BIOMECHANICS OF TRACK AND FIELD ATHLETICS

Peter Susanka, Ph.D.

Introduction

Within the framework of the International Athletics Foundation Scientific Project, software for the analysis of movements of man in the space was developed for obtaining special biomechanics information in track and field athletic events.

The research started at the European Championships in 1978 in Prague. This international research was followed at the 1980 Olympic Games in Moscow, the 1982 European Championships in Athens, the 1983 1st World Championships in Helsinki, the 1986 1st Junior World Championships in Athens and the 1987 2nd World Championships in Rome. This year it will continue at the Olympic Games in Seoul. Next year the plan is for the 2nd Indoor World Championships in Budapest.

At each of these top-class competitions, an international research group of 35-45 workers was involved. For each competition 10-12 high speed Locam and Photosonics film cameras were used with the same or a higher number of video cameras. In some other cases additional measurements were made by applying photo-finish cameras, photo-cells and seismographs. It can be stated that in this 10-year period more than 50 kilometers of film were taken and elaborated.

From measurements made by analyzing these videorecords and film shots, a comprehensive data bank was developed for most athletic events. This data bank together with the knowledge bank enables us to produce expert systems for the next Olympic cycle (1989-1992).

We consider it as a notable contribution that many young co-workers are engaged in the research groups. Young graduates and students have a chance to participate in the development of new methods and to get acquainted with the most modern techniques available in the domain of biomechanics. It can be stated that in the countries participating in the international research, broader groups of graduates from physical education faculties arise with special orientation towards biomechanics. In this way, preconditions are given for the formation of new biomechanics workplaces in these countries.

Methodological Problems

Apart from the run-in methods of three-dimensional analyses made by means of static cameras located usually at 90 degrees to each other and the distance of 20-40 m from the shot point, some other new variants were used. Specific conditions which exist for filming during top-level athletics competitions led us to the formation of special software for three-dimensional reconstruction of movements from film shots made by high speed cameras located arbitrarily anywhere within the stadium. Of course, the crucial condition is their exact placement by means of teodolite, and the equally exact location of the identification points (targets) in the range of the filmed movement in question.

As an example, we show a location scheme of two high speed cameras during film shooting of a triple jump. Cameras fixed on tripods rotate about their vertical axes and follow the final phase of the run-up and the execution of the triple jump until the landing into the sandpit.

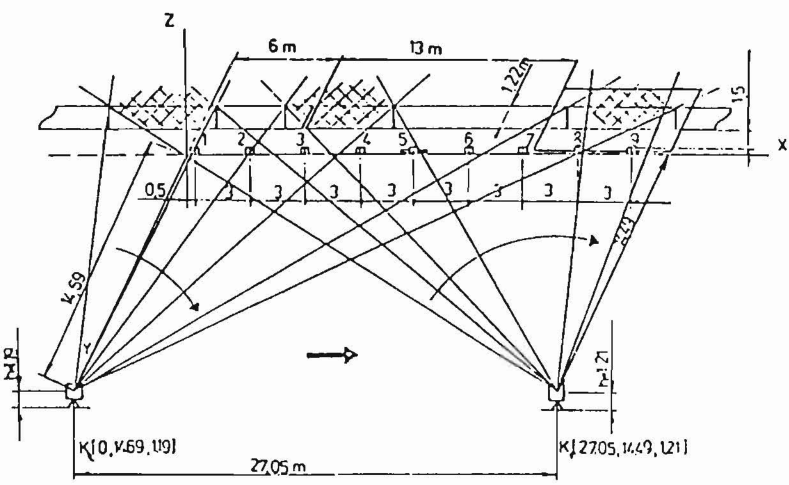


FIGURE 1.

As another example, a new method for the identification of spots of landings on the track during running and hurdling events was developed. Software for the computer ATARI 1040 makes it possible to identify each spot of landing by means of a single high speed camera.

Simultaneously we get information on the length and frequency of each stride and the duration of the support and flight phase. By means of a single high speed camera placed among spectators a span of approximately 60 m can be filmed (Figure 2). For the Olympic Games in Seoul the method is further developed so that the 400 m flat and 400 m hurdles can be observed by means of 6 high speed cameras.

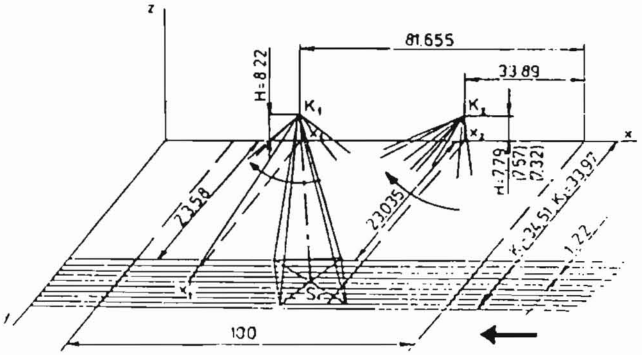


FIGURE 2.

Long term observation of jumping events enabled us to stabilize the methodology of measurement of the mean run-up velocity before the take-off in the long jump, triple jump and pole vault. In order to have comparable measurements, a stable location of photo-cells relative to the take-off line (and to the pole vault box) was suggested. A stable height of photo-cells for men's and women's contests was fixed as well. Identical methods are used in many European countries so that the exchange of measured data is possible and the enlargement of the data bank for further statistical processing is encouraged. The precision of interpretation is also improved.

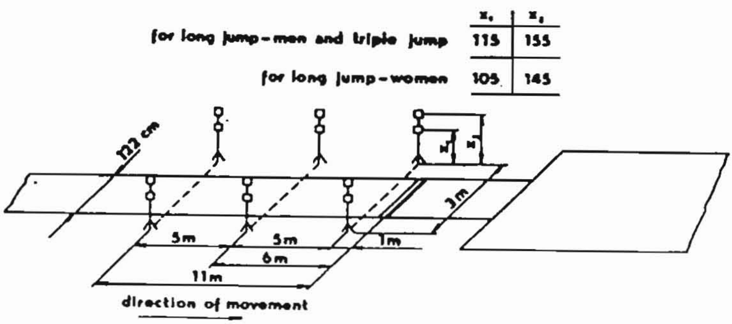


FIGURE 3

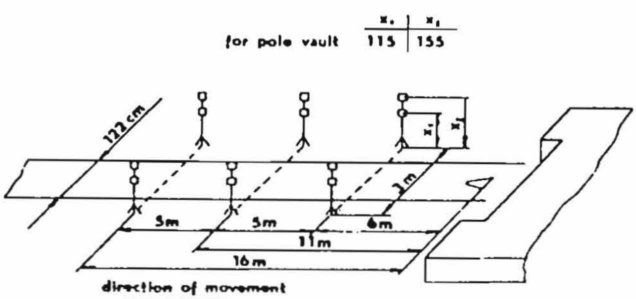
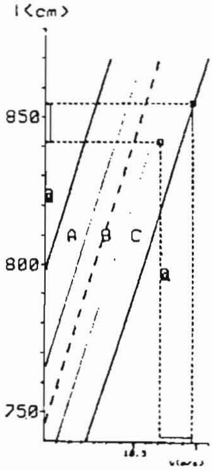


FIGURE 4

CARL LEWIS

I.WC HELSINKI 1983

performance : 855



WIND UNMEASURED:LF 2

	V1(8-1) zone	V2(11-6) wind	PERFORM diff
1.attempt	10.50 C	10.83	853 0
2.attempt	10.70 C	10.50	842 0 842

VARIATION RANGE RUN-UP SPEEDS

V1(8-1m)	V2(11-6m)
(10.70 ; 10.50)	(10.83 ; 10.50)

VARIATION RANGE OF PERFORMANCE

according rules	with difference
(842 ; 853)	(842 ; 853)

WIND UNMEASURED

Attempts where the following is exceeded:

A) DOMINANCE OF THE DYNAMIC STRENGTH OF THE LEGS

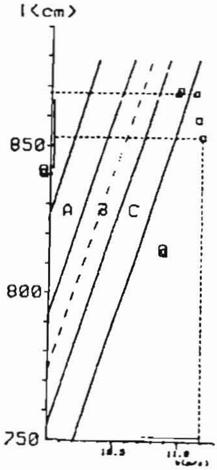
B) UNIFORM DISTRIBUTION OF THE MOVEM. POTENTIAL.

C) DOMINANCE OF RUN-UP SPEED

1.T. (853 ;853)
2.T. (842 ;842)

II.WC ROME 1987

performance : 867



	V1(8-1) zone	V2(11-6) wind	PERFORM diff
1.attempt	11.13 C B	10.41 +0.30	867 2 863
2.attempt	11.01 C	11.14 +0.50	853 3 820
3.attempt	10.30 C	11.11 -0.17	857 [illegible] 853
4.attempt	11.18 C B	11.11 +1.50	843 11 834
5.attempt	10.72	11.00 B	F F
6.attempt	11.16 C B	11.21 +0.20	860 0 860

VARIATION RANGE RUN-UP SPEEDS

V1(8-1m)	V2(11-6m)
(10.72 ; 11.18)	(10.41 ; 11.21)

VARIATION RANGE OF PERFORMANCE

according rules	with difference
(843 ; 867)	(834 ; 870)

VARIATION RANGE WIND SPEED

(-0.17 ;+1.50)

Attempts where the following is exceeded:

A) DOMINANCE OF THE DYNAMIC STRENGTH OF THE LEGS

B) UNIFORM DISTRIBUTION OF THE MOVEM. POTENTIAL.

C) DOMINANCE OF RUN-UP SPEED

1.T. (867 ;863)
2.T. (853 ;870)
3.T. (857 ;853)
4.T. (843 ;834)
6.T. (860 ;860)

TABLE 1

Examples of Research Measurements

In our endeavor to characterize the orientation of the biomechanical research made during top-level athletics competition (such as European Championships, World Championships, Olympic Games) we show selected examples from sprinting, hurdling, jumping and throwing events are shown below.

The limited extent of our paper permits no more than an outline of the possibilities of measurement methods and the procedure of interpreting the data. The full extent of the research observation made at the 2nd World Championships (Rome 1987) is given in 11 Reports which are available during this symposium.

The comparison of time characteristics of the first two finalists in 100 m sprint at the 2nd World Championships (where B. Johnson improved the world record with the time 9.83s) shows that the same or practically the same performance can be achieved by considerably different technical means. The difference in the resulting times between Johnson and Lewis is due above all to the starting action: the difference in the reaction time is 87 ms; in the 100 m distance B. Johnson's gain was only 13 ms in comparison to C. Lewis. It can be stated that their performances on the distance were approximately identical even though kinematic parameters are markedly different in both sprinters.

B. Johnson ran the whole distance (through all ten 10 m sections) with higher mean stride frequency and shorter mean stride length, than C. Lewis. The number of strides on all 10 m sections was higher for B. Johnson by 0.1 - 0.5 strides. A considerable difference can also be seen in the duration of the support phase in the first 20 m of the distance. For B. Johnson the duration of the support phase is significantly shorter (115 and 91 ms) than for C. Lewis (134 and 100 ms). From the 20 m line to the finish line, the mean duration of support phases is practically identical. During the whole distance, the duration of flight phases is shorter for B. Johnson in comparison to C. Lewis (in the range 4 - 24 ms).

The index of running activity, I, is the ratio of the time duration of the support phase to the time duration of the flight phase for one stride. It is a meaningful value when evaluating athletes intraindividually or when estimating different performance levels of athletes. In the case of minimal time differences (e.g. difference max. 10 - 20 ms) the index I_A is not sufficiently sensitive.

TABLE 2

THE COMPARISON OF MEAN VALUES OF SELECTED PARAMETERS ON 10M SECTIONS IN B.JOHNSON'S AND C.LEWIS'S 100M FINAL RACES.
II.WC R O M E 1987

PARAMETERS	NAME	0 - 10 - 10	10 - 20	20 - 30	30 - 40	40 - 50	50 - 60	60 - 70	70 - 80	80 - 90	90 - 100
Intermediate	B.J.	1.73	2.86	3.80	4.67	5.53	5.38	7.23	8.10	8.96	9.83
times (s)	C.L.	1.74	2.96	3.91	4.78	5.64	6.50	7.36	8.22	9.07	9.93
Times at 10 m	B.J.	1.73	1.02	0.94	0.87	0.86	0.85	0.85	0.87	0.86	0.87
sections (s)	C.L.	1.74	1.02	0.95	0.87	0.86	0.86	0.86	0.86	0.85	0.86
Running velocity	B.J.	5.78	9.80	10.64	11.49	11.63	11.76	11.76	11.49	11.63	11.49
(m / s)	C.L.	5.75	9.80	10.53	11.49	11.63	11.63	11.63	11.63	11.76	11.63
Number of	B.J.	7.30	5.30	4.50	4.40	4.30	4.10	4.10	4.05	4.05	4.10
strides (n)	C.L.	6.95	4.80	4.35	4.20	4.10	3.90	3.90	3.90	3.95	3.65
Length of	B.J.	1.37	1.89	2.10	2.27	2.32	2.44	2.44	2.47	2.47	2.44
strides (m)	C.L.	1.44	2.08	2.30	2.38	2.44	2.56	2.56	2.56	2.53	2.74
Frequency of	B.J.	4.22	5.19	4.77	5.05	5.00	4.92	4.92	4.65	4.70	4.71
strides (n/s)	C.L.	3.99	4.78	4.58	4.82	4.77	4.53	4.53	4.53	4.65	4.24
Duration of the	B.J.	115	91	85	87	86	80	85	85	83	80
support phase (ms)	C.L.	134	100	87	85	83	82	85	82	83	80
Duration of the	B.J.	86	99	111	113	122	127	122	122	128	130
flight phase (ms)	C.L.	90	113	121	124	124	133	134	138	135	162
Index of aktivity	B.J.	1.34	0.92	0.76	0.77	0.65	0.63	0.70	0.70	0.65	0.84
(support/flight ph.)	C.L.	1.49	0.88	0.72	0.68	0.67	0.62	0.63	0.59	0.61	0.54

Note . - 10 (without reaction time)

B.J. - Ben JOHNSON

C.L. - Carl LEWIS

DOSTÁL, E., HŮNAL, ? 1988 : KOMPARATIVNÍ ANALÝZA BĚHU NA 100M B.JOHNSONA A C.LEWISE. TRENÉR 32 (1988) N. (IN PRINT).

A significant indicator is the relation between the stride length and stride frequency. B. Johnson achieved his highest mean velocity

11.76 ms^{-1} between 50 and 70 m, while C. Lewis achieved the same velocity between 80 and 90 m. In both cases neither the maximum value of stride length nor the maximum value of stride frequency was achieved. In variables in which the observed athletes achieved higher values, they lowered the achieved maximum values by 7 - 8% (B. Johnson due to the stride frequency, and C. Lewis due to stride length).

Variables in which they achieved lower values, decreased only by 1 - 4% in relation to the achieved maximum. The sprinters achieved their highest velocity by optimization of both parameters. It can be concluded that B. Johnson has a reserve in the final part of the distance while C. Lewis has the reserve in the initial part of the race. We consider the observation of time and geometric characteristics during the training and the race as significant especially when it is carried out on the shortest sections of the race. Analysis of the semifinal and final races at the Olympic Games 1988 in Seoul will be aimed at this problem.

Comment on the reaction time of the sprinters

Measuring reaction times is an intractable problem in athletics. Reaction time ought to be watched and analyzed in races and in training. Measuring reaction times can have a considerable influence on the development of the starting technique in all sprint and hurdle events.

If reaction time data are to be used as comparable quantities, uniform conditions for measuring must be determined. It should be mandatory to have starting blocks with devices for the automatic recording of the reaction time.

Reaction time measured at different athletic competition
(European and World Championships,Olympic Games)

MEN	100m			200m			400m		
	n	x	SD	n	x	SD	n	x	SD
EC78	51	151	20	43	179	41	48	247	67
OG80	110	154	17	112	159	21	108	172	41
EC82	52	147	19	47	171	29	50	226	67
WC83	121	157	25	107	189	34	105	220	41
OG84									
JWC86	138	174	21	131	191	37	71	238	65
EC86									
WC87	103	185	31	94	219	52	56	261	75
AVERAGE	583	164	23	534	186	35	436	220	55
WOMEN	100m			200m			400m		
	n	x	SD	n	x	SD	n	x	SD
EC78	46	159	20	48	180	37	42	248	56
OG80	84	152	27	83	184	24	62	195	45
EC82	42	155	15	24	177	32	24	271	65
WC83	103	173	23	98	201	37	83	235	59
OG84									
JWC86	80	185	41	83	205	41	21	272	75
EC86									
WC87	107	211	52	53	234	60	57	269	67
AVERAGE	462	177	33	387	194	39	286	244	65

TABLE 3 .

Long term investigations have confirmed that in measurements made at the World Junior Championships in Athens 1986 and the II. WC, significantly longer reaction times were recorded than at EC 78, OG 80, EC 82 and WC 83.

The term "reaction time measurement" is used here only for the sake of simplicity. It is the time between the starter's gun and the moment the athlete is able to exert a certain amount of pressure on the starting blocks. This pressure is subject to a variety of definitions. The current method of reaction time measurement includes both the duration of the sound-travel and the mechanical delay on the starting blocks.

No study exists that could be used as a basis for defining a premature start. There is no objective reason for laying down 120 ms (or any other value) as the limit. Many observers were of the opinion that B. Johnson jumped the gun in the II WC - 100 m.

Analysis of pictures made by highspeed cameras (196 frames / sec) and interpolation of the frames were used to calculate the reaction time that passes between the recorded gun-shot smoke and the first noticeable motion of the athlete.

Reaction time of the 100m finalists

NAME	JOHNSON	BRYZGIN	CHRISTIE	PAVONI	LEWIS	KOWACZ	Mc RAE	STEWART
PERFORMANCE	9.93	10.25	10.14	16.23	9.93	10.20	10.34	10.08
RANKING BY REACTION TIMES	1.	2.	3.	4.	5.	6.	7.	8.
LANE	5	1	8	2	6	4	7	3
A	0.143	0.158	0.163	0.173	0.199	0.214	0.224	0.230
B	0.109	0.139	0.135	0.163	0.196	0.201	0.225	0.235
C	0.034	0.018	0.008	0.010	0.003	0.013	-0.001	-0.005

TABLE 4.

A - Reaction time of film analysis (Frequency 196 frames/sec.)

B - Official reaction times

C - Differences between rection times of film analysis and officially printed by firm Seiko

Our conclusion is that Johnson was not guilty of a false start. The starter did not notice a false start. In Johnson's start which differs from that of most other athletes the take-off of the lower extremities precedes the motion ("take-off") of the upper extremities.

We chose track and field events intentionally since they contain the basic locomotion actions and also put heavy demands on the motor apparatus of top-level performers. In 1987-88 we analyzed 500 performances in sprinting and we were able to develop a mathematical model to predict time for a sprinting event. Having developed the model, we were able to proceed to adjust the mathematical relationships of parameters in the model. For distances of 100, 110 and 400 hurdles we derived equations, "Models 1988" for computation of landing times behind each hurdle.

$$D_i = (k_1 + \beta_o^{\bullet} x_i + \beta_1^{\bullet} \Sigma x_i + \beta_2^{\bullet} \Sigma x_i^2) . v , [s]$$

where D_i time of landing the hurdle

x_i hurdle / (x_i = -4, . . . 0, . . . 4)

v resulting time in the competition

k_1 coefficient of regression for the landing behind the 10th hurdle

	100 m hurdles	110 m hurdles	400 m hurdles M	400 m hurdles W
k_1	0.9119260	0.8937510	0.8919519	0.8926136
$\beta^{\bullet}_1$	0.0779334	0.0772186	0.0845363	0.0856281
$\beta^{\bullet}_2$	0.0023850	0.0004170	0.0023337	0.0024641
$\beta^{\bullet}_3$	0.0001909	0.0001587	0.0001332	0.0000366

The mathematical solution with the example of the 100 m hurdles was published at the 5th symposium of the ISBS in Athens 1987. We showed the actual times and model projections for world champions. Together with the information about the reaction time and technique of hurdling it was possible to elaborate on explicitly complex knowledge. In this development stage, the information system will be applied at the Olympic Games in Seoul 1988.

Methodical biomechanical investigations should enable us to provide information in the shortest time. Information on the II World Championships was processed and distributed in a few hours after the competition. We showed one of the possible forms on the example of horizontal jumps. Fast information of triple jump can be distributed from 1 to 2 hours after the training for competition.

On the example of the World Championships Ch. Markov can be shown the extent of the obtained information by photocells and analyzed videoclips. About each attempt it is possible to know:

1) the run-up speed
2) influence of the run-up speed on the result of the attempt.
3) distance of the take-off foot and the take-off line.
4) distance of each hop.
5) percentile quotient of each part of the jump relative to the entire triple jump, and
6) the time of each part of the jump.

More extensive information can be given by using a 3-dimensional cinematographic method of analyzing each event. Also in this case we should try to get information as fast as possible for use in practice. The value of this work is in its availability for practice. Already the visual information about the geometry of movement with a commentary can have an important meaning for the coach. For example showing the frontal plane projection and horizontal plane projection on a computer provides data on the hop, step, jump. This technique enables us to show arbitrary views on chosen details or of the whole movement for pedagocical and training needs. As a further example in the long jump the important tasks of the pre-take-off rhythm are:

a) minimum loss of run-up horizontal velocity.
b) minimum necessary height of the CM parabola - minimum variation range of velocity v_y (movements in the frontal plane)
c) optimum linking of the CM trajectory to the transition between the support and flight phase.
d) increasing the horizontal velocity up to one stride before the take-off.

The loss of the horizontal speed is not as unfavorable as the loss of vertical speed (model DRDACKA - RIDKA 1984).

That is why it is expedient to regulate the vertical movement of the CM during the last two strides. It is also important to minimize the angle at the knee on the takeoff leg during the instant of take-off. These demands can be achieved from the last stride by stepping on a flexed knee and then extending it during the moment when the CM is in front of the vertical.

The lowest point of the CM should be during the flight phase of the penultimate stride (around 6-10 cm). In the support phase of the last stride the lowering of the CM should stop without subsegment elevation. Loss of the horizontal velocity can be reduced by a less significant stride in front of the CM. Figure 5 and 6 shows that C. Lewis made mistakes during the jump (flight phase) of the last stride during the I and II WC.

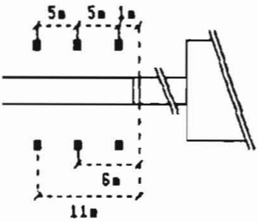
TRIPLE JUMP

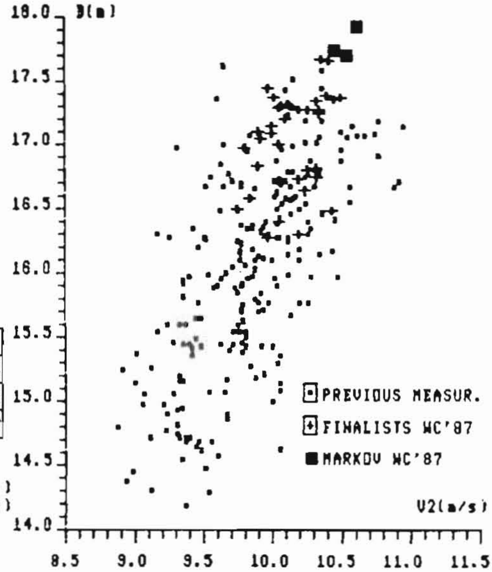
2nd ATHLETICS WORLD CHAMPIONSHIPS R O M E 31.08.87

Christo MARKOV BUL

1 TRIAL	2 TRIAL	4 TRIAL
17.70	17.73	17.92

27.01.1965
185/76
1987 : 17.81
PERS.BEST : 17.81





D	NS	V1	V2	W
17.70	23	10.27	10.55	2.14
17.73	23	10.35	10.46	1.81
17.92	23	10.26	10.62	1.57

D - PERFORMANCE(m)
NS - NUMBER OF RUN-UP STEPS
V1 - RUN-UP SPEED 11-6m (m/s)
V2 - RUN-UP SPEED 6-1m (m/s)
W - WIND (m/s)

DL / DE	d1,2,3	%	T1,2,3	T
0.11 / 17.81	6.55	36.8%	0.69	
	5.35	30.0%	0.62	
	5.90	33.1%	0.83	2.14
0.00 / 17.73	6.45	36.4%	0.68	
	5.55	31.3%	0.68	
	5.73	32.3%	0.88	2.24
0.04 / 17.96	6.54	36.4%	0.68	
	5.30	29.5%	0.61	
	6.12	34.1%	0.92	2.21

DL LOST DISTANCE(m)
DE EFFECTIVE DISTANCE(m)

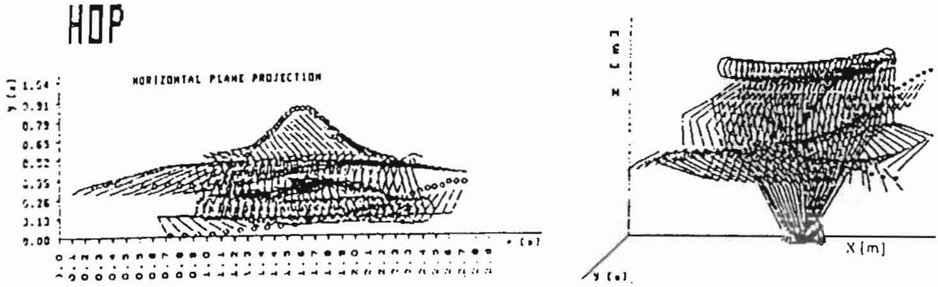
HOP -d1 (m)
STEP-d2 (m)
JUMP-d3 (m)

T1,2,3 -DURATION OF PHASES
T - DURATION OF T.JUMP(s)

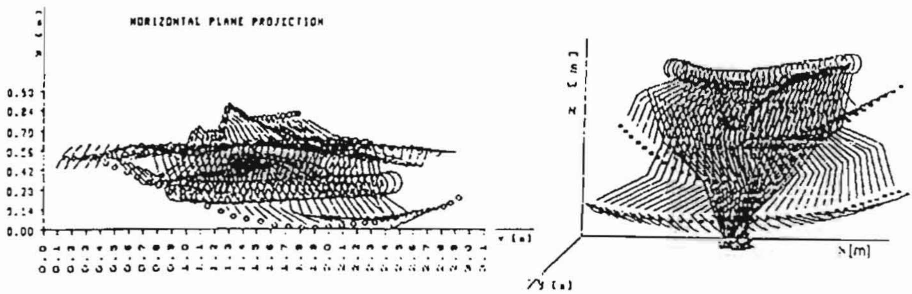
INTERNATIONAL RESEARCH TEAM I A A F © CHARLES UNIVERSITY-FTVS & UMO UV CSTV

MARKOV 17.92 m

HOP



STEP



JUMP

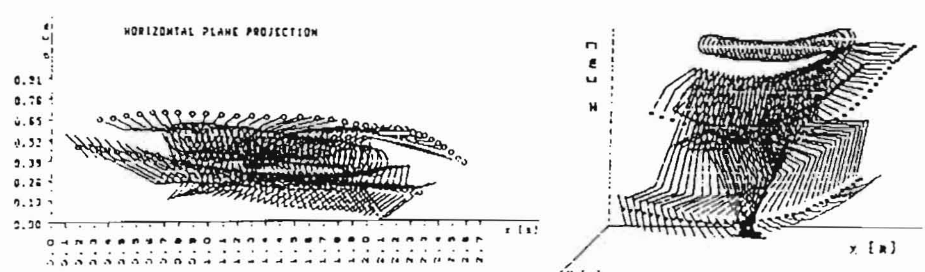


FIGURE 5

The premature extending of the takeoff knee during the takeoff and the lowering of the CM causes great loss in impulsive reactive power in the take-off The athlete must have a 0.0 or a slightly negative vertical velocity of the CM during touchdown. In the case of Lewis, removing his previously mentioned errors would result in his breaking of the 890 cm world record.

LEWIS C. 8.55m I.WC. Helsinki 1983

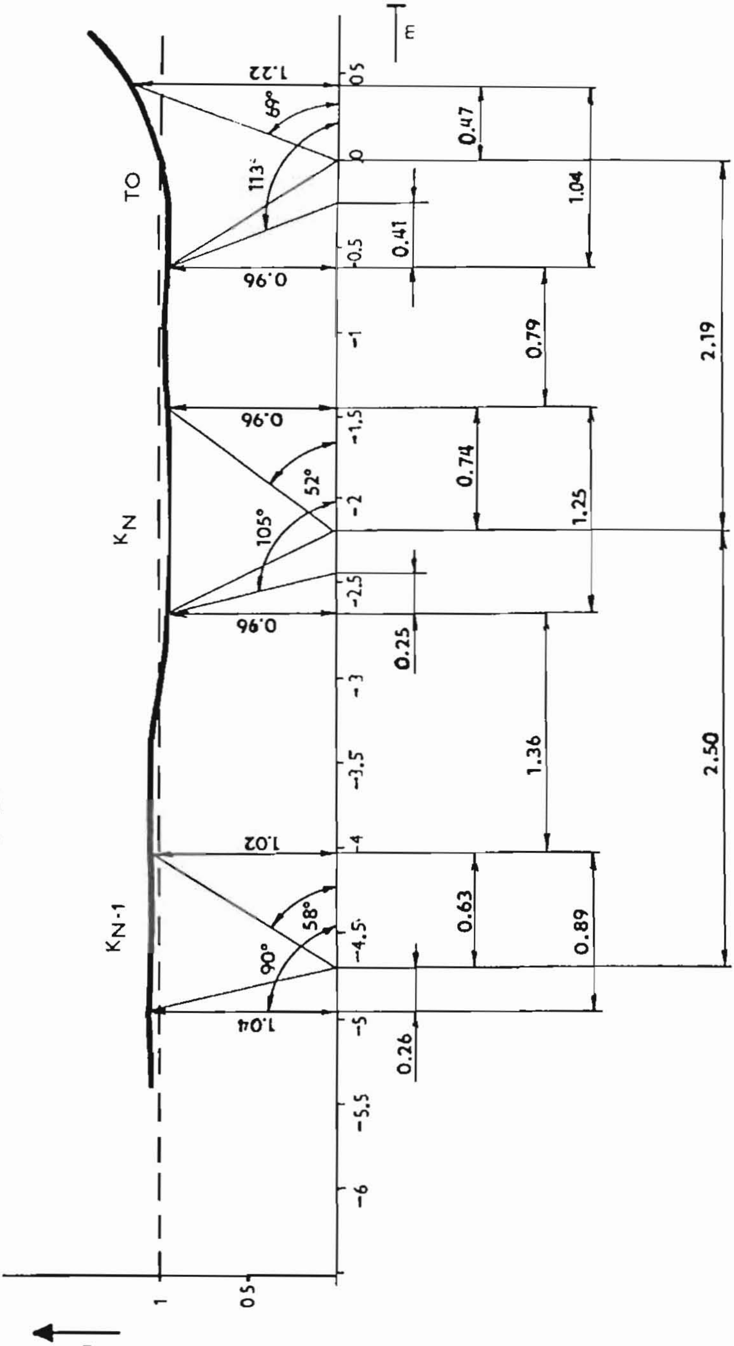


FIGURE 6

L E W I S Carl USA 8.67m (II.WC Rome 1987)

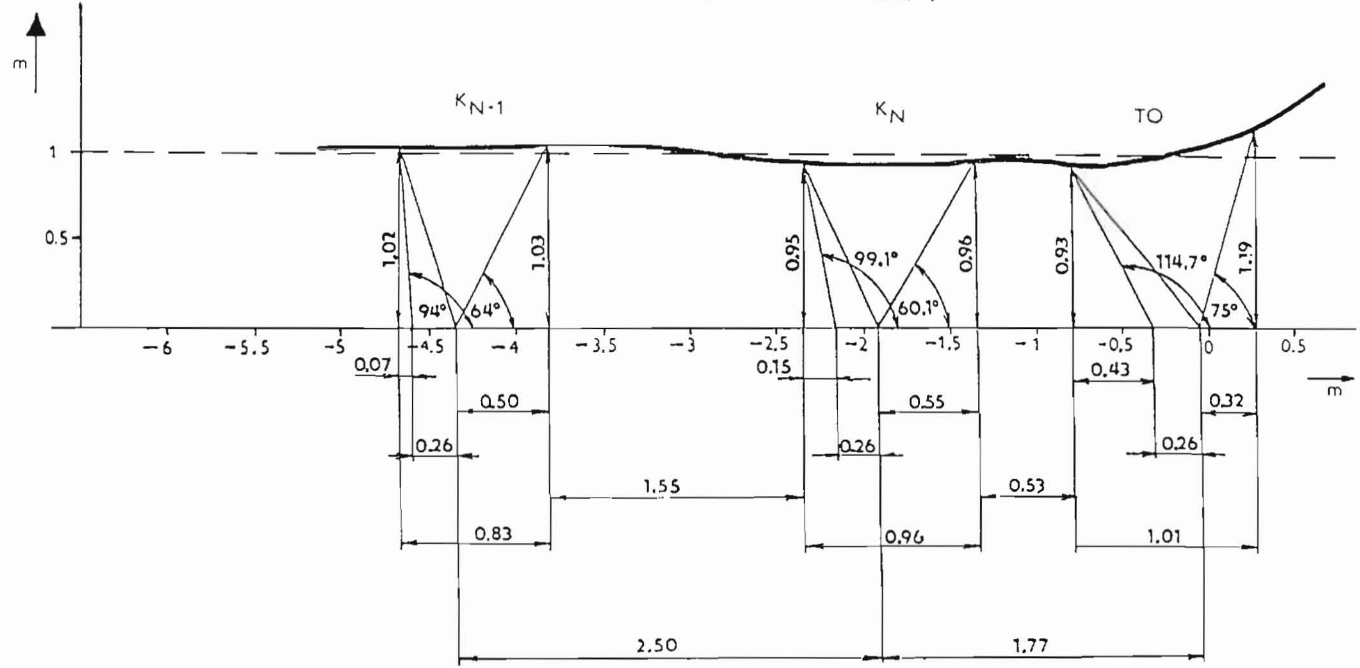


FIGURE 7.

In all throwing events, especially the shot put, we consider the action of the upper body during the putting action to be of extreme importance. We have introduced an auxiliary coordinate system, x',y' into the center of the line connecting both hip joints where the x' axis is identical with the pelvic axis, running through the centers of rotation of the hip joints.

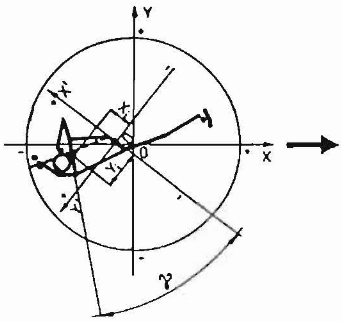


FIGURE 8.

Defined in this way, this coordinate system enables us to express as a ground projection, the position of the center of the line connecting the shoulder joints in relation to the center of the line connecting the hip joints, and also the mutual deviations of the shoulder axis relative to the pelvic axis ( ). We used this method in 1983 when analyzing the hammer throw (Susanka, Stepanek, Miskos, Terauds 1987).

In shotput we can show style differences of the throws of high level athletes. Andrei, Timmermann and Beyer aim at lengthening the effective path of the shot movement in the double-support position, by shortening the glide length during a very wide delivery stance.

Conversely, Brenner and Machura use a longer glide, thus, by leaning and simultaneously rotating the trunk axis, they achieve a greater difference between the position of the right foot landing and the position of the shot in the horizontal direction. The precondition of this variant is an intensive involvement of the main muscle groups of the lower extremities and trunk rotators in the delivery.

Guenthoer used his anthropometric parameters and strength very successfully to combine the advantages of both techniques of delivery — the path of the body CM as well as the shot. Movement in the horizontal direction is relatively straight when compared to the other throwers. Guenthoer mainly uses a twist that is initially displaying a greater angle between his shoulder and pelvis axis (Figure 8).

The new software for three dimensional analysis puts biomechanics in a strong position to assist in training and to improve performances. The future direction of sport biomechanics is in the interaction of the following variables; prevention, rehabilitation, regeneration and recondition. In all these area biomechanics is important. Szechoslavakian researchers will influence research in this direction for the years 1990-95.

References

Dostal, E., Hilna, J. (1988). *Komparativni analyza behu na 100 m T. Johnosona a C. Lewise.*

Drdacka-Ridka, E. (1984). Biomechanicke faktory vykonu skoku do dalky. *Kandidatska prace*, Pag. 318, FTVS UK Praha.

Jurdik, M. (1988). Biomechanicka analyza horiaontalnich skoku. *Diplomova prace*, Pag. 68, FTVS UK, Praha.

Moravec, P., Ruzicka, J., Dostal, E., Susanka, P., Kodejs, M. Nosek, M. (1987). *Time analysis of the sprints.* International Athletics Foundation, Pag. 59, London.

Nixdorf, E., Bruggemann, P. (1987). *Biomechanical analysis of long jump.* International Athletics Foundation, Pag. 54, London.

Susanka, P., Ruzicka, J., Koukal, J., Ridka, E. (1984). *Biomechanical analysis of long jump and triple jump.* The first World Championships in Athletics Helsinki 83. Produced by Kratky film Praha.

Susanka, P., Miskos, G., Millerova, V., Dostal, E., Barac, F. (1987). *Time analysis of the 100 m and 110 m hurdles.*International Athletics Foundation, Pag. 27.

Susanka, P., Kodejs, M., Miskos, G. (1987). *Time analysis of the 400 m hurdles.* International Athletics Foundation, Pag. 31, London.

Susanka, P., Stepanek, J. (1987). *Biomechanical analysis of the shot put*. International Athletics Foundation, Pag. 77, London.
Susanka, P., Stepanek, J., Miskos, G., Terauds, J. (1987). Hammer Athlete relationship during the hammer throw. *Biomechanics in Sports III.*, IV., Pag. 194-200, Research Center for Sports, Del Mar, CA
Susanka, P., Burggemann, P. (1987). *Biomechanical analysis of the second IAAF World Championships in athletics*, Rome, 1987. International Athletics Foundation Scientific Project, Pag. 1157, London.