BIOMECHANICAL ASPECTS OF THE POLE VAULT
ANALYSIS OF THE 4TH IAAF WORLD CHAMPIONSHIPS [1]

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INTRODUCTION and METHODS

World class pole vaulters were analyzed at the 4th IAAF World Championships in Stuttgart, 1993. In order to obtain the performance relevant parameters in competition, the following systems and methods were employed:

Approach run parameters were obtained for all vaults of the finalists. Three sets of doubled infrared photoelectric cells placed at 16, 11 and 6 m distance from the end of the vaulting box were connected to the parallel port of a laptop computer to measure time intervals and average velocities in the latter part of the approach run.

One video camera was placed up in the stands at 90 degrees to the run-up to measure stride parameters.

Two fixed video cameras (NTSC) were set up for three dimensional analysis using the APAS. Calibration points were distributed over the whole field of view. This was made possible by marking the uprights, marking points on the track and introducing a large calibration frame before and after the competition. The 3-d coordinates were computed by APAS using a non-panning DLT algorithm. The data were smoothed using a digital filter with a cut-off frequency of five Hz. The analysis included five selected vaults

Two biaxially panned LOCAM 16-mm cameras operating at 100 Hz generated temporal parameters.

RESULTS AND DISCUSSION

The complete set of results was made available to the German Track and Field association (DLV). Selected aspects are reported in this paper.

The importance of the approach run velocity has to be reconsidered. The simplistic 'the faster - the better' notion cannot be maintained. Even though there is a positive correlation in large, heterogeneous groups, analysis of homogeneous world class groups and intraindividual comparison reveal no similar trend. This is substantiated by comparing fair and foul jumps. In summary, the statement that high approach velocities and acceleration into the take-off are desirable and necessary, but non-sufficient prerequisites for successful vaults can be made with great confidence. Most vaulters have fairly constant stride patterns and velocities throughout the competition. However as in the case of Bubka, he increased the velocity from 9.2 to 9.6 m/s when switching from an 11.6 to 11.2 flex pole. Most athletes have two to four successful attempts, which is indicative of economical vaulting.

The take-off is one of the crucial phases of the vault. It last about 0.1 s. In this time interval touch-down, pole plant and take-off occur. Currently a trend can be observed to minimize the time interval between pole plant and take-off. However the sampling rate of 30 Hz and the low pass filtering did not allow sufficient temporal resolution in the analysis of the data collected in Stuttgart.

The kinematic analysis of the vaults revealed little 'out of plane ' motion. Nevertheless, the 3-d- coordinates were used to compute the respective results for the vault. Huffman used an interesting 'straddle like' clearance Since he cleared a height

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[1] This study was part of the DLV Biomechanical Research Project

1,17m above grip height, which is absolute world class, this technique has to be considered as a serious alternative.

Some of the data gathered will be presented in tabular form. Tables 1 and 5 deal with the mechanical energy and the net work done by the vaulter. This is based on the assumption, that there is no strain energy stored in the pole at take-off. We believe that only an understanding of the energy exchanges and work done by the athlete will allow a complex approach to the event.

Table 1: Kinetic- potential and total energy at takeoff

Name	Epot(TO)		Ekin(TO)		Etot(TO)	
	Joule	Joule/kg	Joule	Joule/kg	Joule	Joule/kg
Bubka (6,14) X	980	12,2	2886	36,1	3908	48,8
Bubka (6.00) O	950	11,9	3257	40,7	4258	53,2
Trandenkov (5.80)O	1003	12,5	2571	32,1	3620	45,3
Huffman (5.80) O	802	10,7	2749	35,5	3613	48,2
Amann (5.55) O	899	11,7	2809	36,5	3754	48,4

The total energy, **Etot(TO)** is greater than **Ep-ot(TO) +Ekin(TO)** since it includes the rotational **kinetic** energy.

Table two summarizes parameters associated with the first phase on the pole lasting from take-off to maximum pole bend (MPB).

Table 2: The first phase on the pole POLE

Name	t 45°	t (MPB)	CLmin	AP(MPB)	AVP(MPB)	t (PS)
	s	s	m	deg.	deg./s	s
Bubka (6,14) X	0,51	0,54	3,67	59	80	1,0
Bubka (6.00) O	0,52	0,52	3,73	58	89	1,0
Trandenkov (5.80)O	0,48	0,54	3,67	62	74	1,1
Huffman (5.80) O	0,49	0,50	3,11	55	125	?
Amann (5.55) O	0,55	0,60	3,69	58	64	1,3

t 45, t (MPB) and t (PS) are times measured from take-off. They denote the instant when the vertical velocity of the CM becomes greater than it's horizontal component. maximum pole bend and the time when the pole is straight again respectively. Clmin, the smallest chord length is quite similar for all vaults except for **Huffman**. He used a 15.4 flex pole and achieved very high pole speeds (AVP).

The second phase on the pole (Table 3) lasts from maximum pole bend to pole release.

Table 3: The second phase on the pole

Name	YCM(MPB)	VYmax	VY(PR)	YCM(PR)	t (PR)
	m	d s	m/s	m	s
Bubka (6.14) X	2,55	5,1	4,8	4,97	1,08
Bubka (6.00) O	2,54	5,1	4,3	5,37	1,12 ?
Trandenkov (5.80)O	2,65	4,8	0,5	5,89	1,31
Huffman (5.80) O	2,29	5,1	2,1	5,58	1,46
Amann (5.55) O	2,46	4,5	2,4	5.22	1,34 ?

YCM(MPB) is the CM height at the beginning of the phase. **VYmax,** the greatest vertical CM velocity during the pole extension is a good indicator for quality vaulting.

The vertical velocity at pole release, **VY(PR)** must be interpreted in conjunction with the CM height and the time of pole release.

Table 4 summarizes data associated with the free flight phase. **YCM(HP)** is the computed value for the maximum CM height. The Standard settings were obtained from the microprocessor controlled prototype developed by BENZ Sports. It is interesting to compare the settings with the actual X coordinate at the high point, **XCM(HP).** The horizontal velocity at HP is an indicator of efficient energy transformation.

Table 4: The free flight phase

Name	Y CM (HP)	STANDARD	X CM (HP)	VX (HP)	t (HP)
	m	m	m	m/s	s
Bubka (6,14) X	6,20	-0,50	-0,23	1,6	1,59
Bubka (6.00) O	6,22	-0,65	-0,58	1,7	1,56
Trandenkov (5.80)O	5,90	-0,60	-0,43	1,7	1,51
Huffman (5.80) O	5,85	-0,80	-0,74	1,7	1,55
Amann (5.55) O	5,55	-0,80	-0,05	1,4	1,59

Table 5 summarizes energy at the peak of the flight parabola and net mechanical work in absolute and relative terms. The data gathered on Bubka's vaults in previous competitions compare well with the present findings.

Table 5: Energy at the highest point and net mechanical work

Name	Epot(HP)		Ekin(HP)		Net Work	
	Joule	Joule/kg	Joule	Joule/kg	Joule	Joule/kg
Bubka (6,14) X	4852	60,6	167	2,1	1149	14,4
Bubka (6.00) O	4857	60,7	225	2,8	865	10,8
Trandenkov(5.80)O	4602	57,5	197	2,5	1198	15,0
Huffman (5.80) O	4283	57,1	209	2,8	914	12,2
Amann (5.55) O	4330	56,2	193	2,5	795	10,3

CM height is to be maximized. Hence all factors influencing the energy balance of the vault must be optimized. This is achieved by reduction of **Ekin(HP),** while maximizing **E(TO)** and mechanical work. If one would combine Bubka's best vaults in this way, the CM could be raised to more than **6,60** m. However such a speculation is oversimplifying the problem since the interdependencies of the variables are neglected. Intraindividual comparison of successful vaults reveals, that the net work done on the pole tends to decrease as the **E(TO)** increases.

CONCLUSION

The findings correspond well with previously reported data by GROS / KUNKEL (1990) and ANGULO-KINZLER et al. (1994). Time dependent force vs. deflection data for specific poles are needed to determine how much energy is stored in the pole and the body, how much energy is dissipated, how much mechanical work is done and when all of this happens during the vault.

REFERENCES

Anguolo-Kinzler et. al. (1994). Analysis of the Pole Vault. Journal of Applied Biomechanics. 2

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