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The pole vault at the 2005 IAAF World Championships in Athletics:

A preliminary report

By Falk Schade, Gert-Peter Brüggemann

ABSTRACT

To improve understanding of the biomechanics of elite pole vaulting and develop practical suggestions to support the members of the pole vault community in their daily work, the IAAF commissioned a study of the event at the 2005 IAAF World Championships in Athletics in Helsinki. The project team collected data from the men's and women's competitions plus the pole vault in the decathlon. Their study included the highlight of the three competitions – the women's world record 5.01m set by Yelena Isinbayeva (RUS). The team used an energy-oriented approach for their analysis, a challenging task that involves crossing the bridge between abstract considerations concerning the energy exchange and the actual movement of the athlete. This preliminary report focuses mainly on the methods applied and gives a short outlook on the results, including approach velocity data, which will be presented in the final report.

AUTHORS

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Introduction

The pole vault has been in the focus of biomechanical analysis for decades. With the introduction of the elastic pole effecting a change in energetic aspects (DILLMANN and NELSON, 1968), the event became a wide field of biomechanical interest, particularly as an example of the interaction between a biological system and an elastic mechanical implement (HUBBARD, 1980; EKEVAD and LUNDBERG, 1995, 1997; ARAMPATZIS et al., 1997, 1999, 2004; LINTHRONE, 2000; SCHADE et al., 2000). The importance of the energy exchange between athlete and pole to improving performance is generally accepted (e.g. HUBBARD, 1980; Ekevad and Lundberg, 1995, 1997; ARAMPATZIS et al., 1997; SCHADE et al. 2000). ARAMPATZIS et al. (1997, 2004) developed criteria, based on kinematic and kinetic data of the vaulter and the pole, to study the energy transfer as the crucial aspect to explain the maximum height achieved by the centre of mass.

A promising aspect concerning the biomechanical impact on the training process and jumping performance seems to deal with mechanical energy considerations (ARAM-

PATZIS et al., 1999; SCHADE et al., 2000). This is why an energy-oriented approach has been selected for the project to analyse the pole vault competition at the 2005 IAAF World Championships in Athletics in Helsinki. To apply energy considerations is a challenging task, similar to crossing the bridge between abstract considerations concerning the energy exchange and the actual movement of the athlete.

The aim of this project is to improve the pole vault specific biomechanical knowledge as far as elite vaulting is concerned and to transform this knowledge into practical suggestions to support the pole vault community in their daily work.

The following preliminary report mainly focuses on the methods applied and gives a short outlook on the results that will be presented in the final report.

Methods

Data were collected at the men's and the women's pole vault finals and the pole vault of the decathlon (group A) at the 2005 IAAF World Championships in Athletics in Helsinki. The vaults were recorded by four genlocked video cameras synchronised using LEDs (light emitting diodes). The video cameras operated at 50 fields per second. Two cameras recorded the movement from the penultimate ground contact to approximately the maximum pole bend position. The other two cameras recorded the ensuing movement up to bar clearance. One camera of each pair was positioned at an angle of approximately 90° to the main plane of movement in the direction of the movement. The second camera was positioned perpendicular to it (Figure 1).

Eighteen body marks were digitised. The three dimensional co-ordinates were calculated using the DLT method (direct linear transformation; Abdel-Aziz and Karara, 1971). Kinematic data was smoothed using a forth order low-pass Butterworth filter with an optimised cut off frequency for each digitised point ("Peak Motus" Motion Analysis System). The origin of the inertial co-ordinate system (ICS) was located above the deepest point of the vault box at ground level in the middle of the runway. The x-axis was defined as the horizontal axis in the main plane of movement. The y-axis was defined as the vertical axis. The z-axis results from the cross product between the x and y axes. The masses and moments of inertia of the various body segments were calculated using the data provided by Zatsiorsky and Seluyanov (1983). For

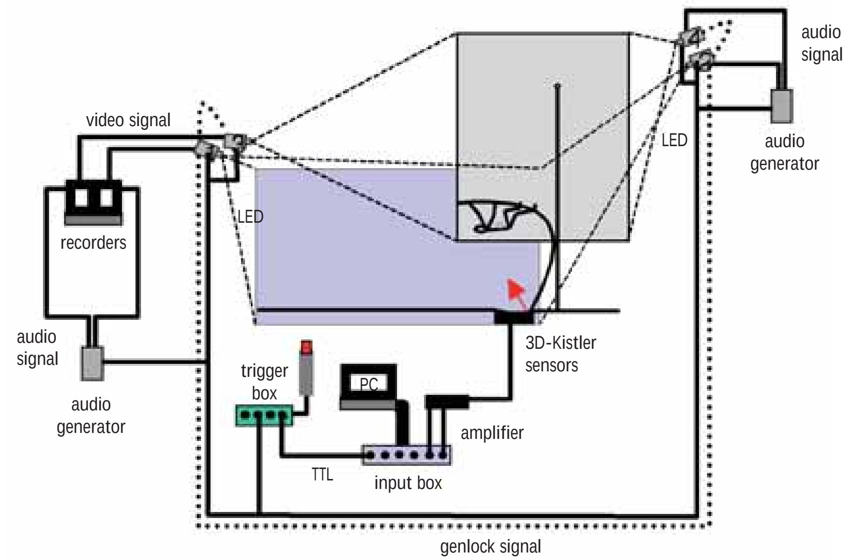

Figure 1: Kinematic and dynamometric set up.

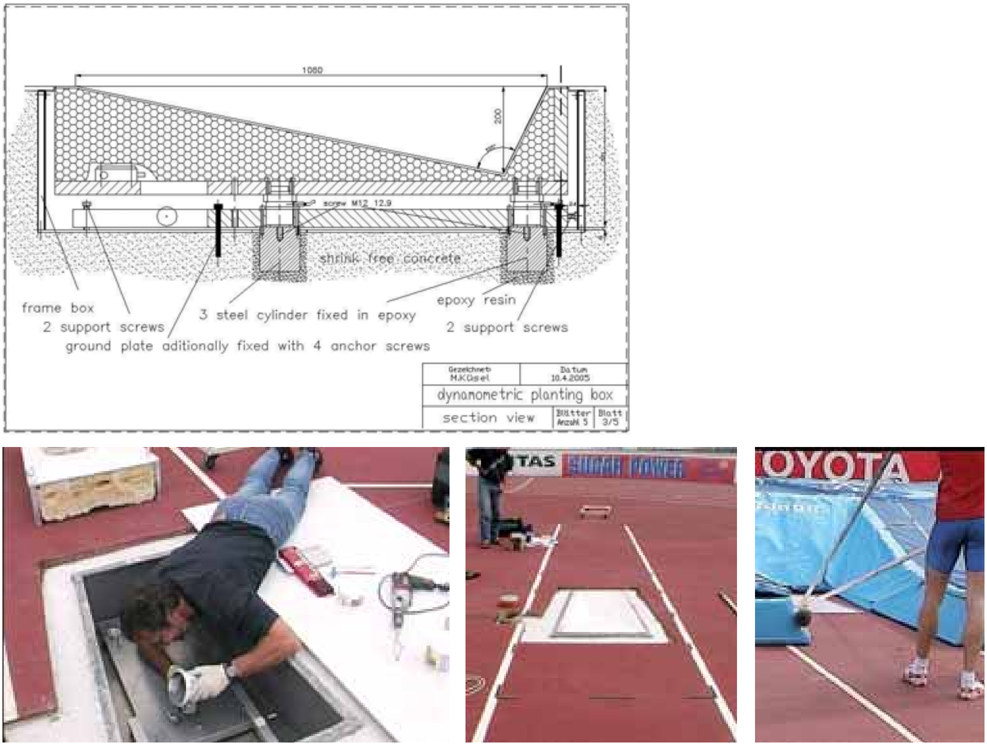

Figure 2: Set up of dynamometric vault box.

this process only the height and body mass of the subjects are needed.

Ground reaction forces exerted on the bottom of the pole were measured at 1000 Hz by fixing the vault box on a three 3D Kistler force sensors (Figure 2). The force data were smoothed using a fourth-order low-pass Butterworth filter with a cut-off frequency of 40 Hz. The synchronisation of the kinematic and dynamic data was achieved by using LEDs (light emitting diodes) and a synchronous TTL signal, which was used to generate an audio signal that was written on the audio line of the video tapes.

Additionally the development of the approach velocity was measured using a Laser distance measurement device (Laveg by Jenoptik), which operated at 100 Hz.

Calculations

The athlete's total body energy will be calculated as follows:

$$E_{tot} = \sum_{i=1}^{12} mgh + \sum_{i=1}^{12} \frac{mv_i^2}{2} + \sum_{i=1}^{12} \frac{I_i \grave{u}_i^2}{2} + \frac{I_{TL} \grave{u}_{TL}^2}{2} \qquad (1)$$

m_i: mass of the ith segment
g: acceleration of gravity (g= 9.8094 m/s_)
h_i: height of the centre of mass of the i^{th} segment
v_i: velocity of the centre of mass of the i^{th} segment
_i: angular velocity of longitudinal axis of the i^{th} segment
I_i: moment of inertia of the i^{th} segment about its transversal axis
$\_{TL}$: angular velocity of the trunk about its longitudinal axis
I_{TL}: moment of inertia of the trunk about its longitudinal axis

The formula takes the potential energy and the kinetic energy (linear and angular) of the 12 segments into account. The angular kinetic energy about the longitudinal axis will only be calculated for the trunk segment.

The angular velocity of the longitudinal axis of the ith segment will be calculated using the following formula:

$$\grave{u}_i = \frac{a_{1i} \times a_{2i}}{|a_{1i} \times a_{2i}|}\frac{\theta_i}{\Delta t}, \quad a_{1i} = \vec{A_iB_i}(t), \quad a_{2i} = \vec{A_iB_i}(t+\Delta t) \qquad (2)$$

A_i: distal endpoint of the i^{th} segment
B_i: proximal endpoint of the i^{th} segment
$\_i$: angle between a_{1i} and a_{2i}
_t: time interval between two successive frames

The angular velocity of the trunk about its longitudinal axis will be calculated as follows:

$$\grave{u}_{TL} = \frac{\grave{u}_{STL} + \grave{u}_{HTL}}{2} \qquad (3)$$

where

$$\grave{u}_{STL} = proj_{u_T}\grave{u}_S = \frac{\grave{u}_S \cdot u_T}{|u_T|^2}u_T, \quad \grave{u}_{HTL} = proj_{u_T}\grave{u}_H = \frac{\grave{u}_H \cdot u_T}{|u_T|^2}u_T$$

and

$$u_T = \vec{O_HO_S}, \quad O_H = \frac{L_H + R_H}{2}, \quad O_S = \frac{L_S + R_S}{2}$$

$$\grave{u}_S = \frac{b_{1S} \times b_{2S}}{|b_{1S} \times b_{2S}|}\frac{\theta_S}{\Delta t}, \quad b_{1S} = \vec{L_SR_S}(t), \quad b_{2S} = \vec{L_SR_S}(t+\Delta t)$$

$$\grave{u}_H = \frac{b_{1H} \times b_{2H}}{|b_{1H} \times b_{2H}|}\frac{\theta_H}{\Delta t}, \quad b_{1H} = \vec{L_HR_H}(t), \quad b_{2H} = \vec{L_HR_H}(t+\Delta t)$$

L_H : point of the left hip
R_H : point of the right hip
L_S : point of the left shoulder
R_S : point of the right shoulder
$\_S$: angle between b_{1S} and b_{2S}
$\_H$: angle between b_{1H} and b_{2H}

The athlete's centre of mass energy will be calculated as follows:

$$E_{CM} = mgH_{CM} + \frac{mv?_{CM}}{2} \qquad (4)$$

m : mass of the athlete
H_{CM} : height of the athlete's centre of mass
v_{CM} : velocity of the athlete's centre of mass

The athlete's angular momentum will be calculated as follows:

$$H_{tot} = \sum_{i=1}^{15} I_i \cdot \grave{u}_i + I_{TL} \cdot \grave{u}_{TL} + \sum_{i=1}^{15} r_i \times m \cdot v_{i,CM} \qquad (5)$$

r_i: vector of the ith segment of centre of mass of the ith segment in relation to the centre of mass of the whole body
$v_{i,cm}$: velocity of the centre of mass of the ith segment in relation to the centre of mass of the whole body

Results

Table 1. Official results of the men's final.

Position	Name	Nationality	Mark (m)
1	Rens Blom	NED	5.80
2	Brad Walker	USA	5.75
3	Pavel Gerasimov	RUS	5.65
4	Igor Pavlov	RUS	5.65
5	Guiseppe Gibilisco	ITA	5.50
5	Nick Hysong	USA	5.50
5	Tim Lobinger	GER	5.50
8	Daichi Sawano	JPN	5.50
9	Patrik Kristianson	SWE	5.50
10	Kevin Rans	BEL	5.35
	Danny Ecker	GER	NM
	Dimitri Markov	AUS	NM

Table 2: Official results of the women's final.

Position	Name	Nationality	Mark (m)
1	Yelena Isinbayeva	RUS	5.01 (WR)
2	Monika Pyrek	POL	4.60
3	Pavla Hamackova	CZE	4.50
4	Tatyana Polnova	RUS	4.50
5	Shuying Gao	CHN	4.50
6	Dana Ellis	CAN	4.35
6	Pavla Hamackova	POL	4.35
8	Vanessa Boslack	FRA	4.35
9	Naroa Agirre	ESP	4.35
10	Carolin Hingst	GER	4.35
11	Jillian Schwart	USA	4.20
12	Tatiana Grigorieva	AUS	4.00
	Tracy O'Hara	USA	NM

Table 3: Mean approach velocity between 16 and 11 metres (V16-11m) and 11 and 6 metres (V11-6m) for the fair vaults of the men's final calculated from laser distance measurement (a few data are missing due to signal irritation by participants crossing the runway). The distances refer to the zero-line.

Name	Bar Height (m)	Trial	V16-11m [m/s]	V11-6m [m/s]	Difference [m/s]
Blom	5.50	3o	9.03	9.04	0.02
Blom	5.65	2o	8.85	8.88	0.03
Blom	5.75	2o	9.04	8.99	-0.05
Blom	5.80	1o	9.01	9.04	0.03
Walker	5.50	3o	8.96	9.23	0.26
Walker	5.65	2o	8.91	9.09	0.18
Walker	5.75	2o	9.16	9.26	0.10
Gerasimov	5.50	1o	8.77	8.77	0.00
Gerasimov	5.65	2o	8.77	8.96	0.19
Pavlov	5.65	3o	8.90	8.94	0.05
Pavlov	5.50	1o	8.77	8.87	0.09
Gibilisco	5.50	1o	9.11	9.23	0.12
Hysong	5.50	1o	8.99	9.16	0.16
Sawano	5.35	2o	8.87	9.21	0.34
Sawano	5.50	1o	9.09	9.21	0.12
Kristianson	5.50	3o	9.38	9.43	0.05
Rans	5.35	1o	8.61	8.91	0.31

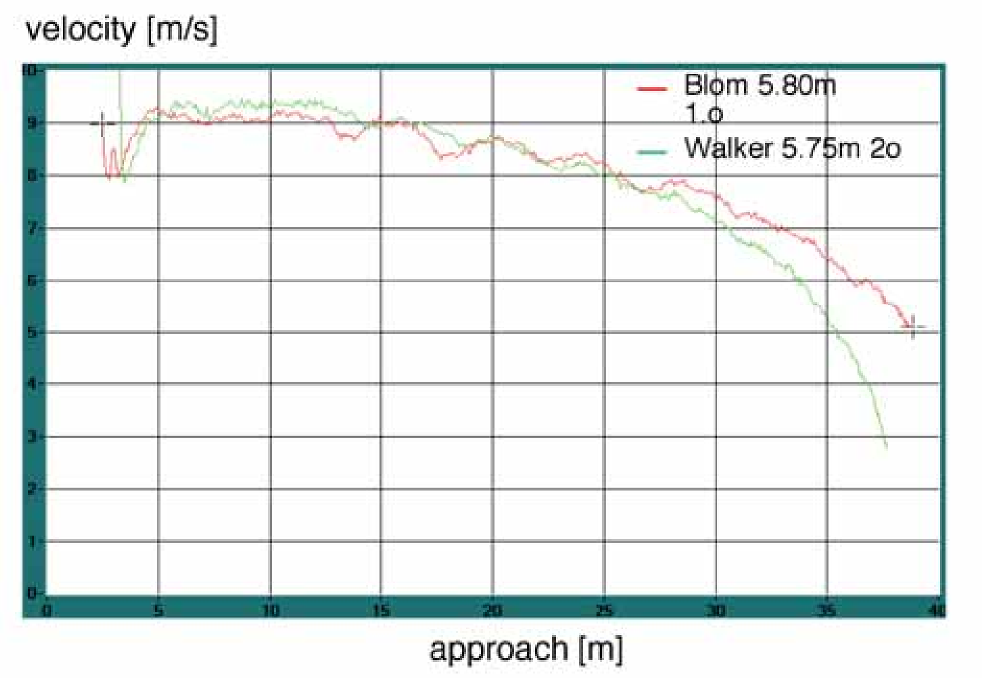

Figure 3: Development of approach velocity of Blom and Walker

Table 4: Mean approach velocity between 15 and 10 metres (V15-10m) and 10 and 5 metres (V10-5m) for the fair vaults of the women's final calculated from laser distance measurement (a few data are missing due to signal irritation by participants crossing the runway). The distances refer to the zero-line.

Name	Bar Height (m)	Trial	V16-11m [m/s]	V11-6m [m/s]	Difference [m/s]
AGIRRE	4.00	1o	7.65	7.66	0.01
AGIRRE	4.20	1o	7.52	7.76	0.25
AGIRRE	4.35	3o	7.69	7.86	0.17
BOSLAK	4.20	2o	7.95	7.94	-0.01
BOSLAK	4.35	2o	7.99	8.05	0.06
ELLIS	4.20	1o	7.52	7.76	0.25
ELLIS	4.35	1o	7.49	7.70	0.22
GAO	4.00	2o	7.85	7.97	0.13
GAO	4.20	1o	7.82	7.97	0.15
GAO	4.35	2o	7.72	7.91	0.20
GAO	4.50	3o	7.75	8.00	0.25
GRIGO	4.00	1o	7.84	8.08	0.24
HAMACK	4.20	2o	7.58	7.73	0.15
HAMACK	4.35	1o	7.66	7.75	0.09
HAMACK	4.50	1o	7.60	7.72	0.12
HINGST	4.00	2o	7.54	7.81	0.27
HINGST	4.20	1o	7.58	7.84	0.26
HINGST	4.35	3o	7.73	7.76	0.04
ISINBAYEVA	4.50	1o	8.28	8.33	0.06
ISINBAYEVA	4.60	1o	8.10	8.49	0.39
ISINBAYEVA	4.70	1o	8.09	8.47	0.38
ISINBAYEVA	5.01	2o	8.10	8.31	0.20
POLNOVA	4.20	1o	7.29	7.51	0.22
POLNOVA	4.35	1o	7.23	7.54	0.32
POLNOVA	4.50	3o	7.39	7.52	0.13
PYREK	4.20	1o	7.69	7.84	0.14
PYREK	4.35	1o	7.84	8.03	0.19
PYREK	4.50	2o	7.74	8.08	0.34
PYREK	4.60	1o	7.80	8.01	0.21
ROGOWSKA	4.35	1o	8.33	8.53	0.20
SCHWARTZ	4.20	2o	7.89	8.03	0.14

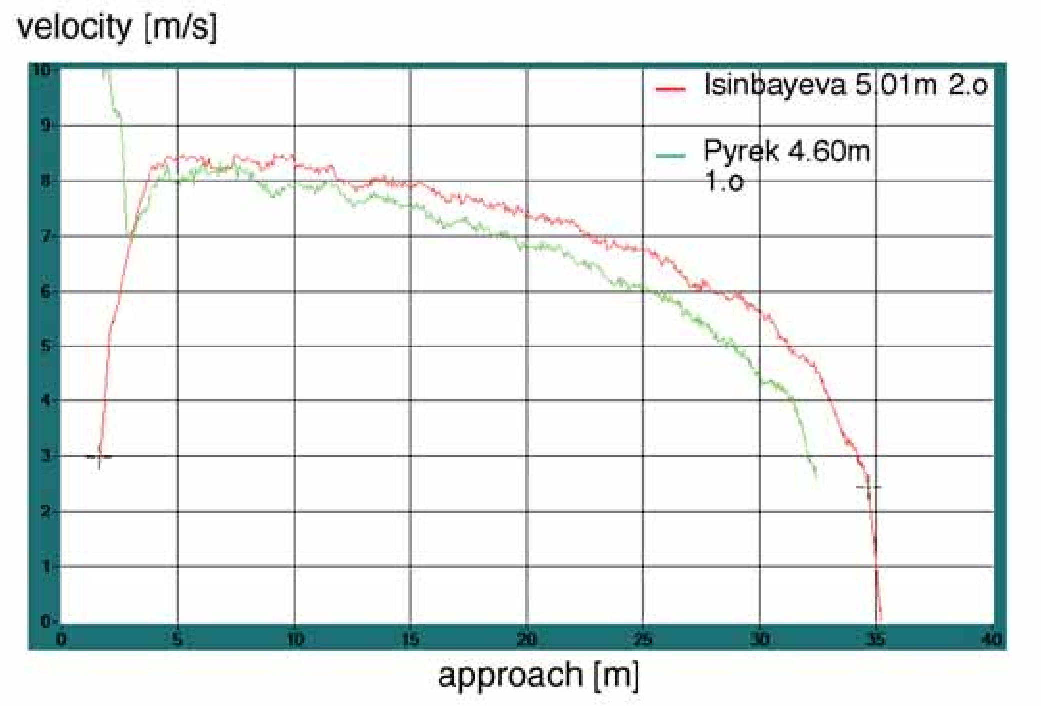

Figure 4. Development of approach velocity of Isinbayeva and Pyrek

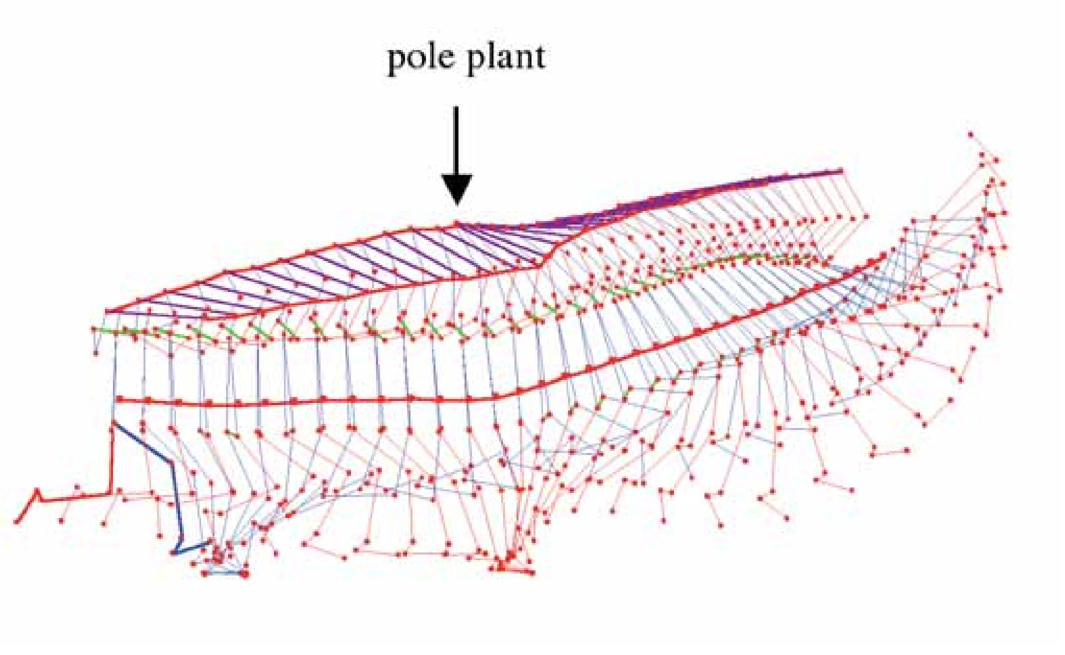

Figure 5: Stick figure of JPC (Jump-Plant Complex) of Isinbayeva clearing 5.01m (WR).

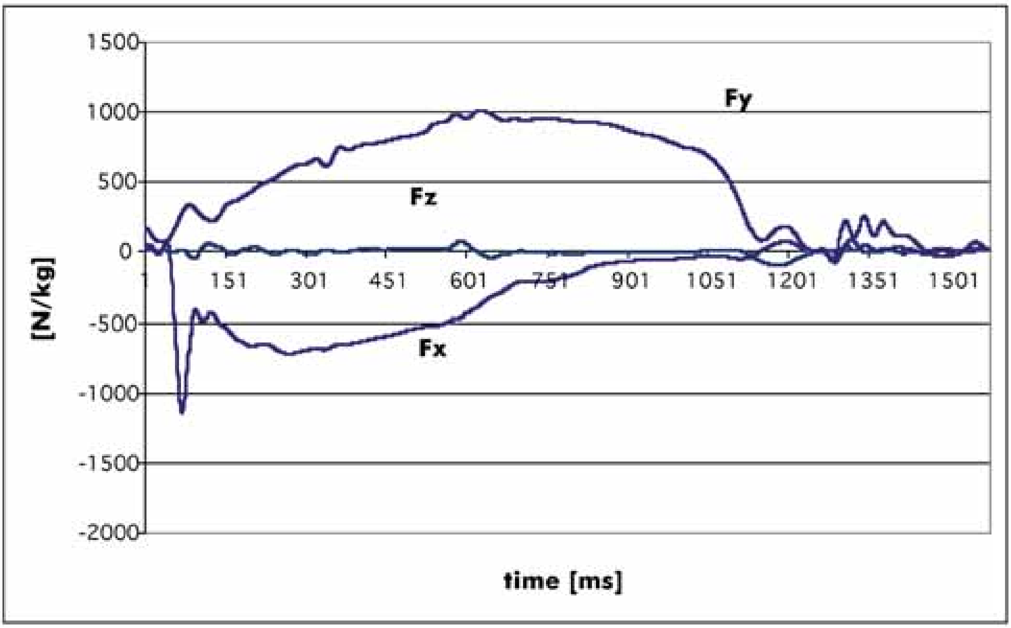

Figure 6: Reaction forces measured in the planting box for a female vaulter (x is in direction of the approach run, y is in vertical direction, z is perpendicular to them).

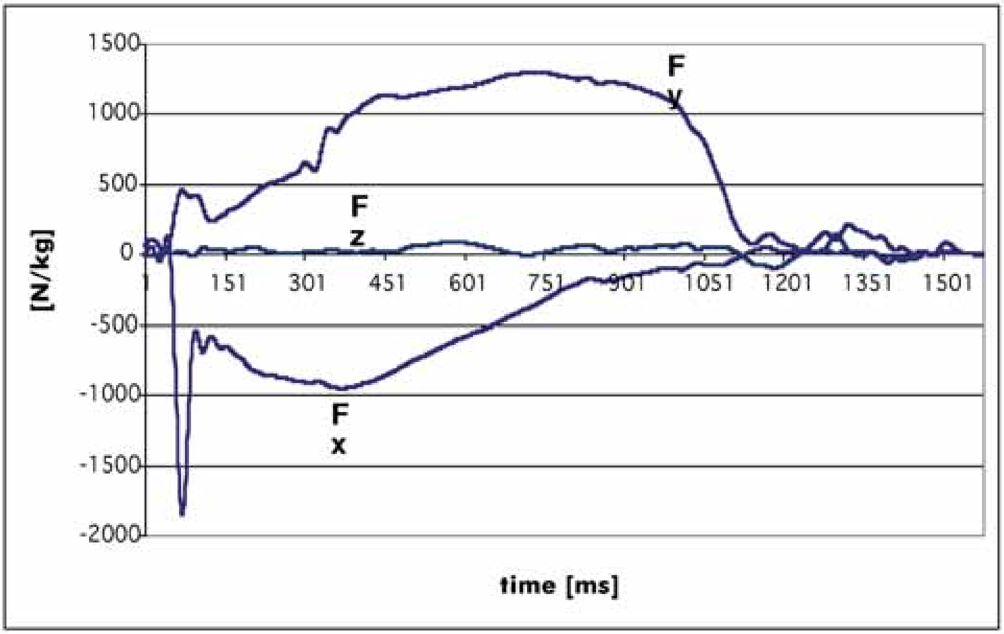

Figure 7: Reaction forces measured in the planting box for a male vaulter (x is in direction of the approach run, y is in vertical direction, z is perpendicular to them).

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