KINEMATIC ANALYSES OF THE DISCUS THROWING COMPETITIONS AT THE WORLD ATHLETICS CHAMPIONSHIPS 1993 IN STUTTGART

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INTRODUCTION

On the occasion of the World Athletics Championships 1993 in Stuttgart the German Athletics **Federation** initiated a scientific research and service project according to those conducted on behalf of the IAAF at former major athletic events. The purpose of the project was to update **and increase** the **kinematic** data base of track and field events and to give the coaches a fast information feedback of their athletes' techniques. Updating existing **kinematic** data is supposed to shape the discipline's performance profile where **kinematic** analyses are only one constituent. Mere description of the techniques in terms of **kinematic** parameters must not be the aim. The height of their influence on the athletes' results is the least demand which should be met.

In discus throwing we are facing a principle dilemma of **kinematic** performance diagnostics. The **kinematic** prerequisites of the athletic result are rather well known and their relationship is **sufficiently** understood. Nevertheless it is nearly impossible to tell a good from a bad throw with the help of **kinematic** parameters as not enough is known about the act of their generation.

PURPOSE OF THE PAPER

This paper wants to discus possibilities and limitations of applied **kinematic** performance diagnostics of discus throwing. This might be taken as an example for other athletic disciplines. On the basis of a data base including 260 throws of world class athletes the applicability of traditional **kinematic** approaches is called into question.

METHODS

The data base exclusively consists of **kinematic** data established via cimematography. In order to increase the number of analysed throws we included data from literature into our data base (Bartlett, 1992). Our own analyses follow a standard procedure with a standardized camera setup which was also used in Stuttgart at the WAC and is shown in figure **1**.

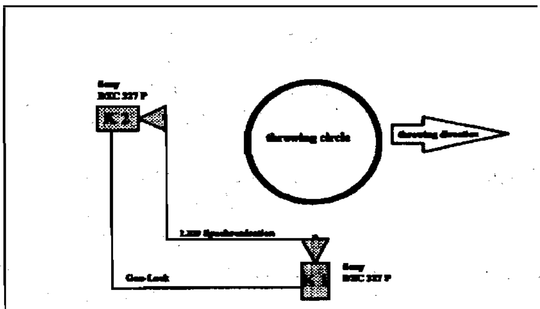

Figure 1: **Camera setup for discus** throwing (right hand throwers)

of the exceptional light conditions shutter speed could be reduced to 1

Figure 1: Camera setup for discus throwing (right hand throwers)

Two genlocked videocameras (SONY DXC **327P)** equipped with Hi8 videorecorders (SONY EVV **9000P)** running with a field rate of 50 fps were focussed on the **circle.**

One camera took the thrower from the side of his throwing arm (K1) the second took the rearview related to the 'direction of the throw. To insure unambiguous correspondence of events both cameras were synchronized by LEDs in front of their lenses which could be identified in the analysis ftame as soon as they were manually switched on. Both views covered a width of 5m related to the center of the circle. Because of the exceptional light conditions shutter speed could be reduced to 1:1000. The resolution of the Hi8 video signal is 400 lines with a signal to noise relationship of 44dB. In order to identify every video field during the analysis a video integrated time code was recorded simultaneously.

Analysis was performed with a PEAK PERFORMANCE. motion analysis system (version 5.0). The resolution of the digitized image is interpolated to 512x512 pixels. The video fields were digitized manually. 17 body landmarks were taken to define the locations of 12 body segments listed in table 1.

Table 1: Body landmarks and definition of the segments

No	landmark	segments. no.	segment	connected landmarks
01	tip of right toe	01	right foot	1-2-3
02	right heel			
03	right ankle			
04	right knee	02	right shank	3-4
05	right hip	03	right thigh	4-5
06	left hip			
07	right knee	04	left thigh	6-7
08	left ankle	05	left shank	7-8
09	left heel			
10	tip of left toe	06	left foot	8-9-10
11	right shoulder	07	throwing arm	11-13
12	right ellbow	08	right upper arm	11-12
13	right wrist	09	right lower arm	12-13
14	discus			
15	left shoulder	10	trunk	5-6-11-15
16	left ellbow	11	left upper arm	15-16
17	left wrist	12	left lower arm	16-17

Thirteen parameters as listed below were derived from the digitized images and a time analysis.

List of parameters:	Abreviation
01 - height of release	height
02 - angle of release	angle
03 - release velocity	vlcty
04 - ballistic flight distance	d-bal
05 - difference between ballistic and official distance	d-dif
06 - duration of entry phase	d-t-2

07 - duration of airborne phase	d-t-3
08 - duration of transition phase	d-t4
09 - duration of delivery phase	d-t-5
10 - change of discus velocity in airborne phase	d-v-3
11 - change of discus velocity in transition phase	d-v-4
12 - change of discus velocity in delivery phase	d-v-5
13 - total change of discus velocity in transition and delivery phase	d-v-end
14 - official throwing distance	dist

Error estimation

In order to estimate possible errors in digitizing the images we assumed an expected maximum velocity (discus) of $25 ms^{-1}$. Given a frame rate of 50 fps and a field width of 5m an object at the criterion speed would cover a maximum distance of 0,5m in one field. It could hardly been identified acurately in the image. The shutter chosen in Stuttgart reduced exposure intervals to 0,001sec. Within this time period the object would travel a distance of 0,005cm thus it could clearly been identified in the image. The visible video image is transferred to a digital matrix on the frame grabber board consisting of 512x512 pixels. The distance between two pixels corresponds to a real distance of 0,98cm to 1,39 cm. An inaccuracy of one pixel in identifying landmarks would result in an error of 0.2% to 0,28%.

Kinematic analysis of the finalists at the WAC in Stuttgart

The kinematic data for the finalists of the WAC in Stuttgart were put into the database of the Instsitute for athletics and gymnastics at the German Sports University in Cologne. They increased the number of analysed throws to 260 with a relationship between female and male athletes of 58:202. Throwing distances range from 37,22m to 68,94m. The following analysis tries to integrate the recent findings into this data base and compare current outcome with earlier results.

Timing parameters

According to related literature the movements of the athletes in the circle are subdevided into five consecutive phases:

a - preparation,	Ph 1,
b - entry,	Ph 2,
c - airborne,	Ph 3,
d - transition,	Ph 4,
e - delivery,	Ph 5.

No general agreement exists between scientists nor coaches about the contribution of the temporal distribution of these phases to a good technique. Bartlett 1992 summarized the related literature and found different opinions and suggestions for the technomotorical solutions within these phases. One reason for the devided opinions amongst the different researchers is revealed by the temporal data itself as shown in table 2.

The analysis of phase durations is a good indicator for the stability of individual movement rhythm and timing. Highest importance is usually awarded to the last three phases of the throw. It is true that the often formulated demand for a possibly short airborne phase can be supported by mechanical considerations but the identified individual variations (see table 2) avoid a significant correlation between this parameter and throwing distance ($r = -.0076$, $p = .919$) as well as release velocity ($r = .0193$, $p = .891$). The same comes true for transition and dilivery phase. No significant correlation to release parameters could be identified (see table 3). If we take a closer look at table 2 this lack of correlation can easily be understood. Within the finalists of

Stuttgatt all possible variations of time distribution to the phases can be found. These variations occur interindividually with astonishing uniform individual timing pattems.

(Although no significant differences between the timing distributions of the distinct phases of women and men could be identified there is a tendency to a longer delivery phase related to transition for the female medalists if compared to the male medalists with the latter demonstrating a markedly longer transition phase relative to the duration of delivery. (see table 2).)

Table 2: Phase durations of throws of the medalists (women and men) WAC 1993

Name	Distance				
Burova	**63,28m**	**0,45s**	**0,13s**	**0,16s**	**0,16s**
	67,40m	**0,44s**	**0,10s**	**0,17s**	**0,16s**
	65,80m	**0,45s**	**0,10s**	**0,15s**	**0,17s**
	67,06m	**0,45s**	**0,12s**	**0,15s**	**0,16s**
	x	**0,44s**	**0,11s**	**0,15s**	**0,17s**
Costian	**63,90m**	**0,47s**	**0,12s**	**0,15s**	**0,16s**
	64,78m	**0,43s**	**0,11s**	**0,16s**	**0,17s**
	64,66m	**0,48s**	**0,11s**	**0,15s**	0.16s
	65,36m	**0,49s**	0.10s	**0,16s**	**0,16s**
	65,12m	**0,46s**	**0,10s**	**0,16s**	**0,18s**
	x	0.46s	**0,12s**	**0,15s**	**0,18s**
Min	**62,16m**	**0,42s**	**0,14s**	**0,10s**	0.19s
	61,88m	**0,47s**	**0,11s**	**0,16s**	**0,18s**
	65,26m	**0,45s**	**0,11s**	0.13s	0.19s
	x	**0,46s**	**0,08s**	**0,13s**	**0,22s**
	64,16m	**0,45s**	**0,10s**	0.13s	**0,19s**
Riedel	**56,24m**	**0,44s**	0.13s	**0,16s**	**0,17s**
	67,72m	**0,45s**	**0,12s**	**0,20s**	**0,16s**
	60,54m	**0,38s**	**0,10s**	**0,19s**	**0,14s**
	64,94m	**0,42s**	**0,12s**	**0,15s**	**0,15s**
	x	**0,44s**	**0,13s**	0.17s	**0,14s**
	67,34m	0.40s	**0,12s**	**0,15s**	**0,18s**
Shevchenko	**61,58m**	0.34s	0.07s	0.20s	**0,17s**
	61,54m	0.37s	0.02s	**0,22s**	0.17s
	x	**0,37s**	**0,00s**	**0,24s**	**0,15s**
	63,94m	**0,37s**	**-0,02s**	**0,25s**	**0,17s**
	66,14m	**0,36s**	**0,05s**	0.20s	**0,17s**
	66,90m	**0,36s**	0.02s	**0,21s**	**0,15s**
Schult	**64,32m**	**0,43s**	0.08s	**0,25s**	**0,13s**
	66.12m	0.44s	0.09s	0.23s	0.16s
	63,32m	**0,44s**	0.08s	**0,24s**	**0,14s**
	62,84m	**0,43s**	**0,09s**	**0,24s**	0.13s
	64,46m	0.41s	0.10s	0.22s	0.14s
	x	**0,44s**	**0,08s**	**0,21s**	**0,17s**

If we compare the men's medalists we find a high constancy in individual movement patterns as far as timing is concerned. Durations of the delivery phases of Riedel and Schult are nearly identical whereas Schult executes a markedly shorter airborne but longer transition phase. Shevchenko on the other hand shows an extremely short airborne phase and is sometimes able to avoid it completely and plant his left foot even before his right foot has lost contact with the ground..

Table 3: Correlation matrix of phase duration and release parameters

	angle of rel.	height of rel.	release vel.	official dist
airborne	r= -.2553	r= -.0381	r= .0193	r= .1528
	p= .091	p= .791	p= ..891	p= .104
transition	r= .2784	r= .1424	r= .0012	r= -.2069
	p= .064	p= .319	p=.993	p= .027
delivery	r= -.2841	r=.0258	r= -.1065	r= -.0009
	p= .059	p= .857	p=.448	p= .992

Release characteristics. Release velocity

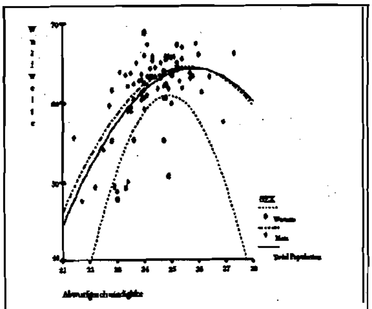

Figure 2: official distance - release velocity diagram with quadratic regression lines inserted

Figure 2: official distance - release velocity diagram with quadratic regression lines inserted

Of all release parameters velocity of release appears to be the most **important**. The assumption, that there is a direct linear relation between release velocity and throwing distance cannot be maintained on the basis of the existing data. Applying a quadratic regression calculation reveals a much more realistic interrelation of the two parameters. The courses of the regression lines indicate an area for optimum release velocities and not as it could have been expected for maximum velocities. This observation can be supported by results from individual performance diagnostics reported earlier (Knicker 1990b). It also accounts for different details on correlation coefficients for release velocity and throwing distance. Schlueter /Nixdorf (1984) found correlations as high as r=.87 whereas Knicker (1990b) calculated a correlation of only r=.41. If we summarize all data available on release velocity and throwing distance the correlation turns out to be r=.55. Correcting throwing distance for the influence of wind and calculating ballistic distance using the release parameters only increases the correlation to r= .90. (see table 4). The negative coefficient for velocity and the difference between ballistic and official distance (r=-.64) indicates a decreasing influence of aerodynamic factors with increasing release velocities.

Nevertheless it is evident that similar distances can be achieved with distinct release velocities and there are conditions wherein discus velocity can be too high for a long throw. It must be assumed that these conditions depend on the athletes' limited motorical abilities to control the discus within the high speed situation. Thus increasing throwing distance by increasing release velocity is primarily an intraindividual problem of movement coordination on a high speed level. This result comes true not only for discus throwing but can also be observed in other throwing events and even athletic jumping events as well.

Table 4: Correlation matrix of flight distances and release parameters

	dist	d-bal	d-dif
veloc	r= .5532	r= .8989	r= -.6380
	p= .000	p= .000	p= .000
angle	r= .0560	r= .4510	r= -.4630
	p= .622	p= .000	p= .000
height	r= .0814	r= -.0338	r= .0882
	p= .487	p= .783	p= .471

Release parameters for the finalists of the WAC in Stuttgart 1993 are summarized in table 4. The given values for angles of release, height of release and release velocities are within the ranges reported in related literature. As there are no comparable data for the analysed athletes it is not possible to give a personal classification of the parameter patterns.

Table 5: Values of release parameters for the finalists of the WAC 1993

Name	**official distance [m]**	**angle of release (°]**	**height of release [m]**	**release velocity [ms-1]**
Burova	**67,40**	**34,6**	**1,49**	**24,5**
Costian	**65.36**	**35.3**	**1,51**	**24,4**
Min	**65,26**	**36,8**	**1,58**	**23.9**
Marten	**64.62**	**389**	**1.67**	**23.9**
Gundler	**6292**	**37.8**	**1,54**	**22,2**
Ecchevarria	**60,16**	**40.0**	**1,60**	**23.9**
Dietzsch	**62.02**	**33,1**	**1.77**	**23,3**
Wyludda	**60,42**	**36.4**	**1,75**	**23.7**
Riedel	**67,34**	**35,0**	**1.65**	**25,5**
Shevchenko	**66,9**	**36.0**	**2.05**	**26,3**
Schult	**66.12**	**36,7**	**1,66**	**24,9**
Ubartas *	**63.98**	**37.3**	**1.98**	**26.8**
Grasu	**65.24**	**34,5**	**1,96**	**26.1**
Zinchenko	**62,02**	**31,4**	**1,65**	**26.7**
Sweeny	**61.26**	**39,5**	**1.70**	**23,8**
Kaptyukh	**61.64**	**39.0**	**1.36**	**24,7**

***=disqualified for drug abuse**

Course of discus velocity

According to earlier studies the course of discus velocity is given as the velocity's change within the destinct phases. In principle we can distinguish four different course patterns:

1. discus velocity is continuously rising from entry to delivery;
2. discus velocity increases until the end of the entry phase, decreases within the airborne phase and increases again until delivery as soon as transition begins;
3. discus velocity decreases in the airborne as well as in the transition phase and increases again in the final double support phase;
4. discus velocity rises until the end of the airborne phase, decreases during transition and increases again in the delivery phase.

None of the four options can be recommended as the optimum solution for there is no significant correlation between the changes of velocity and release velocity of the discus. Though in the past individual styles **profed** to be rather repeatable and typical for a specific athlete. Concerning the analysed trials of the finalists in Stuttgart we find option no. 1 in the majority of the women's throws. An exception is performed by **Min** with the decisive gain of discus velocity in the transition phase and a poor increase in the delivery phase. (see table 5).

Burova, Ecchevarria and Wyludda are the only women to perform option 2 with a decrease of velocity in the airborne phase. Table 5 reveals that Wyludda achieves the highest increase of discus velocity compared to the total sample in the delivery phase.

In the field of the male athletes we find representatives of all five variations with option 2 performed mostly. Schult demonstrates a remarkable velocity pattern with continuous increases even in the airborne phase (+1,52m/s). At the beginning of the delivery phase his discus has allready reached 50% of its release velocity. Therefore the gain in the delivery phase is relatively small (+13,13m/s). The highest final accelerations are performed by Zinchenko (+19,38m/s), Grasu (+18,17m/s) and Riedel (+17,88m/s).

Table 6: Changes of discus velocity during Phases 2 to 5.

Name	official distance [m]	dv2 (m/s)	dv3 (m/s)	dv4 (m/s(	dv5 (m/s)
Burova	67,40	+2,79	+1.39	+4,57	+13,54
Costian	65,36	+1,21	+0,04	+2,48	+16,00
Mi	65,26	+1,31	+1,77	11,80	+3,16
Marten	64,62	-2,05	+2,05	+0,91	+15,39
Gundler	62.92	+4,50	+1,84	+2,54	+10,98
Ecchevarria	60,16	+4,26	-2.76	+3,02	+14,03
Dietzsch	62.02	+2,93	+0,19	-0.40	+16,88
Wyludda	60,42	+2,97	-0.79	+1,62	+16,.91
Riedel	67,34	+2,57	-0.88	+2,23	+17,88
Shevchenko	66,90	+0,97	+ , -	+2,44	+16,72
Schult	66.12	+1,99	+1,52	+3,07	+13,13
Ubartas *	63.98	4.80	-0.70	+1,22	+17,41
Grasu	65.24	+5,54	-0.08	-0.70-	+18,17
Zinchenko	62,02	+4,89	-1.23	-2.38	+19,38
Sweeny	6126	+4,42	-0.61	+0,32	+16,10
Kaptyukh	6164	-1.04	+0,45	-0.92	+16,77

*= disqualified for drug abuse

DISCUSSION

The present kinematic analysis of discus throwing increased the existing data base of the discipline. Timing characteristics shows extreme interindividual variabilities but high intraindividual constancy without significant relations to throwing distance. None of the timing variations can be recommended as the best solution.

The release parameters revealed no further insights into throwing techniques. As release velocity contributes about 80% to the variance of the ballistic distance it is the most important release parameter. The influence of the wind conditions appears to decrease statistically with increasing release velocity on the one hand but on the other hand avoids a higher correlation between release velocity and the official distance. Regression analysis revealed that release velocity must rather be optimized than maximized. This might be due to the individual athletes' ability to control the discus release at high velocities.

History of the discus' acceleration described as change of discus velocity during the crucial phases of the turn again revealed interindividual variations witliout showing a common tendency or even a solution to be called the best.

It must be questioned whether a kinematic analysis of top level athletes' techniques leads to further insights into the discipline itself. The kinematic data are nothing else than a discription of the athletes' movements in a more objective way. Those analyses did not yet identify the ideal technique. Only a very individual performance diagnostics including calculations of mechanical work and power in different variations of the technique will contribute to an improvement of personal performance. Thus an

ideal technique only exists for one special athlete and it cannot be generalized for the whole population of athletes. This means a dilemma for any trainer as he has no criteria to seperate between mistakes and individual variations of movement technique.

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