.25)	0.97 (0.23)	14.466***	*	*	***
T7-10-T4-7	1.51 (0.23)	1.23 (0.23)	0.92 (0.22)	145.45***	***	***	***
T7-10-T1-4	2.28 (0.39)	2.14 (0.42)	1.89 (0.34)	20.733***	**	***	***
T1-4%	23.34 (0.50)	23.52 (0.51)	23.70 (0.430	12.683***	*	*	***
T4-7%	**24.90 (0.20)**	**25.30 (0.09)**	**25.70 (0.21)**	469.78***	***	***	***
T7-10%	28.01 (0.41)	27.84 (0.44)	27.60 (0.35)	22.863***	*	***	***
			4. Spatial variables (number of strides)				
N1-10	123.49 (4.45)	124.89 (4.8)	124.05 (4.97)	1.908^{NS}			
N1-4	39.56 (1.54)	40.08 (1.89)	39.85 (1.86)	1.954 ^{NS}			
N4-7	40.53 (1.58)	41.03 (1.83)	40.93 (1.81)	2.223 ^{NS}			
N7-10	43.40 (1.92)	43.78 (1.66)	43.27 (1.83)	1.763 ^{NS}			
N4-7-N1-4	0.97 (1.00)	0.95 (1.07)	1.08 (0.96)	0.559 ^{NS}			
N7-10-N4-7	2.87 (3.37)	2.75 (1.23)	2.34 (1.38)	3.312*			*
N7-10-N1-4	3.84 (1.75)	3.70 (1.65)	3.42 (1.84)	0.944 ^{NS}			

Table 7

Analysis of variance (ANOVA) of the strategy of the third (%T7-10, „endurance") part of the 400 m hurdle race.

Variable	Group (x±SD)			F value	Post-hoc test		
	A „Fast"	B „Average"	C „Slow"		A-B	B-C	A-C
1. Main variables							
T400H (s)	48.49 (0.77)	48.65 (0.71)	48.77 (0.75)	3.528*			*
T1-10 (s)	37.19 (0.61)	37.33 (0.63)	37.35 (0.62)	2.477^{NS}			
2. Basic variables							
Age (year)	26.37 (3.79)	25.92 (3.54)	26.10 (3.84)	0.568 ^{NS}			
BH (cm)	183.61 (5.92)	185.33(6.25)	186.88 (5.21)	6.563**			**
BW (kg)	75.21 (5.72)	76.07 (6.04)	77.71 (5.10)	4.105*			*
BMI (kg/m^2)	22.29 (1.06)	22.13 (1.16)	22.24 (1.09)	0.599 ^{NS}			
PB400m (s)	45.96 (0.68)	46.02 (0.90)	45.85 (0.86)	1.010 ^{NS}			
TI (s)	2.53 (0.77)	2.63 (0.82)	2.92 (0.84)	6.068**			**
3. Temporal variables (s)							
T0-1	6.03 (0.13)	6.00 (0.12)	5.97 (0.12)	4.139*			**
T1-4	11.57 (0.27)	11.45 (0.25)	11.32 (0.30)	19.137***	*	**	***
T4-7	12.34 (0.27)	12.34 (0.23)	12.25 (0.25)	2.408 ^{NS}			
T7-10	13.27 (0.22)	13.54 (0.20)	13.81 (0.25)	123.59***	***	***	***
T10-F	5.28 (0.29)	5.32 (0.29)	5.44 (0.27)	7.141***		*	***
T4-7-T1-4	0.77 (0.26)	0.89 (0.24)	0.93 (0.26)	12.216***	**		***
T7-10-T4-7	0.93 (0.24)	1.20 (0.18)	1.56 (0.22)	186.44***	***	***	***
T7-10-T1-4	1.70 (0.29)	2.09 (0.20)	2.49 (0.30)	195.17***	***	***	***
T1-4%	23.84 (0.45)	23.53 (0.37)	23.20 (0.46)	55.317***	***	***	***
T4-7%	25.43 (0.39)	25.35 (0.33)	25.12 (0.30)	18.122***		***	***
T7-10%	**27.35 (0.21)**	**27.81 (0.10)**	**28.29 (0.25)**	474.53***	***	***	***
4. Spatial variables (number of strides)							
N1-10	125.41 (5.78)	123.79(4.57)	123.20 (3.49)	5.071***	*	**	
N1-4	40.51 (2.27)	39.66 (1.61)	39.32 (1.04)	11.460***	**	***	
N4-7	41.35 (2.06)	40.68 (1.72)	40.43 (1.26)	6.000**	*	***	
N7-10	43.55 (1.98)	43.45 (1.78)	43.45 (1.69)	0.114 ^{NS}			
N4-7-N1-4	0.84 (0.91)	1.02 (1.18)	1.11 (0.91)	2.635 ^{NS}			
N7-10-N4-7	2.20 (1.49)	2.77 (1.14)	3.02 (1.26)	8.128***	**	***	
N7-10-N1-4	3.04 (1.88)	3.79 (1.62)	4.09 (1.57)	9.947***	**	***	

Discussion

The traditions marked by the search for the optimal strategy in hurdle races in terms of the final result started as early as the 1960s. Cooper (1966), the silver medalist of the 1964 Games, identifies the so-called "coasts" (instants marked by stabilization of the pace) and "kicks" (rapid acceleration) as elements that play decisive roles in the competition (Cooper, 1966). After the introduction of synthetic tracks, basic elements of temporal structure ("split times") and spatial structure ("stride pattern") provided interesting insights for scientific analysis (Ditroilo and Marini, 2000; Guex 2012; Otsuka and Isaka, 2019). Changes in stride variables in different parts of the distance impact the strategy of hurdle races (Martens et al., 2017).

The history of the 400mH competition demonstrates that it is difficult to identify the most effective strategy among the variety of existing tactics. The final events held during the Olympic Games and World Championships indicate that victory is determined by various strategies, i.e., from maintaining high speeds throughout the entire race through sustainable speed strategies ("technique" hurdler), to waiting for the final stage (by "endurance" hurdlers) (Behm, 2016; Quercetani 2009).

Among the current theories applied to short distance running, various aspects were considered, including total strategy, as well as equal or variable stride pattern strategies (Hannon and Thomas, 2011). In the context of the 400 m hurdle race, none of these theoretical solutions can be used. Biomechanical (acceleration) aspects indicate that regardless of the level of performance, there are three stages in the 400mH race: an increase in racing speed (up to the 2nd or 3rd hurdle), relative maintenance (hurdles 2–4) and a constant, systematic decrease of speed (from the 3rd–4th to the final hurdle) (Ditroilo and Marini, 2001; Yasui et al., 1996). Such a phase-based approach to the time taken to complete subsequent parts of the 400mH race is complemented by changes in the spatial structure (stride pattern) in subsequent "rhythmic units" (35 m between hurdles). Some of the researchers consider that one of the significant aspects of the 400mH races includes running the distance from the start to the first hurdle (Ozaki et al., 2019).

A vast majority of the reports on the analysis (temporal and spatial) of the 400mH apply a holistic approach to the problem, without analyzing the types and particular sections of the race. Yasui et al. (1996) and Lopez del Amo et al. (2012) divide the distance into 3 parts, i.e., 1-3H, 4-7H and 7-10H. This classification was supported by earlier metabolic and biomechanical analysis and observations performed by coaches.

Correlation and variance analyses have demonstrated not only a great diversity of running strategies, but also variable determinants which influenced them.

The adoption of a fast-running strategy from the beginning of the race has been confirmed in runners who applied the so-called "double cut down", i.e., changed the stride pattern from 13 to 15 steps (Hiserman, 2011; Iskra 2008). A faster start of the race results in significant losses of running speed in the latter stages of the distance (T7-10-T1-4 = 2.50 s for the "speed" group and only 1.68 s for the "endurance" group). In fact, Otsuka and Isaka (2019) reported that a positive relationship was observed between the split-times during the first- and second-halves of the race ($r = 0.63$). The main reason seems to be associated with the need to abruptly shorten the step length when changing the stride pattern from 13 to 15 strides. This style of running was common in the 1960s and 1970s (Quercetani, 2009).

The results of the assessment of hurdling performance based on three parts of the race demonstrate significant differences in the adopted running plan. The faster initial part (1-4H) offers the athletes the capability to successfully continue in the middle part of the distance, however, a consequence of such a "running plan" is the rapid deterioration of speed in the later part of the race. Coaches report this situation in the following manner – "if you're using up too much energy in the early part of the race, the later stages of the race will be dramatic" (McGill, 2007).

In the category of hurdlers who constitute the so-called "technique" group, there are tall and slim hurdlers who adopt a long stride pattern throughout the middle part of the distance. This section of the race is sometimes treacherous, as running speed always decreases, and some runners, using a favorable wind, try to run too fast and they finally are not able to maintain this high speed in the last straight (Queen, 2010).

Perhaps the common viewpoint of coaching represents the misunderstanding of the importance of this section of the race. In the training process, the so-called "short rhythm endurance" (running distances up to 150-200 m) is considered a relatively simple, yet effective aspect of training (Iskra, 2012; McFarlane 2004).

The data derived from biochemical tests indicate that the 400mH distance is a typical glycolytic run. After 300 m, the concentration of LA (lactate) reaches over 13 mmol/l (Kłapcińska et al., 2001), thus glycolysis provides most of the ATP for muscular contractions in the 400mH race. High post-exercise lactate concentrations (above 15 mmol/l) in the 400/400m hurdle races were also reported by Goupta et al. (1999) and Zouchal et al. (2010). In this work, the preferred endurance strategy relies on the physiological and biochemical foundations. The final straight plays a decisive role in the ability to maintain a specific stride pattern over a distance of 400mH. The smallest loss of racing speed in this section could be associated with successful performance.

The majority of reports in this area simplify the problem of the 400mH strategy into two mathematically equal parts (first 200 m + the second 200 m part of the race), with an emphasis on time differences between them (Hiserman, 2011; McFarlane 2004). In accordance with such classic designs, this difference in favor of the early half should be as small as possible (around 2.5 s for the best athletes). However, at this level a small difference due to the slow first half is not an alternative at the elite level. This point of view has been confirmed empirically by Guex (2012).

The athletic performance evaluation system applying the standard index (TI) does not always utilize sufficient information. In the "technique" category of athletes, the relation measured by the TI was not observed, however, this group of athletes performed significantly better in terms of split times only between the hurdles (T1-10; $p = 0.01$) (Table 4). The question regarding the results of the "stride pattern" analysis for various types of strategies is largely answered by the presented different running strategies. In previous works, no preferences were established in terms of a specific "stride pattern" (Iskra, 2008). However, the results of previous analysis indicate minimal changes in the number of steps in the final section of the distance (Table 7).

The need to refer to the 13-step "stride pattern" is most evident among the best hurdlers of 2019 (Karsten Warholm, Rai Benjamin, Abderrahman Samba). In the group of tall hurdlers (187-191) with a slim body (75-78 kg), a 13-step stride pattern is followed until the end or to the final straight (Matthews, 2019). It has been reported that only several hurdlers in the world maintain the 13-step stride pattern all the way to the finish line (Otsuka and Isaka, 2019).

An approach which involves the identification of three parts of the distance and assigns three strategies to them allows for the analysis of nine specific running plans. For example, the strategy of five world class hurdlers included three parts of the run (1-4H, 4-7H and 7-10H) and three strategies ("fast", "average" and "slow") presented below:

1. 46.78 s – "average" + "average" + "fast"
2. 47.18 s – "slow" + "fast" + "fast"
3. 47.25 s – "fast" + "average" + "average"
4. 47.30 s – "slow" + "average" + "fast"
5. 47.46 s – "average" + "fast" + "slow"

Conclusions

1. Three strategies can be identified as a result of the assessment of the distribution of the pace rhythm (temporal structure) and the so-called stride pattern over the 400mH race: "speed", "technique" and "endurance".

2. There are elite hurdlers who represent each of the strategies, and the selection of a specific strategy depends mainly on predominant motor abilities, technical preparation and anthropometric characteristics of athletes.

3. A too fast pace at the start of the race significantly reduces the stride pattern in its latter stages and reduces performance in the third part of the race. This way of running is preferred by short hurdlers whose pace rhythm includes 14 to 15 steps.

4. The strategy of fast running in the middle section of the distance significantly decreases the racing speed in the final straight (in particular after the final hurdle).

5. Elite hurdlers often choose to follow the endurance strategy. The time differences of individual parts of the race are then small. Runners from this group clear the distance between hurdles in a 13 to 14 step rhythm.

6. The evaluation of different pacing strategies in three parts of the distance in elite hurdlers needs to be studied individually.

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