Hints on Computer Processing of Biomechanical Data

P. Sušanka

Department of Biomechanics and Computing Dep., Faculty of Physical Education and Sports, Charles University, Prague, Czechoslovakia

INTRODUCTION

Fieldwork specialists keep insisting that research workers and scientists should provide a faster flow of feedback information and facilitate its application in training with a view to improving performance. Specialized systems of data processing and computer evaluation of kinematic action in elite competitive sports can provide an important answer to the justified calls of coaches and staff in training practice. The first attempts to tackle the problem are still being made: the best evidence is the pervasive vacuum in the pertinent literature.

Individual analyses obtained in a research project undertaken in the period 1977-1987 have provided a wealth of biomechanical data in all track and field events. The research method entailed three-dimensional high-speed cinematography / Photosonics 500 cameras /, dynamography / Kistler biomechanical force plate /, and other measurements, e.g. seismographic and photo-cells, used occasionally, as required mainly by the character of the event concerned.

Simplified information material for coaches and athletes, Fast Information should be considered an intermediate stage in working out the so called specialised expert systems aimed at the computer evaluation of athletic performance and at defining the share of an athlete's action potential in the resulting performance.

An important consideration is that the techniques of obtaining the basic information should not require sophisticated equipment and subsequent processing. We are talking, in other words, of working with videorecordings and/or measurement data provided by photocells — an easy job for any qualified coach.

The progress of the project will now be demonstrated by means of the following track and field events: sprinting - 100 m women; hurdling - 100 m hurdles women; throwing events - shot put; jumping events - triple jump.

It should be emphasized that this is not an exhaustive analysis of an athletic performance that would take into account all the viewpoints available and all the knowledge provided by all the branches of science: what we are concerned with is only technical execution. Moreover, the analysis of execution is limited to material that can be obtained at the individual athlete within 1-2 hrs. of the end of a training sesion or race.

1. Time Analysis of Sprinting (100 m)

1.1. Input information

Reaction time (starting blocks)
Intermediate times over 10 m sections (video with time indicator)
Number of strides throughout the whole race distance and in predetermined sections (videorecording).

1.2. Model intermediate times

Long-term evaluation and statistical processing of sets of measurements were used for determining model intermediate times with a variation range of 9,9 ~ 12,5 s (MORAVEC 1986). Although the sample of athletes evaluated was fairly large, the model intermediate times as published should be taken only as rough indicators.

Model intermediate times for the 10 m sections of the distance computed (BARAC, 1986) for each individual performance according to the mathematical formula:

$$Di(p) = A_i + B_i \cdot e^{\beta_i p}$$

i = 1, 2...10 sections of the 100 m race distance

TABLE 1

SECTION [m]	i	PARAMETERS A_i	B_i	β_i
0-10	1	−169.784901	170.224532	0.000832
10-20	2	0.520091	0.184428	0.102713
20-30	3	0.239470	0.257173	0.102713
30-40	4	0.643084	0.035678	0.205462
40-50	5	−4.122138	4.038998	0.020861
50-60	6	−3.381882	3.349302	0.023828
60-70	7	−163.486199	163.276934	0.000655
70-80	8	−116.472826	116.286426	0.000908
80-90	9	−157.790479	157.639297	0.000653
90-100	10	−151.282319	151.096387	0.000711

Intermediate times Di(p) can only be computed if their sum equals the specific sprinting performance.

$$\sum_{i=1}^{10} D_i(p') \rightarrow p$$

That is guaranteed by the computer with the iteration process.

1.3. Output information

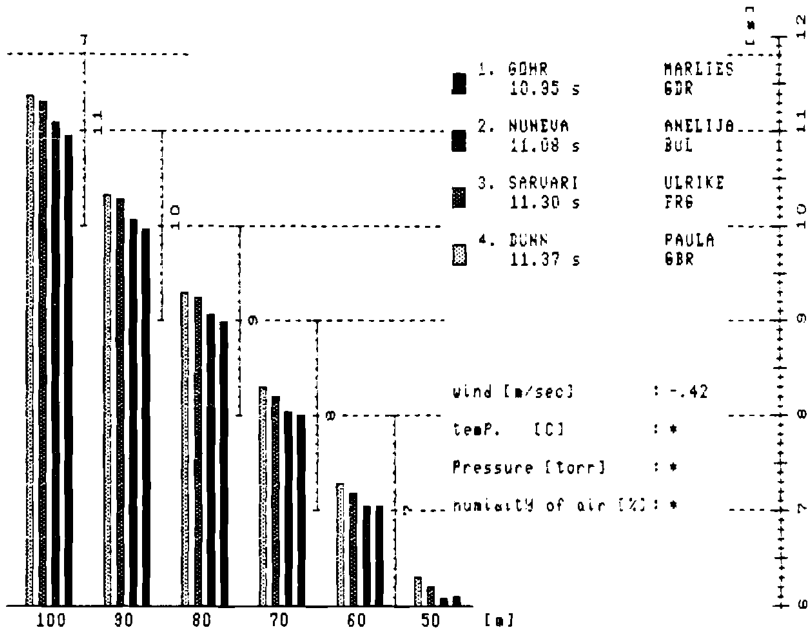
The input information quoted above (Diagrams 1,3 or 2,4) can be used for evaluating:

— starting reaction to the gun;

— times Δt over equidistant distance sections, their percentage value in relation to the maximum velocity over the 10 m sections;

— number of strides, mean stride length and frequency throughout the length of the distance and in chosen sections (Diagrams 3,4).

Comparisons with the model intermediate times can be used for assessing the level of acceleration, speed stamina etc. Training performances in any section (whether starting from blocks or with flying start) can be compared with data from the race (Tables 2, 3, 4).



TIME ANALYSIS OF SPRINT 100 m W F

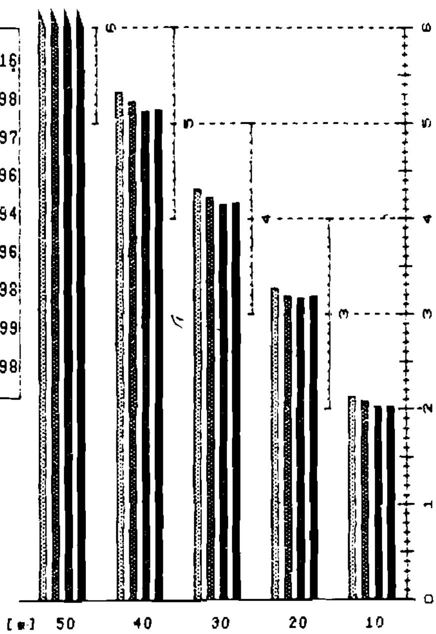
EUROPSKY POHAR PRAHA

BRUNA ZAULIHO 27.-28.06.87

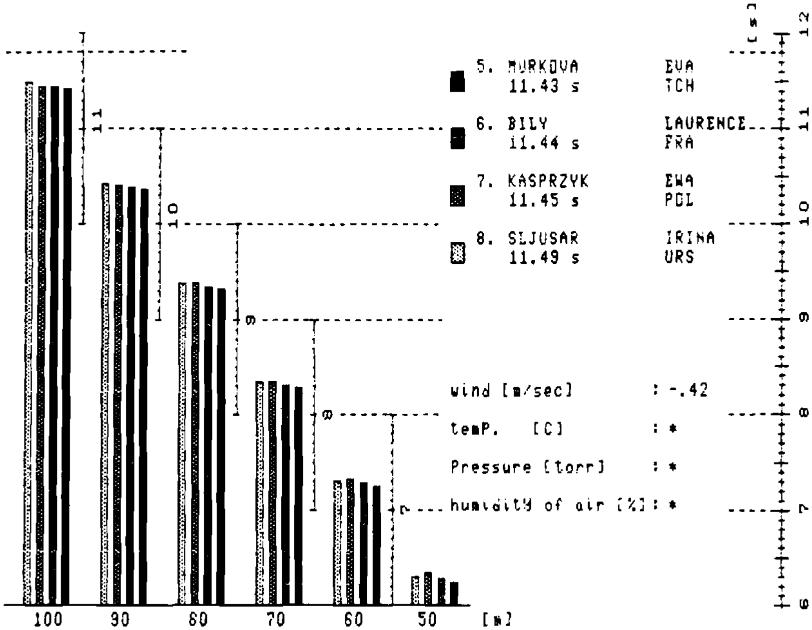
10.	2.12	2.08	2.03	2.03
	1.15	1.11	1.13	1.16
20.	3.27	3.19	3.16	3.19
	1.04	1.04	0.99	0.98
30.	4.31	4.23	4.15	4.17
	1.02	1.00	0.97	0.97
40.	5.33	5.23	5.12	5.14
	0.98	0.98	0.96	0.96
50.	6.31	6.21	6.08	6.10
	0.98	0.98	0.97	0.94
60.	7.29	7.19	7.05	7.04
	1.02	1.01	0.99	0.96
70.	8.31	8.20	8.04	8.00
	1.00	1.04	1.02	0.98
80.	9.31	9.24	9.06	8.98
	1.02	1.04	1.01	0.99
90.	10.33	10.28	10.07	9.97
	1.04	1.02	1.01	0.98
100.	11.37	11.30	11.08	10.95

TIME OF PERFORMANCE: 17:40 - 17:45

EXIT : 06:20 (09:00)



Diag. 1



TIME ANALYSIS OF SPRINT 100 m W F

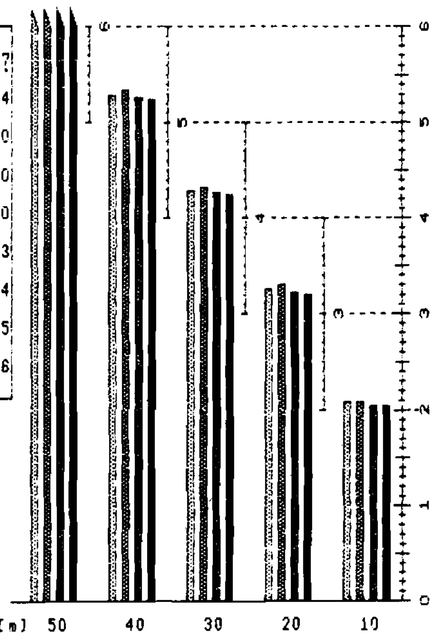
EVROPSKY POHAR PRAHA

BRUNA ZAULIHO 27.-28.06.87

10.	2.09	2.09	2.04	2.04
	1.17	1.21	1.19	1.17
20.	3.26	3.30	3.23	3.21
	1.03	1.03	1.03	1.04
30.	4.29	4.33	4.26	4.25
	1.00	1.02	1.01	1.00
40.	5.29	5.35	5.27	5.25
	1.01	0.99	1.02	1.00
50.	6.30	6.34	6.29	6.25
	1.00	0.99	1.00	1.00
60.	7.30	7.33	7.29	7.25
	1.04	1.02	1.02	1.03
70.	8.34	8.35	8.31	8.28
	1.04	1.03	1.03	1.04
80.	9.38	9.38	9.34	9.32
	1.05	1.03	1.04	1.05
90.	10.43	10.41	10.38	10.37
	1.06	1.04	1.06	1.06
100.	11.49	11.45	11.44	11.43

TIME OF PERFORMANCE: 17:40 - 17:45

EXIT : 06:20 (09:00)



Diag. 2

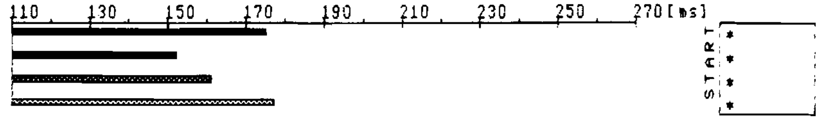
100 m W -F

EUROPSKY POHAR
PRAHA

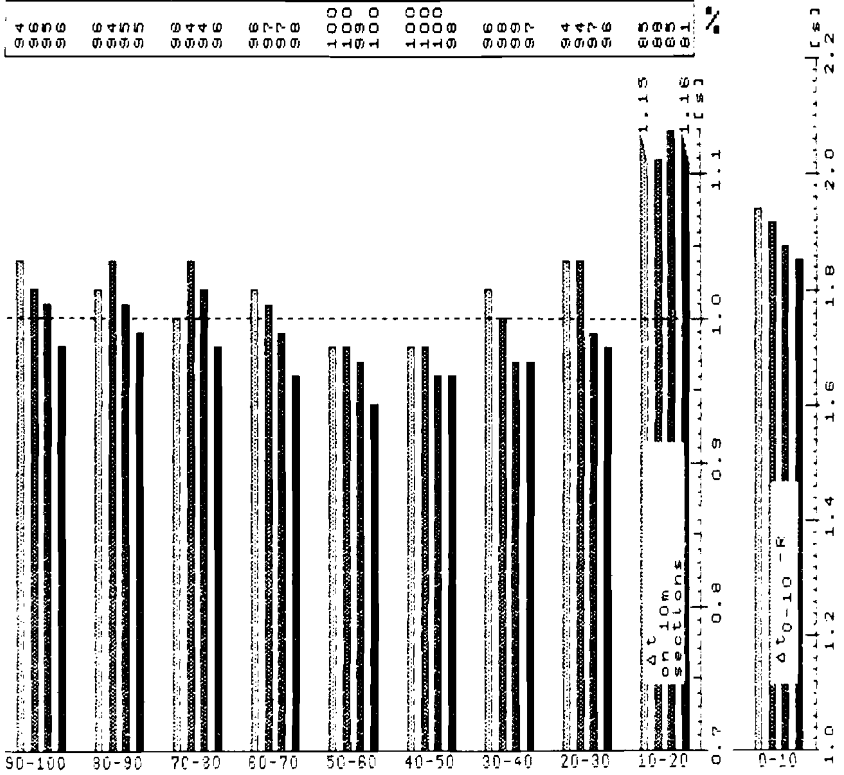
BRUHA ZAULIHO
27.-28.06.87

1. GOHR	2. NUNEVA	3. SARVARI	4. DUNN
10.95 [s]	11.08 [s]	11.30 [s]	11.37 [s]

REACTION TIME



	SECTION	NUMBER STEPS	AVERAGE FREQUENCY STEPS [st/sec]	AVERAGE LENGTH STEPS	THE FASTEST 10m SECTION
1. GOHR	0-100	55.0	5.02	1.82	
	10-30	10.8	5.05	1.85	
	40-60	9.6	5.05	2.08	0.94 / 50-60
	70-90	9.8	4.97	2.04	
2. NUNEVA	0-100	50.9	4.59	1.96	
	10-30	11.0	5.19	1.82	0.96 / 40-50
	40-60	9.7	5.03	2.06	
	70-90	9.9	4.88	2.02	
3. SARVARI	0-100	52.6	4.65	1.90	
	10-30	10.4	4.84	1.92	0.98 / 40-50
	40-60	9.1	4.64	2.20	
	70-90	9.4	4.52	2.13	
4. DUNN	0-100	53.9	4.74	1.86	0.98 / 40-50
	10-30	10.3	4.70	1.94	
	40-60	9.3	4.74	2.15	
	70-90	9.4	4.65	2.13	



Diag. 3

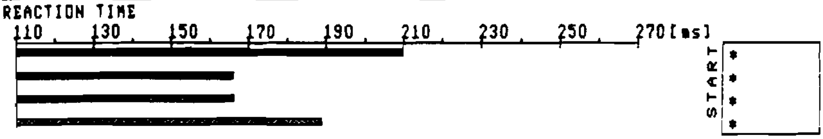
100 m W -F

EUROPSKY POHAR
PRAHA

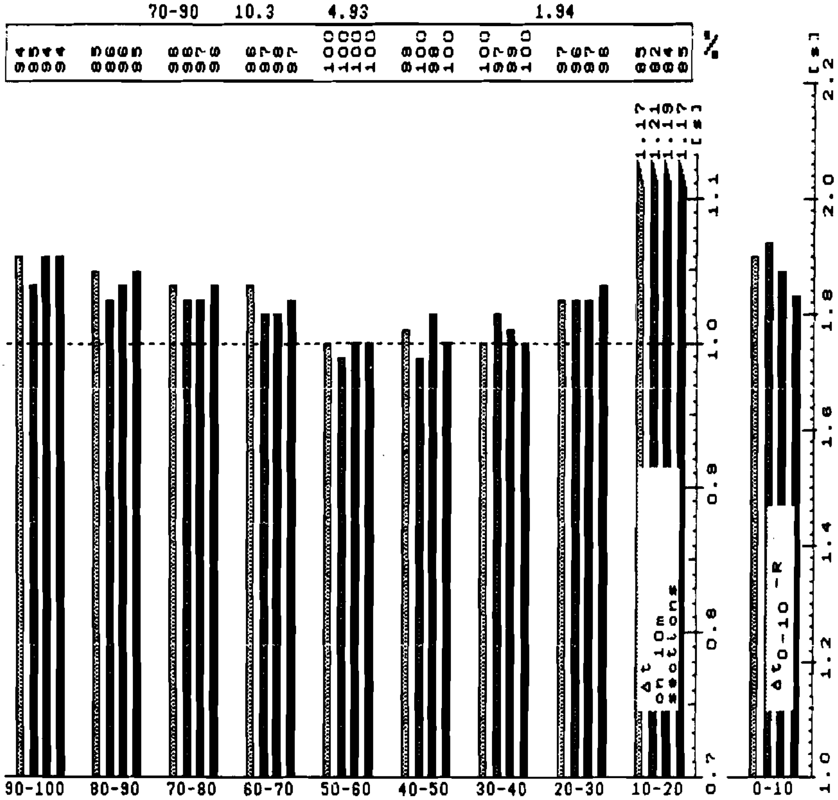
BRUNA ZAULIHO
27.-28.06.87

5. MURKOVA	6. BILY	7. KASPRZYK	8. SLJUSAR
11.43 [s]	11.44 [s]	11.45 [s]	11.49 [s]

REACTION TIME



	SECTION	NUMBER STEPS	AVERAGE FREQUENCY STEPS [st/sec]	AVERAGE LENGTH STEPS	THE FASTEST 10m SECTION
5. MURKOVA	0-100	50.9	4.45	1.96	
	10-30	11.1	5.02	1.80	
	40-60	10.1	5.05	1.98	1.00 / 30-40
	70-90	10.1	4.83	1.98	
6. BILY	0-100	52.4	4.58	1.91	
	10-30	11.2	5.05	1.79	
	40-60	10.0	4.95	2.00	1.00 / 50-60
	70-90	10.0	4.83	2.00	
7. KASPRZYK	0-100	55.3	4.83	1.81	
	10-30	10.5	4.69	1.90	0.99 / 40-50
	40-60	9.6	4.85	2.08	
	70-90	9.8	4.76	2.04	
8. SLJUSAR	0-100	52.7	4.59	1.90	1.00 / 30-40
	10-30	11.4	5.18	1.75	
	40-60	10.3	5.12	1.94	
	70-90	10.3	4.93	1.94	



Diag. 4

TABLE 2

TIME ANALYSIS OF SPRINT 100 m

27.6.87 EUROPEAN CUP 100m WOMEN - F

	100	RT	10	20	30	40	50	60	70	80	90
		---- Model inter mediate time ---									

10 m	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-1
Speed V1-10	V01	V12	V23	V34	V45	V56	V67	V78	V89	V91
20 m	0-2	1-3	2-4	3-5	4-6	5-7	6-8	7-9	8-1	
30 m	0-3	1-4	2-5	3-6	4-7	5-8	6-9	7-0		
40 m	0-4	1-5	2-6	3-7	4-8	5-9	6-0			
50 m	0-5	1-6	2-7	3-8	4-9	5-0				
60 m	0-6	1-7	2-8	3-9	4-0					
70 m	0-7	1-8	2-9	3-0						
80 m	0-8	1-9	2-0							
90 m	0-9	1-0								

1. GOnR M.

		100	10	20	30	40	50	60	70	80	90
(1958)	GDR	10.95	2.03	3.19	4.17	5.14	6.10	7.04	8.00	8.98	9.97
Model :		10.95	2.00	3.09	4.12	5.11	6.06	7.02	7.98	6.96	9.95

10 m	2.03	1.16	0.98	0.97	0.96	0.94	0.96	0.98	0.99	0.98
Speed V1-10	4.92	8.62	10.20	10.30	10.41	10.63	10.41	10.20	10.10	10.20
20 m	3.19	2.14	1.95	1.93	1.90	1.90	1.94	1.97	1.97	
30 m	4.17	3.11	2.91	2.87	2.86	2.88	2.93	2.95		
40 m	5.14	4.07	3.85	3.83	3.84	3.87	3.91			
50 m	6.10	5.01	4.81	4.81	4.83	4.85				
60 m	7.04	5.97	5.79	5.80	5.81					
70 m	8.00	6.95	6.78	6.78						
80 m	8.98	7.94	7.76							
90 m	9.97	8.92								

2. NUNEVA A.

		100	10	20	30	40	50	60	70	80	90
(1962)	BUL	11.08	2.03	3.16	4.15	5.12	6.08	7.05	8.04	9.06	10.07
Model :		11.08	2.02	3.12	4.16	5.16	6.12	7.10	8.09	9.08	10.07

10 m	2.03	1.13	0.99	0.97	0.96	0.97	0.99	1.02	1.01	1.01
Speed V1-10	4.92	8.84	10.10	10.30	10.41	10.30	10.10	9.80	9.90	9.90
20 m	3.16	2.12	1.96	1.93	1.93	1.96	2.01	2.03	2.02	
30 m	4.15	3.09	2.92	2.90	2.92	2.98	3.02	3.04		
40 m	5.12	4.05	3.89	3.89	3.94	3.99	4.03			
50 m	6.08	5.02	4.88	4.91	4.95	5.00				
60 m	7.05	6.01	5.90	5.92	5.96					
70 m	8.04	7.03	6.91	6.93						
80 m	9.06	8.04	7.92							
90 m	10.07	9.05								

TABLE 3

	100	RT	10	20	30	40	50	60	70	80	90
		---- Model intermediate time ---									
10 m		0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-1
Speed V1-10		V01	V12	V23	V34	V45	V56	V67	V78	V89	V91
20 m		0-2	1-3	2-4	3-5	4-6	5-7	6-8	7-9	8-1	
30 m		0-3	1-4	2-5	3-6	4-7	5-8	6-9	7-0		
40 m		0-4	1-5	2-6	3-7	4-8	5-9	6-0			
50 m		0-5	1-6	2-7	3-8	4-9	5-0				
60 m		0-6	1-7	2-8	3-9	4-0					
70 m		0-7	1-8	2-9	3-0						
80 m		0-8	1-9	2-0							
90 m		0-9	1-0								

	100	RT	10	20	30	40	50	60	70	80	90
3. SARVARI L.											
(1964) FRG	11.30		2.08	3.19	4.23	5.23	6.21	7.19	8.20	9.24	10.28
Model :	11.30		2.07	3.18	4.23	5.22	6.22	7.22	8.23	9.24	10.26
10 m		2.08	1.11	1.04	1.00	0.98	0.98	1.01	1.04	1.04	1.02
Speed V1-10		4.80	9.00	9.61	10.00	10.20	10.20	9.90	9.61	9.61	9.80
20 m		3.19	2.15	2.04	1.96	1.96	1.99	2.05	2.08	2.06	
30 m		4.23	3.15	3.02	2.96	2.97	3.03	3.09	3.10		
40 m		5.23	4.15	4.06	3.97	4.01	4.07	4.11			
50 m		6.21	5.11	5.01	5.01	5.05	5.05				
60 m		7.19	5.12	6.05	6.05	6.07					
70 m		8.20	7.16	7.09	7.07						
80 m		9.24	8.10	8.11							
90 m		10.28	9.22								
4. DUNN P.											
(1964) GBR	11.37		2.12	3.27	4.31	5.33	6.31	7.29	8.31	9.31	10.33
Model :	11.37		2.08	3.19	4.24	5.24	6.25	7.26	6.25	9.30	10.32
10 m		2.12	1.15	1.04	1.02	0.98	0.95	1.02	1.00	1.02	1.04
Speed V1-10		4.71	8.69	9.61	9.80	10.20	10.20	9.80	10.00	9.80	9.61
20 m		3.27	2.19	2.06	2.00	1.96	2.00	2.02	2.02	2.06	
30 m		4.31	3.21	3.04	2.98	2.96	3.00	3.04	3.06		
40 m		5.33	4.19	4.02	4.00	3.98	4.02	4.06			
50 m		6.31	5.17	5.04	5.00	5.00	5.06				
60 m		7.29	6.19	6.04	6.02	6.04					
70 m		8.31	7.19	7.06	7.05						
80 m		9.31	8.21	8.10							
90 m		10.33	9.25								
5. MURKOVA E.											
(1962) TCH	11.43		2.04	3.21	4.25	5.25	6.25	7.25	8.28	9.32	10.37
Model :	11.43		2.08	3.20	4.26	5.26	6.26	7.30	8.32	9.35	10.36
10 m		2.04	1.17	1.04	1.00	1.00	1.00	1.03	1.04	1.05	1.06
Speed V1-10		4.90	8.54	9.61	10.00	10.00	10.00	9.70	9.61	9.52	9.43
20 m		3.21	2.21	2.04	2.00	2.00	2.03	2.07	2.09	2.11	
30 m		4.25	3.21	3.04	3.00	3.03	3.07	3.12	3.15		
40 m		5.25	4.21	4.04	4.03	4.07	4.12	4.18			
50 m		6.25	5.21	5.07	5.07	5.12	5.18				
60 m		7.25	6.24	6.11	6.12	6.18					
70 m		8.28	7.28	7.16	7.18						
80 m		9.32	8.33	8.22							
90 m		10.37	9.39								

TABLE 4

	100	RT	10	20	30	40	50	60	70	80	90	
			---- Model intermediate time ---									
10 m			0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-0
Speed V1-10			V01	V12	V23	V34	V45	V56	V67	V78	V89	V90
20 m			0-2	1-3	2-4	3-5	4-6	5-7	6-8	7-9	8-	
30 m			0-3	1-4	2-5	3-6	4-7	5-8	6-9	7-0		
40 m			0-4	1-5	2-6	3-7	4-8	5-9	6-0			
50 m			0-5	1-6	2-7	3-8	4-9	5-0				
60 m			0-6	1-7	2-8	3-9	4-0					
70 m			0-7	1-8	2-9	3-0						
80 m			0-8	1-9	2-0							
90 m			0-9	1-0								

	100	RT	10	20	30	40	50	60	70	80	90	
6. BILY L.												
(1960) FRA	11.44		2.04	3.23	4.26	5.27	6.29	7.29	8.31	9.34	10.38	
Model :	11.44		2.08	3.20	4.26	5.26	6.28	7.30	8.33	9.36	10.39	
10 m			2.04	1.19	1.03	1.01	1.02	1.00	1.02	1.03	1.04	1.06
Speed V1-10			4.90	8.40	9.70	9.90	9.80	10.00	9.80	9.70	9.61	9.43
20 m			3.23	2.22	2.04	2.03	2.02	2.02	2.05	2.07	2.10	
30 m			4.26	3.23	3.06	3.03	3.04	3.05	3.09	3.13		
40 m			5.27	4.25	4.06	4.05	4.07	4.09	4.15			
50 m			6.29	5.25	5.08	5.08	5.11	5.15				
60 m			7.29	6.27	6.11	6.12	6.17					
70 m			8.31	7.30	7.15	7.18						
80 m			9.34	8.34	8.21							
90 m			10.38	9.40								

	100	RT	10	20	30	40	50	60	70	80	90	
7. KASPRZYK E.												
(1957) POL	11.45		2.09	3.30	4.33	5.35	6.34	7.33	8.35	9.38	10.41	
Model :	11.45		2.09	3.21	4.27	5.27	6.29	7.31	8.34	9.37	10.40	
10 m			2.09	1.21	1.03	1.02	0.99	0.99	1.02	1.03	1.03	1.04
Speed V1-10			4.78	8.26	9.70	9.80	10.10	10.10	9.80	9.70	9.70	9.61
20 m			3.30	2.24	2.05	2.01	1.98	2.01	2.05	2.06	2.07	
30 m			4.33	3.25	3.04	3.00	3.00	3.04	3.06	3.10		
40 m			5.35	4.25	4.03	4.02	4.03	4.07	4.12			
50 m			6.34	5.24	5.05	5.05	5.06	5.11				
60 m			7.33	6.26	6.08	6.08	6.10					
70 m			8.35	7.29	7.11	7.12						
80 m			9.38	8.32	8.15							
90 m			10.41	9.36								

	100	RT	10	20	30	40	50	60	70	80	90	
8. SLJUSAR I.												
(1963) URS	11.49		2.09	3.26	4.29	5.29	6.30	7.30	8.34	9.38	10.43	
Model :	11.49		2.09	3.21	4.28	5.29	6.31	7.33	8.36	9.39	10.43	
10 m			2.09	1.17	1.03	1.00	1.01	1.00	1.04	1.04	1.05	1.06
Speed V1-10			4.78	8.54	9.70	10.00	9.90	10.00	9.61	9.61	9.52	9.43
20 m			3.26	2.20	2.03	2.01	2.01	2.04	2.08	2.09	2.11	
30 m			4.29	3.20	3.04	3.01	3.05	3.08	3.13	3.15		
40 m			5.29	4.21	4.04	4.05	4.09	4.13	4.19			
50 m			6.30	5.21	5.08	5.09	5.14	5.19				
60 m			7.30	6.25	6.12	6.14	6.20					
70 m			8.34	7.29	7.17	7.20						
80 m			9.38	8.34	8.23							
90 m			10.43	9.40								

Note: All the examples are taken from «FAST INFORMATION» produced at the Europe Cup Group A (June 27-28, 1987) for the benefit of the best European teams participating in the Meet (SUŠANKA, ŠTĚPÁNEK, BÖSWART et al. 1987). The departments processing the various output data can be found with the respective Tables and Diagrams (BARAC, BÖSWART, JURDÍK, SUŠANKA, ŠTĚPÁNEK).

2. Analysis of Intermediate Times in 100 m Hurdles Women

2.1. Input information
Reaction time (starting blocks)
Intermediate times taken at each touchdown (video with time indicator)

2.2. Model intermediate times
A correlation dependence is assumed between the times measured at each touchdown and the resulting performance in the race. The technique was used in processing first extensive samples from the 1978 European Championships, and published in a graduate thesis (ČECH, 1979).

The dependent variable is the time of touchdown (t_D), the independent variable is the resulting performance (t_p). The correlation coefficient is computed from the well-known equation

$$r_{xy} = \frac{n\sum x_i y_i - \sum x_i \sum y_i}{\sqrt{[n\sum x_i^2 - (\sum x_i^2)^2] \cdot [n\sum y_i^2 - (\sum y_i)^2]}}$$

When correlation dependence occurs, the method of regression analysis is applied. The regression line is assumed to be a straight line

$$y(x) = \beta_0 + \beta_1 x$$

Parameters β_0, β_1 entail

$$\beta_0 = \frac{\sum y_i \sum x_i^2 - \sum x_i \sum y_i x_i}{n\sum x_i^2 - (\sum x_i)^2}$$

$$\beta_1 = \frac{n\ y_i x_i - y_i\ x_i}{n\sum x_i^2 - (\sum x_i)^2}$$

n — the amount of data measured

β_0 — expresses the deflection of the intersection of the regression straight line with the y axis from the origin of the coordinate system.

β_1 — tangent of the direction angle of the regression straight line, termed the regression coefficient b_{yx}. In this case, b_{yx} expresses the change of touchdown with a one-second change of the resulting performance.

After taking into account all the preceding measurements, including the 1987 Europe Cup Group A, we express the parameters β_0, β_1 for the separate sections of the race distance. The sections are defined by the touchdowns behind the hurdles.

TABLE 5

i	r_{xy}	β_0	β_1
1	0.785	1.014234	0.123020
2	0.894	1.154528	0.193109
3	0.922	1.196221	0.268690
4	0.941	1.059026	0.356691
5	0.963	0.811444	0.452973
6	0.972	0.774013	0.533517
7	0.980	0.540810	0.629836
8	0.985	0.529617	0.709849
9	0.992	−0.010862	0.831104
10	0.995	0.104971	0.904030

For better orientation, the lay-out of the measured values, the correlation coefficients and the parameters β_0 and β_1 are shown on figures 1, 2, 3. It is obvious that the regression straight lines pass in close proximity to the origin (see magnitude β_0).

(**Note:** Only those measurements in which the athlete has approximated his personal best can be included in the set of data. That is also true of other methods where statistical data processing is used).

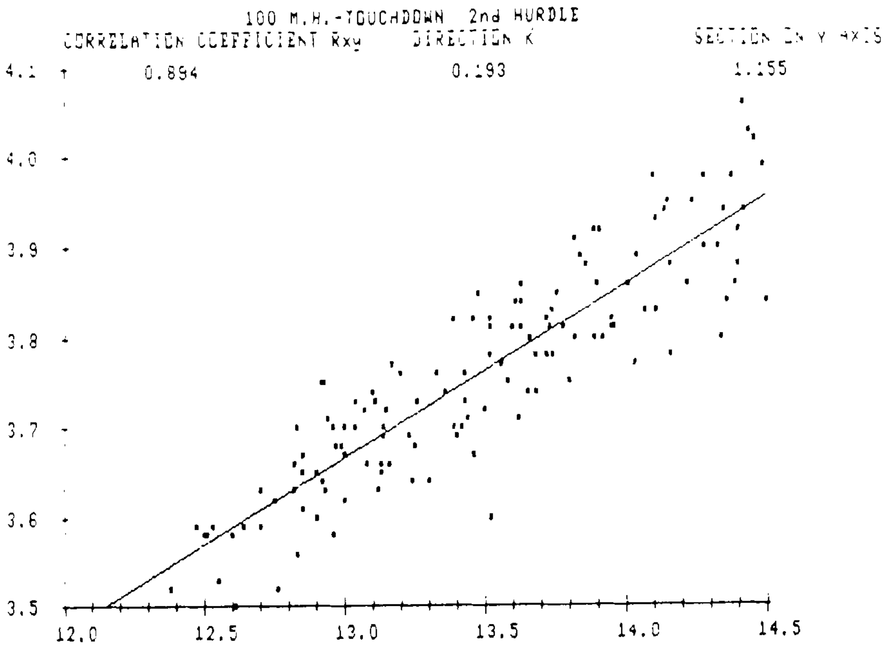

100 M.H.-TOUCHDOWN 2nd HURDLE
CORRELATION COEFFICIENT Rxy
DIRECTION K
SECTION ON Y AXIS
0.894
0.193
1.155
4.1
4.0
3.9
3.8
3.7
3.6
3.5
12.0
12.5
13.0
13.5
14.0
14.5

Fig. 1

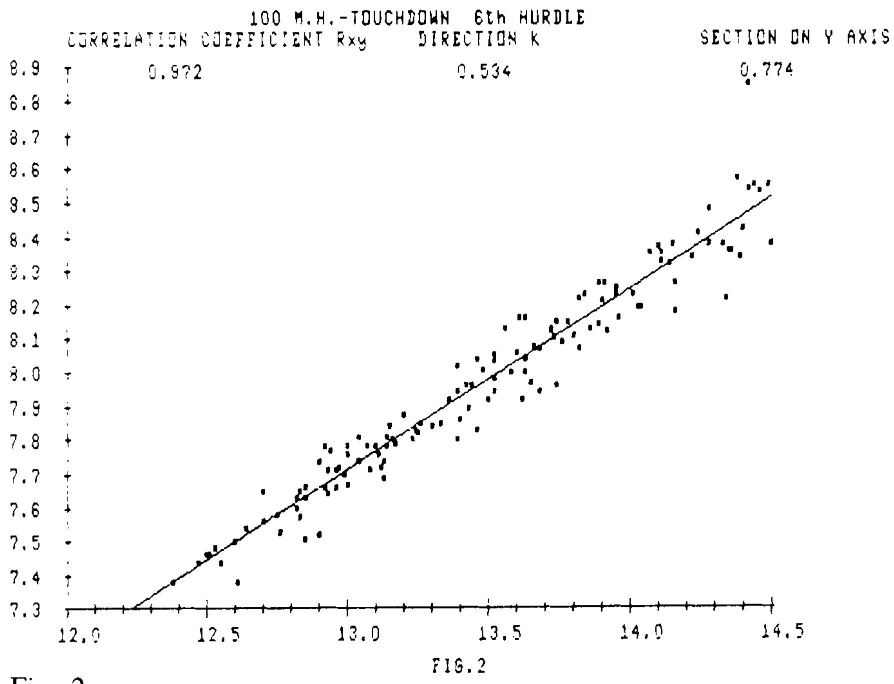

100 M.H.-TOUCHDOWN 6th HURDLE
CORRELATION COEFFICIENT Rxy
DIRECTION K
SECTION ON Y AXIS
0.972
0.534
0.774
8.9
8.8
8.7
8.6
8.5
8.4
8.3
8.2
8.1
8.0
7.9
7.8
7.7
7.6
7.5
7.4
7.3
12.0
12.5
13.0
13.5
14.0
14.5
FIG.2

Fig. 2

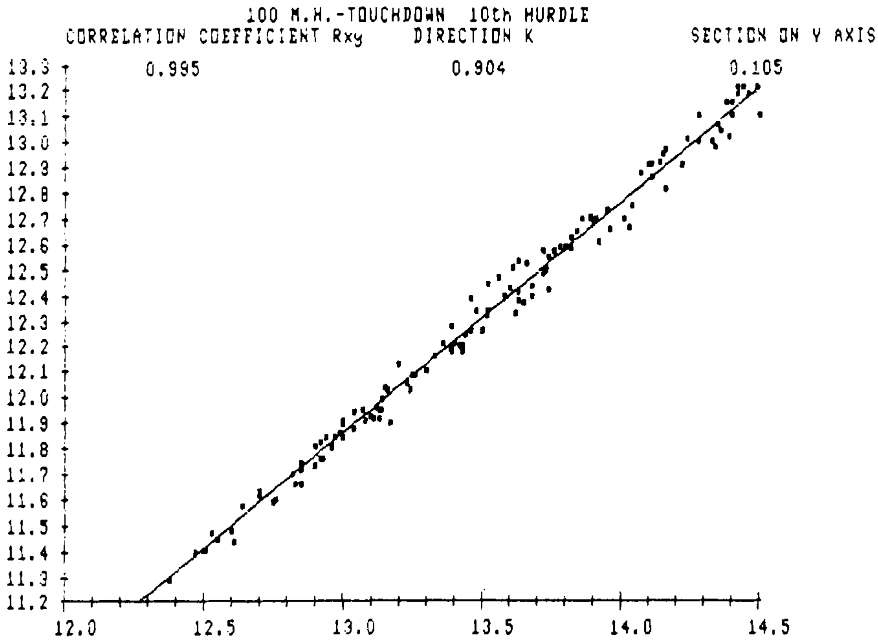


Fig. 3

In the course of extending the set, parameter β_0 was diminished. Consequently, the method was simplified, and the original regression straight lines were replaced by straight lines cutting through the origin.

The turning round points with the x-coordinate $\bar{x}$ [arithmetic mean (n = 180)] and the y - coordinate $\bar{y}_i = \beta_0 + \beta_1\bar{x}$ (Fig. 4, 5).

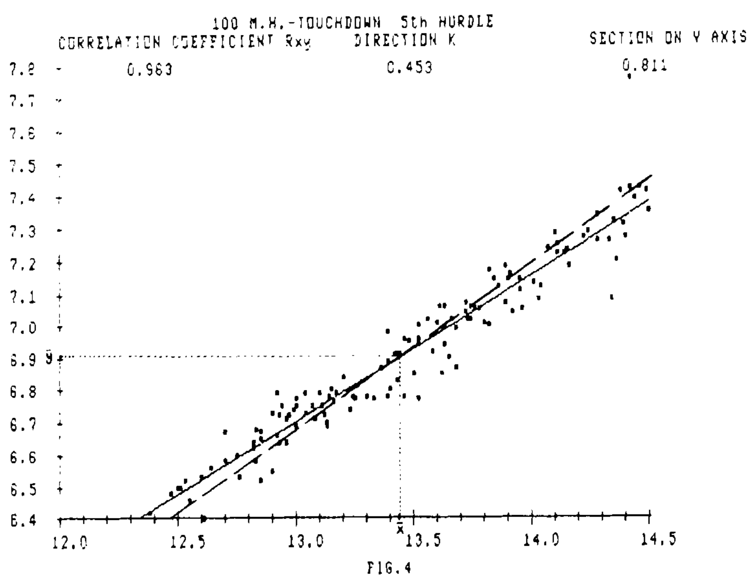


Fig. 4

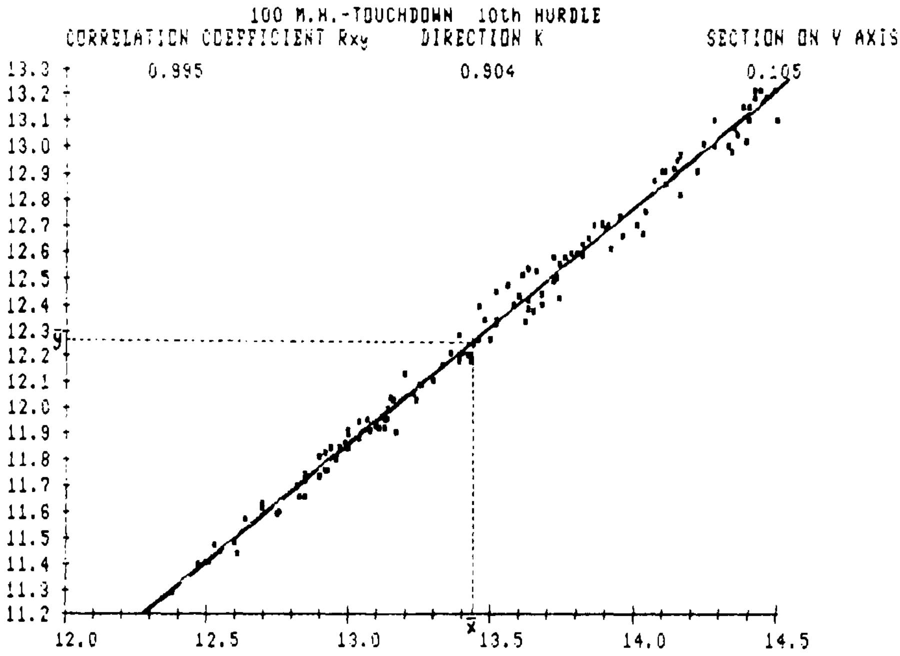


Fig. 5

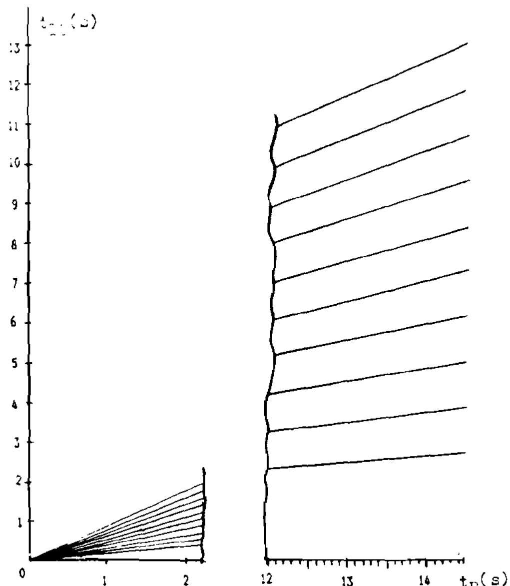


Fig. 6

In that way we obtain a system of regressive straight lines cutting through the origin (Fig. 6).

$$y = k_i x \qquad i = 1,2 \ldots 10$$

$$k_i = tg y_i$$

TABLE 6

i	K_i
1	0.198216
2	0.278706
3	0.357378
4	0.435208
5	0.513133
6	0.590900
7	0.669931
8	0.749146
9	0.830299
10	0.911812

Let us assume that for a certain performance the dependence between the average speed and the distance approximates the shape of a concave parabola. (During the performance the average speed between hurdles gains it maximum).

It follows from the system of regression straights that the touchdown time behind a i-hurdle is direct proportional to the constant k_i (i indicates the order of hurdles). From the relations for two subsequent touchdown times

$$t_{di} = p \cdot k_i$$
$$t_{di-1} = p \cdot k_{i-1}$$

we derive the relation for the time difference between the hurdles

$$\Delta t_i = t_{di} - t_{di-1} = p \cdot (k_i - k_{i-1}) = I - \Delta k_i$$

It is obvious that the time difference between the hurdles Δt_i is indirect proportional to the average speed. Consequently, the dependence of time differences on distance has a shape of a convex parabola.

It follows from the precedent relation that for a given performance /P=constant/ the time differences are direct proportional to the differences between separate k : consequently, the dependence of Δk_i on the distance is also expressed by a convex parabola.

From the relation for time differences it ensues that

$$\Delta k_i = k_i - k_{i-1} \qquad i = 2,3,\cdots,10$$

The least squares method produces the relations for the absolute term.

$$\beta^*_0 = \frac{\sum y_i \sum x_i^4 - \sum x_i^2 \sum y_i x_i}{n \sum x_i^4 - (\sum x_i^2)^2}$$

the linear term

$$\beta^*_1 = \frac{\sum y_i x_i}{\sum x_i^2}$$

the quadratic term

$$\beta^*_2 = \frac{n \sum y_i x_i^2 - \sum y_i \sum x_i^2}{n \sum x_i^4 - (\sum x_i^2)^2}$$

y_i .... difference ($\triangle k_2, \triangle k_3 \ldots \triangle k_{10}$)

x_i .... intervals ($x_i = -4, \cdots, 0, \cdots, +4$)

n .... number of intervals = 9

These relations are valid only for $\sum x_i = 0$ a transformation must therefore be carried out:

$x_i = 2,3,\ldots,10 \rightarrow X_I = -4,\ldots,0,\ldots,+4$

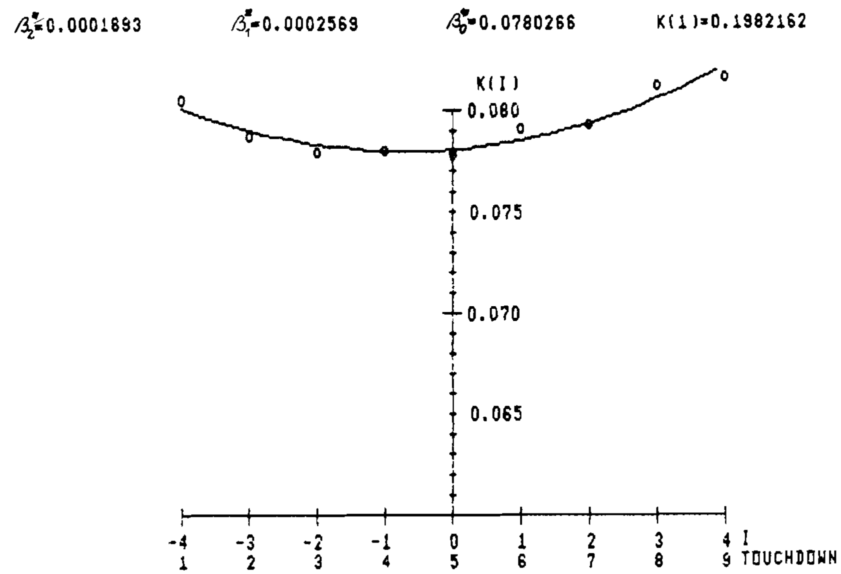


Fig. 7

The relation for computing the differences $\triangle k_i$, i = 2,3,...,10 can now be expressed by the following relation:

$$\triangle k_{i+6} = \beta^*_2 \cdot i^2 + \beta^*_1 \cdot i + \beta^*_0 \qquad i = -4,\ldots,0,\ldots+4$$

TABLE 7

j	i	REAL $\triangle k_j$	FROM PARABOLA $\triangle k_{i+6}$
2	−4	0.080489	0.080028
3	−3	0.078672	0.078960
4	−2	0.077830	0.078290
5	−1	0.077925	0.077959
6	0	0.077767	0.078027
7	1	0.079031	0.078473
8	2	0.079215	0.079297
9	3	0.081153	0.080501
10	4	0.081513	0.082083

$$\triangle k_i = \beta^*_2 \cdot i^2 + \beta^*_1 \cdot i + \beta^*_0$$

The regression-parabola equation thus computed can be used for deriving adjusted constants k for each interval; on that basis, the regressive coefficients k^*_i for each hurdle can be adjusted. In that way the definitive shape of the regression straight lines is obtained:

$$y = k^*_i x$$

where y .... time of touchdown
x .... resulting performance (s).

The regressive straight lines available can now be used for computing the «optimal» touchdown times for the respective performance.

Let us further assume that the relations quoted above are valid for the closest vicinity of the extreme values of the definition field under scrutiny, i.e. extrapolation can be applied within at least ± 0.3 s.

Computing the general relation for touchdown time

$$D_i = (k_i + \triangle k_i)p \qquad (s)$$

$$\triangle k_i = \triangle k_i(\beta^*_0, \beta^*_1, \beta^*_2)$$

$$D_i = D_i(\beta^*_0, \beta^*_1, \beta^*_2, k_1)$$

A more promising approach is likely to be the reverse: from the regression coefficient for touchdown behind the 10th hurdle where the correlation between touchdown time and overall performance significantly approaches one (0.995).

Touchdown is thus computed in the following way:

$$D_i = (k_1 + \beta^*_0 x_i + \beta^*_1 \sum x_i + \beta^*_2 \sum x_i^2)p \qquad (s)$$

where

D_i .... time of touchdown
x_i .... hurdle ($x_i = -4,\ldots,0,\ldots,+4$)

p .... overall performance
k_1 .... interval regression coefficient for 1st-Hurdles

In the 100 m hurdles

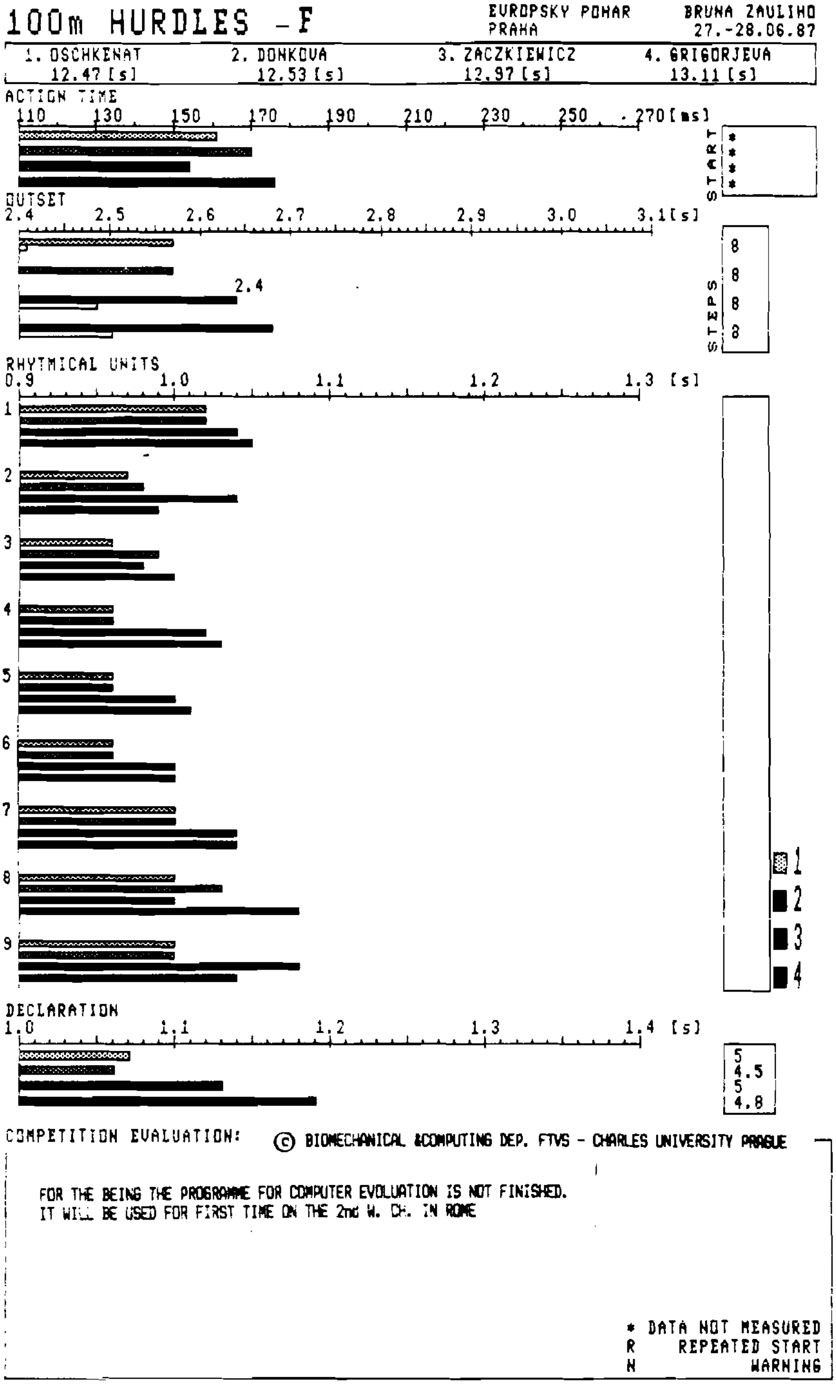
k_1	= 0,1982162
β^*_0	= 0,0780266
β^*_1	= 0,0002569
β^*_2	= 0,0001893

2.3. Output information (Diagrams 5,6; Tables 8,9)

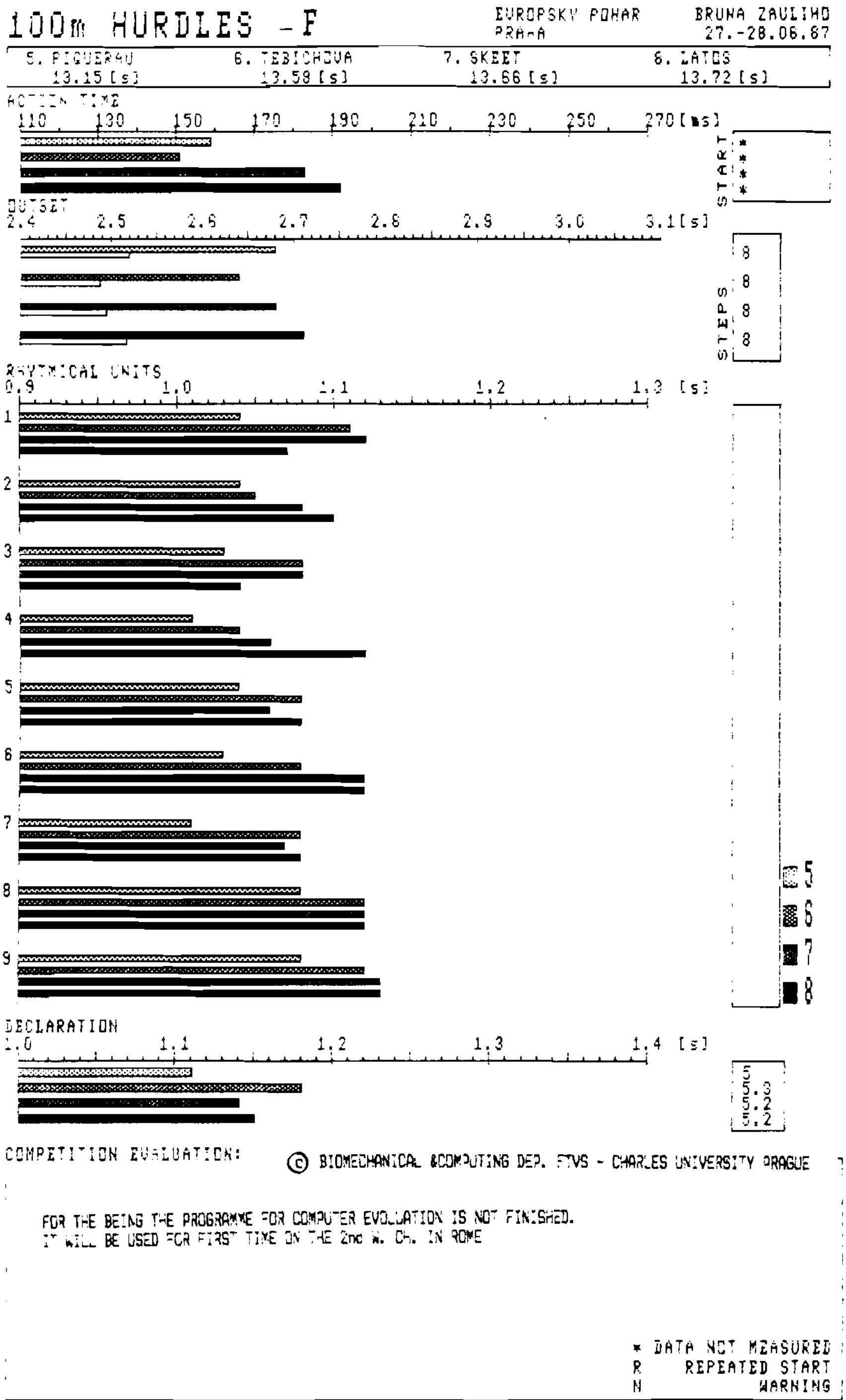
The level of reaction time at the start, and acceleration in the course of the run-up and the first two intervals.

Evaluation of the ability of keeping up the rhythm and minimum time in each interval (rhythmic unit), and the level of the special «hurdling speed stamina».

At the same time, it is possible (much as in sprinting, the above example) to evaluate the course of the whole event and to judge the potential, special skills and shortcomings of each athlete that may have affected the placing in the race.


100m HURDLES -F
EUROPSKY POHAR PRAHA
BRUNA ZAULIHO 27.-28.06.87
1. OSCHKENAT 12.47 [s]
2. DONKOVA 12.53 [s]
3. ZACZKIEWICZ 12.97 [s]
4. GRIGORJEVA 13.11 [s]
ACTION TIME
110 130 150 170 190 210 230 250 270 [ms]
START
* * * *
OUTSET
2.4 2.5 2.6 2.7 2.8 2.9 3.0 3.1 [s]
2.4
STEPS
8 8 8 8
RHYTMICAL UNITS
0.9 1.0 1.1 1.2 1.3 [s]
1 2 3 4 5 6 7 8 9
1 2 3 4
DECLARATION
1.0 1.1 1.2 1.3 1.4 [s]
5 4.5 5 4.8
COMPETITION EVALUATION:
© BIOMECHANICAL &COMPUTING DEP. FTVS - CHARLES UNIVERSITY PRAGUE
FOR THE BEING THE PROGRAMME FOR COMPUTER EVOLUATION IS NOT FINISHED.
IT WILL BE USED FOR FIRST TIME ON THE 2nd W. CH. IN ROME
* DATA NOT MEASURED
R REPEATED START
N WARNING

Diag. 5


100m HURDLES -F
EUROPSKY POHAR PRAHA
BRUNA ZAULIHO 27.-28.06.87
5. PIGUERAU 13.15 [s]
6. TEBICHOVA 13.58 [s]
7. SKEET 13.66 [s]
8. LATOS 13.72 [s]
ACTION TIME
110 130 150 170 190 210 230 250 270 [ms]
START
* * * *
OUTSET
2.4 2.5 2.6 2.7 2.8 2.9 3.0 3.1 [s]
STEPS
8 8 8 8
RHYTMICAL UNITS
0.9 1.0 1.1 1.2 1.3 [s]
1 2 3 4 5 6 7 8 9
5 6 7 8
DECLARATION
1.0 1.1 1.2 1.3 1.4 [s]
5 5.3 5.2 5.2
COMPETITION EVALUATION:
© BIOMECHANICAL &COMPUTING DEP. FTVS - CHARLES UNIVERSITY PRAGUE
FOR THE BEING THE PROGRAMME FOR COMPUTER EVOLLATION IS NOT FINISHED.
IT WILL BE USED FOR FIRST TIME ON THE 2nd W. Ch. IN ROME
* DATA NOT MEASURED
R REPEATED START
N WARNING

Diag. 6

TABLE 8

100m HURDLES

EUROPSKY POHAR PRAHA — BRUNA ZAULIHO 27.-28.06.87

TIME ANALYSIS — FINAL

PLACING 1.	OSCHKENAT	CORNELIA	61	GDR	RESULT 12.47						
HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.57	3.59	4.56	5.52	6.48	7.44	8.40	9.40	10.40	11.40	12.47
B.	2.47	3.47	4.46	5.43	6.41	7.38	8.36	9.35	10.35	11.37	12.47
C.		1.02	0.97	0.96	0.96	0.96	0.96	1	1	1	1.07
D.		1.00	0.99	0.98	0.97	0.97	0.98	0.99	1.00	1.02	1.10
E.	-0.05	-0.07	-0.05	-0.04	-0.02	-0.01	---	---	-0.01	---	

PLACING 2.	DONKOVA	JORDANKA	61	BUL	RESULT 12.53						
HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.57	3.59	4.57	5.56	6.52	7.48	8.44	9.44	10.47	11.47	12.53
B.	2.49	3.49	4.48	5.46	6.44	7.41	8.40	9.39	10.40	11.43	12.53
C.		1.02	0.98	0.99	0.96	0.96	0.96	1	1.03	1	1.06
D.		1.00	0.99	0.98	0.98	0.98	0.98	0.99	1.01	1.03	1.10
E.	-0.03	-0.05	-0.04	-0.05	-0.03	-0.02	---	---	-0.03	---	

PLACING 3.	ZACZKIEWICZ	CLAUDIA	62	FRG	RESULT 12.97						
HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.64	3.68	4.72	5.70	6.72	7.72	8.72	9.76	10.76	11.84	12.97
B.	2.57	3.61	4.64	5.65	6.66	7.67	8.69	9.72	10.76	11.83	12.97
C.		1.04	1.04	0.98	1.02	1	1	1.04	1	1.08	1.13
D.		1.04	1.02	1.02	1.01	1.01	1.02	1.03	1.04	1.06	1.14
E.	-0.02	-0.02	-0.03	---	-0.01	---	---	---	---	---	

PLACING 4.	GRIGORJEVA	NATALJA	62	URS	RESULT 13.11						
HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.68	3.73	4.72	5.72	6.75	7.76	8.76	9.80	10.88	11.92	13.11
B.	2.60	3.65	4.69	5.71	6.74	7.76	8.79	9.83	10.88	11.95	13.11
C.		1.05	0.99	1	1.03	1.01	1	1.04	1.08	1.04	1.19
D.		1.05	1.04	1.03	1.02	1.02	1.03	1.04	1.05	1.08	1.16
E.	-0.03	-0.03	---	---	---	---	---	---	---	---	

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
TOLERANCE:	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.04	±0.04

A. REAL TOUCH DOWN
B. MODEL TOUCH DOWN
C. REAL RYTHMICAL UNIT
D. MODEL RYTHMICAL UNIT
E. DEVIATION FROM THE MODEL

TIME OF MEASURMENT: 17:00 - 17:03
OUTPUT: 23:40 (13:00)

TABLE 9

100m HURDLES

EUROPSKY POHAR PRAHA

BRUNA ZAULIHO 27.-28.06.87

TIME ANALYSIS — FINAL

PLACING 5.	PIQUERAU	ANNE	64	FRA	RESULT 13.15					
HURDLES:										
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.68	3.72	4.76	5.79	6.80	7.84	8.87	9.88	10.96	12.04	13.15
B.	2.61	3.66	4.70	5.73	6.76	7.78	8.81	9.86	10.91	11.99	13.15
C.		1.04	1.04	1.03	1.01	1.04	1.03	1.01	1.08	1.08	1.11
D.		1.05	1.04	1.03	1.03	1.03	1.03	1.04	1.06	1.08	1.16
E.	-0.02	-0.01	-0.01	-0.01	---	-0.01	-0.01	---	-0.01	-0.01	

PLACING 6. TEBICHOVA MILENA 62 TCH RESULT 13.58

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.64	3.75	4.80	5.88	6.92	8.00	9.08	10.16	11.28	12.40	13.58
B.	2.69	3.78	4.85	5.92	6.98	8.04	9.10	10.18	11.27	12.38	13.58
C.		1.11	1.05	1.08	1.04	1.08	1.08	1.08	1.12	1.12	1.18
D.		1.09	1.07	1.06	1.06	1.06	1.07	1.08	1.09	1.11	1.20
E.	---	---	---	---	+0.01	---	---	---	---	---	

PLACING 7. SKEET LESLEY 67 GBR RESULT 13.66

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.68	3.80	4.88	5.96	7.02	8.08	9.20	10.27	11.39	12.52	13.66
B.	2.71	3.80	4.88	5.95	7.02	8.08	9.15	10.24	11.34	12.46	13.66
C.		1.12	1.08	1.08	1.06	1.06	1.12	1.07	1.12	1.13	1.14
D.		1.09	1.08	1.07	1.06	1.07	1.07	1.08	1.10	1.12	1.20
E.	---	---	---	---	---	---	---	---	-0.01	-0.02	

PLACING 8. LATOS BARBARA 65 POL RESULT 13.72

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	FINISH
A.	2.71	3.78	4.88	5.92	7.04	8.12	9.24	10.32	11.44	12.57	13.72
B.	2.72	3.82	4.90	5.98	7.05	8.12	9.19	10.28	11.39	12.51	13.72
C.		1.07	1.1	1.04	1.12	1.08	1.12	1.08	1.12	1.13	1.15
D.		1.10	1.08	1.07	1.07	1.07	1.08	1.09	1.10	1.13	1.21
E.	---	---	---	+0.01	---	---	---	---	-0.01	-0.02	

HURDLES:	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
TOLERANCE:	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.05	±0.04	±0.04

A. REAL TOUCH DOWN

B. MODEL TOUCH DOWN

C. REAL RYTHMICAL UNIT

D. MODEL RYTHMICAL UNIT

E. DEVIATION FROM THE MODEL

TIME OF MEASURMENT: 17:00 - 17:03

OUTPUT: 23:40 (13:00)

3. Elementary Biomechanical Analysis of the Shot Put

3.1. Input information

The timing of the athlete's action in the course of the put in focal moments - Table 6; the duration of the shot flight from the moment of release to the moment of landing. The vertical position of the implement in focal moments, and the length of the glide (two videorecorders with time indicators; the video recorders to be sited axially and at right angles to the axis of the shot put).

The duration of the implement flight and the position of the implement at the moment of release can be used for determining, with sufficient accuracy, the parameters of the kinematic geometry of the implement at the moment of release, i.e. release angle a_0 and release velocity v_0, as well as - obviously - the x and y components of release velocity (v_x, v_y).

3.2. Output information

A fairly elementary analysis of the videorecording (by means of a nomogram L/*a*,v/) makes it possible to determine, with sufficient accuracy, the angle and velocity of implement release; also, on the basis of that information, the zone of each trial in terms of the release angle. The nomogram shows clearly that trials in the 4th zone had angles of less than 39°, which significantly affected the athlete's performance.

(**Note:** The nomogram is only valid for a constant height H_0. If significant scatter in release height H_0 occurred in the trials of the athlete concerned the marking of the trials should be seen merely as rough pointers).

Possible shortcomings in the geometry of movement can also be pinpointed on the basis of previous threedimensional analyses of top level athletes and analyses of particular competitions. In addition to computing the components of the release velocity, it is possible to determine if the performance is influenced primarily by the strength of the lower extremities or the action of the trunk and the putting arm.

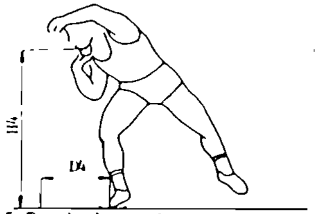
TABLE 10

EUROPEAN CUP BRUNO ZAULI PRAHA 27.6.87

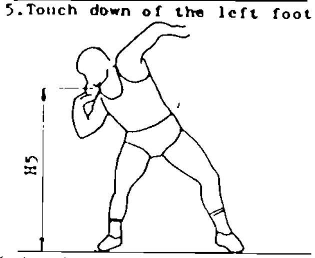
SHOT PUT - FM

1.	TIMMERMANN ULF GDR 1.11.62 194/118 87:21.72 PR:22.62	22.01

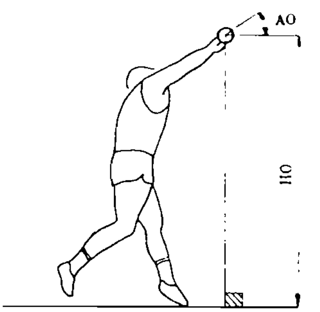
1. Start point from stand
2. Lowest point of the shot
3. Start point of the glide
4. End of the glide



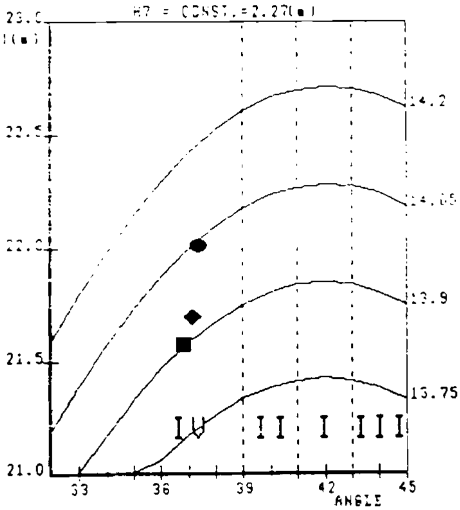
5. Touch down of the left foot



6. Shoulders parallel with the axis of the shot
7. Delivery moment



Trial no.-symbol	3. ●	5. ◆	6. ■
Performance (m)	22.01	21.7	21.57
2. time 1-2 (s)	4.13	4.32	4.12
3. time 2-3 (s)	0.26	0.25	0.24
4. time 3-4 (s)	0.08	0.09	0.1
H4 (m)	1.02	1	1.06
D4 (m)	0.84	0.86	0.85
5. time 4-5 (s)	0.09	0.12	0.1
H5 (m)	1.07	1.15	1.1
6. time 5-6 (s)	0.1	0.06	0.09
7. time 6-7 (s)	0.15	0.15	0.16
HO (m)	2.27	2.3	2.26
AO (D)	37.39	37.15	36.84
VO (m/s)	14.06	13.98	13.97
VX (m/s)	11.17	11.14	11.18
VY (m/s)	8.4	8.22	8.07
Theoret.Perf.(m)	22.33	22.09	22.08



CONCLUSION :
GLIDE TECHNIQUE
DOMINANCE OF THE DYNAMIC STRENGTH OF THE PUTTING ARM AND THE TRUNK

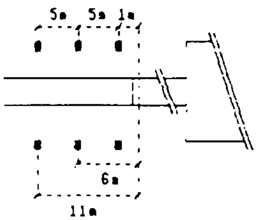
LABORATORY OF ELITE ATHLETICS SVMC UMO UV CSTV - PRAGUE	TIME IN : 27.6.87 18:40 TIME OUT: 28.6.87 14:57

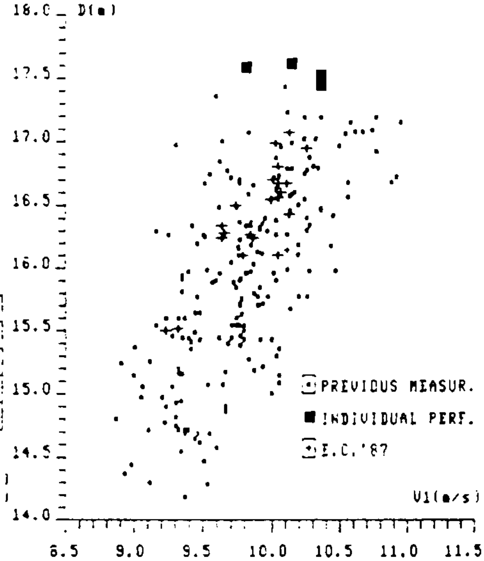
TABLE 11

TRIPLE JUMP

EUROPEAN CUP PRAGUE'87 28.06.87

PROCENKO URS				TEMPERATURE :
1 ATTEMPT	2 ATTEMPT	3 ATTEMPT	6 ATTEMPT	BAROMETRIC PRESSURE :
17.58	17.43	17.51	17.61	HUMIDITY :

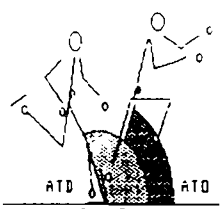




D	P	V1	V2	W
17.58	20	9.82	9.86	-0.47
17.43	20	10.37	10.20	-1.55
17.51	20	10.37	10.25	0.44
17.61	20	10.16	9.98	0.51

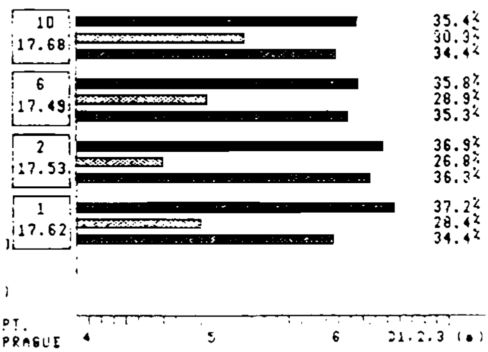
D - PERFORMANCE(m)
P - LENGHT OF RUN-UP(StePs)
V2 - RUN-UP SPEED 11-6m (m/s)
V1 - RUN-UP SPEED 6-1m (m/s)
W - WIND (m/s)
E.C.'87 - EUROPEAN CUP'87

	HOP			STEP			JUMP			
D	ATD	ATO	T1	ATD	ATO	T2	ATD	ATO	T3	T
17.58	124	56	0.66	120	55	0.62	116	61	0.88	2.16
17.43	122	63	0.66	118	55	0.56	116	63	0.91	2.13
17.51	123	62	0.67	121	57	0.53	116	60	0.91	2.11
17.61	125	63	0.70	115	55	0.58	116	60	0.90	2.18



HOP (D1)
STEP (D2)
JUMP (D3)
ATO-TAKEOFF ANGLE
ATD-TOUCHDOWN ANGLE
T1,2,3-DURATION OF JUMPS(s)
T-DURATION OF TRIPLE JUMP(s)

W	DIST.FROM BOARD(cm)
DS	PERF.FROM TAKEOFF (m)



BIOMECHANICS & COMPUTING DEPT.
of FTVS,CHARLES UNIVERSITY PRAGUE

4. Elementary Biomechanical Analysis of the Triple Jump

4.1. Input information

The performance (as laid down by the judge); the number of strides in the approach run; run-up speed (photocells - siting Table 7); the length of hop, step and jump, their take-off and landing angles; the distance between take-off proper and take-off board N (three videorecorders at right angles to the expected take-off spots).

4.2. Output information

Graph d(v) makes it possible to evaluate the influence of run-up speed on the performance (■). Comparisons can be made between the trials in the competition and previous measurements (.) and with the performances of the other athletes in the competition concerned (+). Take-off execution can also be evaluated on the basis of videorecordings and elementary geometrical and time data. The percentage shares of hop, step and jump in the resulting performance can also be stated.

The material assembled enables determining the kind of technical execution of the triple jump, pointing out possible shortcomings or kinematic-geometry parameters that helped the best athletes to achieve their performances.

CONCLUSION

Videoanalysis has obvious limitations in providing geometric and time information, but it is a suitable tool for obtaining quick and rough information on technical execution. Examples of a few typical track and field events — sprinting, hurdling, throwing and jumping events — have been used here to demonstrate the methodology of producing «fast information» for the coach and the athlete to benefit the training process.

In sprinting (100 m) the mathematical method for establishing model intermediate times is published here (for performances ranging from 9.9 ~ 12.5 s).

The example of the 100 hurdles has been used for describing the method of establishing model intermediate times and time differences. As published here, the method includes equations and their parameters for establishing model intermediate times from 12.3 ~ 14.5 s.

The examples (100 m hurdles, shot put, triple jump) are used for showing the potential of the use of computers for speeding up the transfer of biomechanical information on the technical execution of an event, or the evaluation of a competition or training session in terms of biomechanics.

REFERENCES

Barac, F., A Mathematical Model of the Response of the Human Organism to Physical Loads, Graduate thesis, 61 pp., Faculty of Electrical Engineering, Czech Technical University, Prague, 1985.

Čech, P., Some Aspects of the Kinematic Analysis of the 100 m and 100 m Hurdles, Graduate thesis, 46 pp. Faculty of Physical Education and Sport, Charles University, Prague, 1979.

Moravec, P., Models of Intermediate, VMO ÚV ČSTV, In press, Prague, 1986.

Sušanka, P., Brüggemann, P., Tsarouchas, E. and col., Athletics Biomechanical Research 1st Juniors World Championship Fast Information, Scientific Report IAAF, Pag 66, Athens, 1986.

Sušanka, P., Štěpánek, J., Böswart, J. and col., European Cup Bruno Zauli - Fast Information, Report EAA, Pag 72, Prague, 1987.

Sušanka, P., Štěpánek, J., Böswart, J. and col., Euromeeting - E. Rošichý Memorial - Fast Information Report SVMC VMO ÚV ČSTV, Pag 59, Prague, 1987.