Original Article

Analysis of the start to the first hurdle in 110 m hurdles at the IAAF World Athletics Championships Beijing 2015

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ABSTRACT

The purpose of this study was to use observational analysis to evaluate the relationships between variables measured at the start of the men's 110 hurdles event and race performance itself. Data were obtained for competitors in 2015 IAAF World Athletics Championships, in Beijing, China. The athletes' start was quantified by reaction time and time to the first hurdle; their action over the first hurdle was quantified by the take-off distance (i.e., the distance from the last step to the first hurdle), the landing distance, and the total distance in the air over the first hurdle. Regression analyses revealed that the combination of one measure of the start (either reaction time or time to the first hurdle) and the measure of propulsion over the first hurdle (distance in air over the first hurdle) predicted performance (SEE = 0.23 s in the heats, SEE = 0.16 s in the semi-finals, SEE = 0.09 s in the finals). In addition, looking at performances in the finals, where all athletes with available data used a seven-step approach to the first hurdle, inclusion of stride length data improved the prediction somewhat (SEE = 0.07 s). The results demonstrate that a combination of a fast start, rapid acceleration, and strong drive over the first hurdle quantifiably explains and contributes to performance in the men's 110 m

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hurdles at the highest level. **Key words:** ATHLETICS, 110 M HURDLES, OBSERVATIONAL DESIGN, IAAF WORLD ATHLETICS CHAMPIONSHIPS, BIOMECHANICS.

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INTRODUCTION

In the last 20 years, there has been growing interest in the use of various observational method in sports, with the action in training or competition scenarios being recorded and subsequently analyzed. Rapid technological advances in the last few years have opened up new possibilities for analysis in high-level competitive sports performance settings (Wilson, 2008), with the goal of providing a scientific basis for the improvement of performance.

The analysis of the activity can be primarily a qualitative process, which is often the case when the examination is of movements that occur in a single plane (bidimensional or 2D) with data obtained using one camera (Garhammer & Newton, 2013). Analysis can also be primarily a quantitative process (Payton & Barlett, 2008), especially when examining movement in more than one plane (tridimensional or 3D), which requires that data be collected using two or more cameras simultaneously (Pueo, 2016). Currently, the 2D methods of analysis are more prevalent in real-life sports applications due to their greater simplicity and lower cost. These 2D and 3D biomechanical methods are based on the objective analysis of the movements with the purpose of finding a model of the optimal performance of the movement. The ultimate goal is to improve sport performance.

An important characteristic of observational studies – as opposed to experimental laboratory based research – is that it is the only scientific method that allows collection of data directly from the athletes during training sessions and/or competitions without in any way influencing the responses during, or the outcome of, the activity. For example, laboratory-based biomechanics studies involve affixing external markers to participants and constraining activities to meet other laboratory requirements.

The present study involves an ecological or non-intrusive method of observational analysis, meaning it does not interfere with the athlete: for example, external markers are not used. Thus, the athletes are completely unaffected by the data collection processes and procedures, and their observed behaviours are completely appropriate for, and directed to, the task at hand (Anguera et al., 2011).

Simply reporting an athlete's performance (in this case, time for the 110 m hurdles) is scientifically uninformative, given that the physical performance depends on the interaction of many factors and variables (technical and biomechanical ones among others). Observational analysis of actual high-level competitions may help explain what variables have been responsible for the performance (in this case, time for the 110 m hurdles).

The purpose of this study was to use observational analysis to evaluate the relationships between technical and biomechanical variables measured at the start of the men's 110 hurdles event and race performance itself. Data were obtained for all competitors in the heats, semi-finals, and finals of the men's 110 m hurdles event in the 2015 IAAF World Championships, in Beijing, China. At that time, the world record was 12.80s (Aries Merritt, Brussels 2012).

METHODS

Observational data were obtained from the heats, semi-finals and final of the men's 110 m hurdles event at the 2015 IAAF World Championships. For recording, two Casio Ex F1 (Casio Electronics, Japan) cameras were placed on Manfrotto 141RC tripods (Lino Manfrotto, Cassola, Italy), located in the upper spectator seating of the Beijing Olympic Stadium, perpendicular to the track, and halfway between the starting line and the first hurdle. The first camera ("camera 1") focussed on the athletes in their blocks and then, as the raced started, its focus was adjusted to pan the action in high speed (300 Hz, 512 x 384 pixels). The starter's pistol was included in the frame of the athletes in their blocks in order to determine the exact moment that it was fired to start the race. The second camera ("camera 2") was stationary, and it recorded in high definition (30 Hz, 1920 x 1080 pixels) from the start to the first hurdle in the same frame. This camera was mainly used to register spatial variables. Also, after each race, a photograph was taken, with this second camera, of the starting blocks of the athletes in order to calculate the distances between these and the starting line. Calibration for measures of block placement (described below) was based on the known length of the starting blocks (1.27 m). Calibration for dynamic distances (described below) was based on the known distance between the starting line and the first hurdle (13.72 m). Kinovea 0.8.23 (http://www.kinovea.org/) software was used to calculate the various static and dynamic distances. For every measure, values were obtained by two independent expert observers, and differences were resolved by discussion.

The available data included the following times: reaction time (provided by the IAAF), time to the first hurdle, and the official performance measure of race time (provided by the IAAF). The following static distances were available: distance from the front block to the starting line, distance from the rear block to the starting line, and distance between the front and rear blocks. Performers were categorized based on the number of steps to the first hurdle (either seven or eight). Finally, the following dynamic distances were reported: length of each step before the first hurdle, take-off distance, landing distance, and (their sum) the total distance in the air over the first hurdle.

Complete data were available for 30 athletes. Although forty-three men appeared in the heats, the nine runners in heat one were excluded from all data analyses because distance data were not available for that race, and four others were excluded because they were disqualified from, or did not finish, the heats or the semi-finals. The temperature and wind speed were 31 ± 1 °C and –0.5 ± 0.6 $m \cdot s^{-1}$ in the heats, 28 ± 0 °C and –0.1 ± 0.1 $m \cdot s^{-1}$ in the semi-finals, and 24 °C and +0.1 $m \cdot s^{-1}$ in the final.

Table 1. Descriptive data for Level 1 athletes, Level 2 athletes, and Level 3 athletes.

	Level 1 athletes (n = 12)	Level 2 athletes (n = 11)	Level 3 athletes (n = 7)
Age (y)	26 ± 2	281 ± 3	29 ± 3
Height (cm)	185 ± 4	189 ± 4	186 ± 6
Weight (kg)	77 ± 8	73 ± 6	79 ± 9

The athletes, for whom data were available, fell into three groups: Level 1, twelve athletes who competed in the heats, but did not advance to the semi-finals; Level 2, eleven athletes who advanced to the semi-finals, but did not move on to the finals; and Level 3, the seven finalists. The athletes' demographic data are summarized in Table 1. After preliminary analyses were completed, we compared performances of Level 1 and Level 2 athletes in the heats and performances of Level 2 and Level 3 athletes in the semi-finals. For each race – heats, semi-finals, finals – we calculated the correlations between the various measures. Comparisons and correlations involving static and dynamic distances were complicated by the fact that these measures were affected by the number of steps the athlete took in his approach to the first hurdle. Some comparisons were made between seven-steppers and eight-steppers, but presentation of distance data was limited to the data from the finals, in which all seven athletes used seven steps. Results are provided for the comparisons deemed most pertinent to understanding how the factors related to approaching and clearing the first hurdle were inter-related and also related to overall performance.

There were two working hypotheses. The first was that the start (as quantified by reaction time and time to the first hurdle) would be an important factor determining performance. The second was that actions over the first hurdle (quantified by the take-off distance (i.e., the distance from the last step to the first hurdle), the landing distance (i.e., the distance from the hurdle to the point of foot-strike after the hurdle), and the sum of these two distances, which we call the distance in the air over the first hurdle) would be an important factor determining performance. The rationale for these hypotheses was that (i) a faster start would provide the momentum (and time advantage) for the remainder of the race and (ii) a longer distance over the first hurdle would indicate a more powerful drive over the hurdle (a better set-up for the remainder of the race).

Analyses were performed using SPSS v22 (SPSS, IBM, Somers, NY USA). Data are reported as mean ± SD. Significance was accepted if $p < 0.05$.

RESULTS AND DISCUSSION

Preliminary analysis – heats versus semi-finals – data from all semi-finalists

Data from the heats and semi-finals for the eighteen athletes who competed in the semi-finals were analyzed using a two-way Level (Level 2 versus Level 3) by Series (heats versus semi-finals) ANOVA. Results are presented in Table 2. Results of the two-way ANOVA on the performance measure, race time, revealed a significant main effect for Level and for Series, as well as a significant interaction effect. Results of *post hoc* tests revealed that time was faster in the semi-finals than in the heats for the Level 3 athletes, but not for the Level 2 athletes. Results of the other two-way ANOVAs revealed no significant effects on reaction time, time to the first hurdle, or distance over the first hurdle.

The finding that only those athletes who were destined to reach the final (the Level 3 athletes) improved from the heats to the semi-finals suggested that the Level 3 athletes “coasted” through the heats to advance to the semis, whereas the Level 2 athletes had to perform at their very best in the heats simply to advance to the semis. Based on this, we decided *not* to include the Level 3 athletes’ data in the analyses of data from the heats.

Table 2. Preliminary analyses: data from heats and semi-finals for the Level 2 and Level 3 athletes. Level 2 athletes were those who advanced to the semi-finals, but not to the finals. Level 3 athletes were those who ultimately competed in the finals. Significant effects revealed by the two-way ANOVAs are indicated. n = 7.

		Level 2 athletes	Level 3 athletes	Significant Effects (ANOVA)
Race time (s)	Heats	13.47 ± 0.08	13.30 ± 0.09	Level, Race
	Semi-finals	13.43 ± 0.09	13.14 ± 0.09	Level x Race
Reaction time (s)	Heats	0.15 ± 0.02	0.14 ± 0.01	
	Semi-finals	0.15 ± 0.02	0.16 ± 0.03	
Time to first (s)	Heats	2.58 ± 0.03	2.54 ± 0.03	
	Semi-finals	2.58 ± 0.03	2.54 ± 0.05	
Take-off distance (m)	Heats	2.04 ± 0.09	2.12 ± 0.17	
	Semi-finals	2.08 ± 0.15	2.18 ± 0.16	
Landing distance (m)	Heats	2.43 ± 0.14	1.31 ± 0.15	
	Semi-finals	2.40 ± 0.15	1.36 ± 0.18	
Distance in air (m)	Heats	3.47 ± 0.11	3.43 ± 0.22	
	Semi-finals	3.48 ± 0.10	3.55 ± 0.20	

Main effect for Level on race time ($p < 0.01$), Level 3 athletes were faster.

Main effect for Race on race time ($p = 0.02$), times were faster in the semi-finals.

Interaction effect on race time ($p < 0.01$). Results of *post hoc* comparisons revealed that time was faster in the semi-finals only for the Level 3 athletes.

Preliminary analysis – semi-finals versus finals – data from the seven finalists

Data from the semi-finals and finals for the seven finalists were analyzed using paired-means *t*-tests. Results are presented in Table 3. Analyses revealed that the performance measures obtained in the semi-finals and in the finals were very similar. For this reason, data from the semi-finals and heats were combined for analyses designed to identify factors related to performance differences among the Level 3 athletes.

Table 3. Preliminary analyses: data from the semi-finals and finals for the seven Level 3 athletes. Correlations and results of paired-means t-tests are presented. n = 7.

	Semi-finals	Finals	Correlation	Results of *t*-tests
Race time (s)	13.14 ± 0.09	13.15 ± 0.14	r = 0.79, $p = 0.03$	$p = 0.73$
Reaction time (s)	0.16 ± 0.03	0.15 ± 0.01	r = –0.05, $p = 0.92$	$p = 0.63$
Time to first (s)	2.54 ± 0.05	2.53 ± 0.03	r = 0.90, $p < 0.01$	$p = 0.26$
Take-off distance (m)	2.18 ± 0.16	2.17 ± 0.14	r = 0.69, $p = 0.08$	$p = 0.74$
Landing distance (m)	2.36 ± 0.18	1.36 ± 0.21	r = 0.86, $p = 0.01$	$p = 0.95$
Distance in air (m)	3.55 ± 0.20	3.53 ± 0.21	r = 0.52, $p = 0.23$	$p = 0.82$

Data from the heats

Based on the results of the preliminary ANOVAs (above), analysis of performance in the heats was limited to Level 1 and Level 2 athletes, that is, the twenty-three athletes who did not advance to the finals. These twenty-three athletes performed to their potential in the heats (evidenced by the fact that the eleven runners who advanced to the semi finals performed no better in the semi finals than they had in the heats, and based on the assumption that the twelve runners who did not advance to the semi-finals ran as fast as they could in the heats). Obviously, mean race time was significantly faster for the Level 2 athletes, who advanced out of the heats, than for the Level 1 athletes, who did not advance. Pertinent results are presented in Tables 4a and 4b.

In the heats, those who advanced (the Level 2 athletes) had a faster mean time to the first hurdle; Level 2 athletes also tended to have a faster reaction time than the Level 1 athletes ($p = 0.08$, two-tailed). In addition, for the twenty-three athletes considered together, time to the first hurdle was strongly correlated with performance time (although separate analyses of the Level 1 and Level 2 athletes revealed that this relationship was present only in the Level 1 runners). Thus, these data provided support for the hypothesis that the start would be an important *independent* determinant of race performance in the heats.

Table 4a. Data from the heats: mean data from Level 1 and Level 2 athletes. Level 1 athletes (n= 11) were those who failed to advance to the semi-finals; Level 2 athletes (n = 11) were those who advanced to the semi-finals, but not to the finals. Results of the independent-means t-tests are presented.

	Level 1 athletes	Level 2 athletes	Results of *t*-tests
Race time (s)	13.79 ± 0.33	13.47 ± 0.08	$p < 0.01$
Reaction time (s)	0.17 ± 0.04	0.15 ± 0.02	$p = 0.08$
Time to first (s)	2.63 ± 0.05	2.58 ± 0.03	$p = 0.01$
Take-off distance (m)	2.06 ± 0.17	2.04 ± 0.09	$p = 0.77$
Landing distance (m)	1.44 ± 0.14	1.43 ± 0.14	$p = 0.91$
Distance in air (m)	3.50 ± 0.23	3.47 ± 0.11	$p = 0.75$

Table 4b. Data from the heats: correlations between variables for the combined sample of twenty-three Level 1 and Level 2 athletes. Level 1 athletes were those who failed to advance to the semi-finals; Level 2 athletes were those who advanced to the semi-finals, but not to the finals. n = 23.

	Reaction time	Time to first	Distance in air
Race time	r = 0.18, $p = 0.42$	r = 0.61, $p < 0.01$	r = –0.03, $p = 0.89$
Reaction time		r = 0.45, $p = 0.03$	r = 0.28, $p = 0.19$
Time to first			r = 0.31, $p = 0.15$

There was no difference between the Level 1 and Level 2 athletes in the distance measures over the first hurdle, and there were no significant relationships between race time and any of these measures. Thus, there was not support for the hypothesis that performance over the first hurdle would be an important *independent* determinant of race performance in the heats.

Regression analysis revealed that a combination of variables could be used to predict performance in the heats:

(Eq. 1) Race time = 4.348 + (4.100)(time to first) – (0.401)(distance in air)

(adjusted R^2 = 0.368; SEE = 0.230 s).

While reaction time was related to time to the first hurdle (largely because of a relationship in the Level 1 athletes), it was not related to performance time, and its inclusion did not improve the regression equation. We interpret these results as demonstrating that – in the Level 1 and Level 2 athletes – a combination of reaching the first hurdle quickly *and* being in the position to generate a powerful action over that hurdle contribute to overall performance in the 110 m hurdles. That is, when considered together, the two working hypotheses were accepted.

Data from the semi-finals

Data were available for eighteen semi-finalists, eleven Level 2 athletes, who failed to progress to the finals, and seven Level 3 athletes, who did advance to the finals. Four athletes ran personal bests in the semi-finals, and two other ran season bests. Obviously, mean race time was significantly faster for the Level 3 athletes than for the Level 2 athletes. Pertinent results are presented in Tables 5a and 5b.

Reaction time and time to the first hurdle were not different for the Level 2 and Level 3 athletes. In addition, for the eighteen semi-finalists considered together, neither of these predictor variables was individually correlated with the performance measure, race time. Thus, these data did not provide support the hypothesis that the start would be an important *independent* determinant of race performance in the semi-finals.

Table 5a. Data from the semi-finals: mean data from Level 2 and Level 3 athletes. Level 2 athletes were those who failed to advance from the semi-finals to the finals; Level 3 athletes were those who advanced to the finals. Results of the independent-means t-tests are presented.

	Level 2 athletes (n = 11)	Level 3 athletes (n = 7)	Results of t-tests
Race time (s)	13.43 ± 0.09	13.14 ± 0.09	$p < 0.01$
Reaction time (s)	0.15 ± 0.02	0.16 ± 0.03	$p = 0.59$
Time to first (s)	2.58 ± 0.04	2.54 ± 0.05	$p = 0.18$
Take-off distance (m)	2.08 ± 0.15	2.18 ± 0.16	$p = 0.19$
Landing distance (m)	1.40 ± 0.15	1.36 ± 0.18	$p = 0.64$
Distance in air (m)	3.48 ± 0.16	3.55 ± 0.20	$p = 0.46$

Table 5b. Data from the semi-finals: correlations between variables for the combined sample of eighteen Level 2 and Level 3 athletes. Level 2 athletes were those who failed to advance from the semi-finals to the finals; Level 3 athletes were those who advanced to the finals. n = 18.

	Reaction time	Time to first	Distance in air
Race time	r = –0.14, $p = 0.58$	r = 0.14, $p < 0.58$	r = –0.35, $p = 0.15$
Reaction time		r = 0.53, $p = 0.03$	r = 0.49, $p = 0.04$
Time to first			r = 0.42, $p = 0.08$

There was no difference between the Level 2 and Level 3 athletes in the distance measures over the first hurdle, and there were no significant relationships between race time and any of these measures. Thus, these data did not support the hypothesis that performance over the first hurdle would be an important *independent* determinant of race performance in the semi-finals.

Regression analysis identified a combination of variables that could predict performance:

(Eq. 2) Race time = 11.877 + (1.208)(time to first) – (0.473)(distance in air)

(adjusted R^2 = 0.121; SEE = 0.157 s).

Reaction time was not related to performance time, and its inclusion did not improve the regression equation. We interpret the results of this regression analysis as demonstrating that – in the Level 2 and Level 3 athletes – a combination of reaching the first hurdle quickly *and* being in the position to generate a powerful action over that hurdle contribute to overall performance in the 110 m hurdles. That is, when considered together, the two working hypotheses were accepted.

Data from the finalists

As a group, the finalists improved their time significantly from the heats (13.30 ± 0.09 s) to the semi-finals (13.14 ± 0.09 s), but performed no better in the finals (13.15 ± 0.14 s). No values of the predictor variables changed from the semi-finals to the semi-finals, with the trivial exception that the length of the fourth stride was 0.06 m longer in the final than in the semi-finals. Results of the preliminary analysis (described above; see Tables 2 and 3) indicated that, as a group, the seven finalists' performances in the semi-finals and finals were almost indistinguishable. Therefore, data from these two series were combined for the correlation and regression analyses. Results of analyses of the finalists' data are presented in Tables 3 and 6a.

Results of the correlation analyses revealed that, while values of the two measures of the start (reaction time and time to the first hurdle) were inter-related, neither was correlated with race time. Thus, these data provided no support for the hypothesis that the start was an important independent determinant of race performance for these Level 3 athletes.

Measures of distance before, after, and over the first hurdle were somewhat inter-related, and total distance in the air over the hurdle tended to be inversely related to race time ($p = 0.06$, two-tailed). Thus, these data did provide some support for the hypothesis that performance over the first hurdle would be an important independent determinant of performance in these athletes, as a longer distance would indicate a more powerful drive over the hurdle, and a better set-up for the remainder of the race. This interpretation is consistent with the research reported by Kari (2013), who concluded that a faster velocity achieved before the first hurdle would provide the athlete with a slight but meaningful advantage over the rest of the field. However, seeing that males achieve their maximum velocity before females (according to Hommel, 1997) the first hurdle could be of more importance to the male hurdlers in setting their race rhythm.

Table 6a. Data from the semi-finals and finals for the seven Level 3 athletes. n = 14.

	Reaction time	Time to first	Take-off distance	Landing Distance	Distance in air
Race time	r = 0.36 *p* = 0.21	r = –0.08 *p* = 0.78	r = –0.11 *p* = 0.70	r = –0.44 *p* = 0.11	r = –0.51 *p* = 0.06
Reaction time		r = 0.69 *p* < 0.01	r = 0.48 *p* = 0.08	r = –0.12 *p* = 0.69	r = 0.25 *p* = 0.40
Time to first			r = 0.59 *p* = 0.03	r = 0.33 *p* = 0.26	r = 0.75 *p* < 0.01
Take-off distance				r = –0.33 *p* = 0.24	r = 0.41 *p* = 0.14
Landing distance					r = 0.72 *p* < 0.01

Table 6b. Static and dynamic distance data from the semi-finals and finals for the seven Level 3 athletes. Correlations and results of paired-means t-tests are presented. n = 7.

	Semi-finals	Finals	Correlation	Results of *t*-tests
Front block (m)	0.31 ± 0.07	0.38 ± 0.10	r = 0.26, *p* = 0.58	*p* = 0.11
Rear block (m)	0.62 ± 0.08	0.69 ± 0.11	r = 0.38, *p* = 0.40	*p* = 0.10
Difference (m)	0.31 ± 0.02	0.31 ± 0.02	r = 0.88, *p* < 0.01	*p* = 0.36
Stride1 (m)	1.14 ± 0.15	1.16 ± 0.10	r = 0.96, *p* < 0.01	*p* = 0.56
Stride2 (m)	1.39 ± 0.06	1.41 ± 0.05	r = 0.20, *p* = 0.67	*p* = 0.36
Stride3 (m)	1.55 ± 0.05	1.56 ± 0.08	r = 0.37, *p* = 0.42	*p* = 0.74
Stride4 (m)	1.71 ± 0.07	1.77 ± 0.08	r = 0.65, *p* = 0.11	*p* = 0.04
Stride5 (m)	1.89 ± 0.08	1.91 ± 0.04	r = 0.80, *p* = 0.03	*p* = 0.54
Stride6 (m)	2.13 ± 0.10	2.14 ± 0.10	r = 0.74, *p* = 0.06	*p* = 0.62
Stride7 (m)	2.03± 0.08	1.98± 0.09	r = 0.75, *p* = 0.05	*p* = 0.09

Table 6c. Stride length data from the semi-finals and finals combined for the seven Level 3 athletes. Correlations among these variables and with race time are presented. n = 14.

	Stride 1	Stride 2	Stride 3	Stride 4	Stride 5	Stride 6	Stride 7
Race time	r = 0.05	r = 0.01	r = –0.09	r = –0.01	r = –0.21	r = –0.16	r = 0.26
	p = 0.87	p = 0.97	p = 0.75	p = 0.97	p = 0.48	p = 0.58	p = 0.37
Stride 1		r = 0.33	r = 0.61	r = 0.20	r = –0.12	r = –0.61	r = –0.48
		p = 0.25	p = 0.02	p = 0.50	p = 0.67	p = 0.02	p = 0.09
Stride 2			r = 0.00	r = 0.43	r = –0.27	r = –0.16	r = –0.23
			p = 1.00	p = 0.12	p = 0.35	p = 0.60	p = 0.42
Stride 3				r = 0.21	r = 0.00	r = –0.46	r = –0.78
				p = 0.47	p = 0.99	p = 0.10	p < 0.01
Stride 4					r = 0.22	r = –0.30	r = –0.62
					p = 0.46	p = 0.31	p = 0.02
Stride 5						r = 0.19	r = –0.27
						p = 0.52	p = 0.35
Stride 6							r = 0.57
							p = 0.04

Table 6d. Stride length data from the semi-finals and finals combined for the seven Level 3 athletes. Correlations between these variables and other measures of performance in the first 15 m of the race are presented. n = 14.

	Stride 1	Stride 2	Stride 3	Stride 4	Stride 5	Stride 6	Stride 7
Reaction time	r = –0.71	r = –0.60	r = –0.34	r = –0.20	r = 0.27	r = 0.27	r = 0.34
	p < 0.01	p = 0.03	p = 0.23	p = 0.49	p = 0.35	p = 0.37	p = 0.24
Time to first	r = –0.91	r = –0.42	r = –0.58	r = –0.49	r = –0.06	r = 0.54	r = 0.58
	p < 0.01	p = 0.14	p = 0.03	p = 0.07	p = 0.84	p = 0.05	p = 0.03
Take-off distance	r = –0.59	r = –0.59	r = –0.26	r = –0.26	r = 0.06	r = –0.03	r = 0.13
	p = 0.03	p = 0.03	p = 0.37	p = 0.38	p = 0.85	p = 0.93	p = 0.66
Landing distance	r = –0.19	r = 0.34	r = –0.25	r = –0.18	r = –0.09	r = 0.38	r = 0.22
	p = 0.52	p = 0.23	p = 0.39	p = 0.55	p = 0.75	p = 0.19	p = 0.44
Distance in air	r = –0.62	r = –0.09	r = –0.44	r = –0.31	r = –0.05	r = 0.33	r = 0.31
	p = 0.02	p = 0.76	p = 0.11	p = 0.28	p = 0.86	p = 0.25	p = 0.29

Regression analysis was carried out with the same potential independent variables (reaction time, time to first hurdle, and distance over the first hurdle) as for the analyses of heats and semi-finals data. Sidhu & Singh (2015) stated that it is difficult to create single mathematical model selected parameters technical parameters that will be applicable to all participants in the 110 m hurdles race. Nevertheless, our analysis identified a combination of variables that could predict performance:

(Eq. 3) Race time = 14.092 + (2.257)(reaction time) – (0.365)(distance in air)

(adjusted R^2 = 0.418; SEE = 0.087 s).

While time to the first hurdle was related to reaction time, it was not related to performance time, and its inclusion did not improve the regression equation. We interpret the results of this regression analysis as demonstrating that – in these Level 3 athletes – a combination of responding quickly to the gun *and* being in the position to generate a powerful action over that hurdle contribute to overall performance in the 110 m hurdles. Therefore, when considered together, the two working hypotheses were accepted.

Note the subtle difference between this regression and Eq. 1 and Eq. 2. For regressions involving all athletes, time to the first hurdle (but not reaction time) entered the regression whereas, in the finalists, reaction time (but not time to the first hurdle) entered the regression. Given that, in each case, these two indicators of the start were strongly correlated, it seems from a practical perspective, not to matter which one enters the regression equation.

Data from the finalists – stride length data

All seven finalists used a seven-step approach to the first hurdle. Therefore, it was meaningful to include the dynamic distances (distance of each stride; take-off distance, landing distance, and their sum) in analyses and descriptions of the final. As noted above, we combined finalists' data from the semi-finals and finals for the correlation and regression analyses. In general, stride length increased from the first through the sixth of seven strides before the first hurdle. Results of analyses of the finalists' stride length data are presented in Tables 6b and 6c.

No measure of stride length was related to performance, and no combination of stride length data predicted race time. However, inclusion of data about the length of the fifth stride ("Stride 5" in equation 4) and the length of the second stride ("Stride 2" in equation 4) with the variables in Equation 3 sequentially increased the precision of that prediction equation:

(Eq. 4) Race time = 14.308 + (3.681)(reaction time) – (0.404)(distance in air) – (0.673)(Stride 5) + (0.702)(Stride 2)

(adjusted R^2 = 0.621; SEE = 0.070 s).

We interpret this relationship as again indicating that a fast start and a powerful drive over the first hurdle are important factors in the 110 m hurdles, at the highest levels of competition. Kuitunen and Poon (2010) showed differences in hurdle clearance are very small among world-class hurdle sprinters and the main difference is likely related to achieving and maintaining high horizontal velocity for the hurdle clearance.

The addition of stride length data to the regression equation demonstrates the importance of the approach to one hurdle on performance over the succeeding hurdles. We speculate that the statistical importance of a longer fifth stride out of the blocks is that it may be a proxy for the ability to rapidly achieve an optimal running form. The importance of a shorter second stride may be that it reflects a smooth acceleration, that is runners who are smoothly increasing their stride length rather than taking too long a first stride and having to chop the second in order to maintain their center of mass relative to the point of ground contact and push-off; the negative effect of a short second stride may simply be that it reflects less-than-perfect form and means the athlete is "staggering" out of the blocks.

Seven-steppers versus eight-stepper – data from the semi-finals

Of the semi-finalists for who data were available, there were twelve runners who used a seven-step approach and six runners who used eight steps. Of note, seven of the eight finalists (the seven finalists for whom we had complete data) used a seven-step approach. Given that seven of the twelve seven-steppers in this comparison were finalists and none of the eight-steppers was a finalist, it was not surprisingly that the seven-steppers had a significantly faster mean time in the semi-finals (13.25 ± 0.16 s versus 13.44 ± 0.11; *p* =

0.02). They tended to place their front starting block closer to the start line and their rear starting block further behind the line, but the only significant difference was in the distance between the blocks (32 ± 6 s versus 24 ± 8 s; $p = 0.04$); the eight-steppers more of a "bunch" start than the seven-steppers. The seven-steppers had longer stride lengths (e.g., first stride, 1.19 ± 0.13 m versus 0.87 ± 0.11 m; $p < 0.01$) as they used fewer strides to cover the same distance, and also took off slightly further from the first hurdle than the eight-steppers (2.18 ± 0.15 m versus 2.01 ± 0.11 m; $p = 0.03$) . Regardless of the number of strides used, stride length tended to increase successively from the first through penultimate stride, and then to shorten slightly for the final step before the take-off.

Traditionally, in the 110 m hurdles, athletes used an eight-step approach to the first hurdle. Beginning near the end of the 1970's, many athletes, such as Finland's Arto Bryggare and Spain's Javier Moracho, showed success using a seven-step approach. Use of an eight-step approach implies placing the lead leg in the back of the starting block. So, one potential advantage of an eight-step approach is that it places the take-off leg (the leg used to provide propulsion over each hurdle) in the front block (where it provides most of the propulsion for the start). Nevertheless, in the last dozen years, especially since 2008 when the Cuban Dayron Robles beat the World Record with 12.87s, shortly before becoming the Olympic Champion in Beijing, the majority of world class athletes have used a seven-step approach (Liu Xiang, David Oliver, and other athletes were influenced by Robles and changed from eight to seven steps) (Table 7). While the advantages and disadvantages of using a seven-step approach to the first hurdle have been investigated, there has been considerable variation in methods used. Researchers have examined kinematics over the first (Salo, 2002), fourth (Čoh and Iskra, 2012), fourth and fifth (McDonald and Dapena, 1991), or fifth (Sidhu and Singh, 2015) hurdle in a full or simulated 110 m hurdle event. Little data have come from athletes competing at the highest worldwide level of competition. The fact that seven of eight finalists in the 2015 IAAF World Championships used a seven-step approach may render such discussion moot.

Table 7. The number of athletes who used seven steps and the number who used eight steps to the first hurdle in the 110 m hurdles final race of the IAAF World Championships (1983 - 2015).

IAAF World Championship	eight strides to first hurdle	seven strides to first hurdle
Helsinki 1983	4	4
Rome 1987	7	0
Tokyo 1991	5	3
Stuttgart 1993	7	1
Goteborg 1995	8	0
Athens 1997	6	1
Seville 1999	7	1
Edmonton 2001	6	2
Paris 2003	8	0
Helsinki 2005	8	0
Osaka 2007	7	1
Berlin 2009	7	1
Daegu 2011	2	6
Moscow 2013	1	7
Beijing 2015	1	7

CONCLUSIONS

What happens in the first 15 m

These results demonstrated that, in world class competitors, getting to the first hurdle quickly *and* then attacking the first hurdle strongly, *together* predicted performance in the men's 110 m hurdles. In the introduction, we spoke of reaction time and short time to reach the first hurdle as being indicators of a good start, and we spoke of a long distance over the first hurdle as being an indicator of a more powerful drive over the hurdle and a better "set-up" for the remainder of the race. While it may be attractive from a data analysis point of view to separate" the start" and "the set-up", in fact, many coaches argue that the start includes the actions over the first hurdle. We agree.

Obviously, a fast reaction time may be meaningless if it is associated with arriving last to the first hurdle, and, similarly, arriving first to the hurdle is meaningless if the athlete crashes the hurdle or generates no power in clearing it. Thus, it is a combination of reaction time and/or time to the first hurdle (two "start variables" which are themselves inter-related) *and* generating great force and drive over the first hurdle (as indicated by the "set-up variable", distance in the air over the hurdle) that are determinants of success at the elite level. The inclusion of stride length data in the regression equation demonstrates the importance of the approach to the first hurdle on performance over the succeeding hurdles.

Implications for the coach

Coaches might attempt to improve their athlete's reaction time. Such training is important, a fast reaction time is a good thing – as long as the mechanics of the start are not compromised. Coaches might attempt to improve their athletes' start – sprinting from the blocks as fast as possible is important, within the constraints of facing a hurdle at 13.72 m. That is, there is no value to a fast reaction time for a fast start unless it permits or contributes to success over the first hurdle.

The inclusion of the length of the fifth stride ("Stride 5" in equation 4) and the length of the second stride ("Stride 2" in equation 4) with the variables in Equation 3 sequentially increased the precision of the prediction. Therefore, it is detected the importance of the technical work of the coach towards obtaining a shorter second stride and a longer fifth stride out of the blocks is that it may be a proxy for the ability to rapidly achieve an optimal running form. The negative effect of a long second stride may simply be that it reflects less-than-perfect form and means the athlete is "staggering" out of the blocks.

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CONFLICT OF INTEREST

None.

REFERENCES

Anguera, MT., Blanco, A., Hernández, A. & Losada, JL. (2011). Diseños observacionales: Ajuste y aplicación en psicología del deporte. Cuadernos de Psicología del Deporte, Vol. 11(2), 63-76.

Čoh, M., & Iskra, J. (2012). Biomechanical studies of 110 m hurdle clearance technique. Sport Science, 5 (1), 10-14.

Garhammer, J. & Newton, H. (2013). Applied video analysis for coaches: Weightlifting examples. International Journal of Sports Science & Coaching, 8(3), 581-593. https://doi.org/10.1260/1747-9541.8.3.581

Hommel, H. M. (1997). Biomechanical Research Project at the VIth World Championships in Athletics, Athens 1997. New Studies in Athletics, 2-3, 43-73.

Kari, M. (2013). Kergejõustiku hüppealade hoojooksu ja äratõuke tehnika võrdlev analüüs (Doctoral dissertation, Tartu Ülikool).

Kuitunen, S., & Poon, S. (2010). Kinematic analysis of hurdle clearance of 60-m hurdles in elite hurdle sprinters during world indoor championships 2010. In ISBS – Conference Proceedings Archive (Vol. 1, No. 1).

McDonald, C., & Dapena, J. (1991). Linear kinematics of the men's 110-m and women's 100-m hurdles races. Medicine and Science in Sports and Exercise, 23(12), 1382-1391.

Payton, C. & Barlett, R. (Eds.) (2008). Biomechanical Evaluation of Movement in Sport and Exercise. Routledge: New York.

Pueo, B. (2016). High speed cameras for motion analysis in sports science. Journal of Human Sport and Exercise, 11(1), 53-73. https://doi.org/10.14198/jhse.2016.111.05

Salo, A. I. (2002). Technical changes in hurdle clearances at the beginning of 110 m hurdle event-a pilot study. In ISBS – Conference Proceedings Archive (Vol. 1, No. 1).

Schluter, W. (1981). Kinematische merkmale der 110-m hurdentechnik. Leistungssport, 2, 118-127.

Sidhu, A. S., & Singh, M. (2015). Kinematical analysis of hurdle clearance technique in 110m hurdle race. International Journal of Behavioural Social and Movement Science, 4(2), 28-35.

Wilson, B.D. (2008). Development in video technology for coaching. Sports Technology, 1 (1), 34-40. https://doi.org/10.1080/19346182.2008.9648449