Biomechanical analysis of the pole vault at the 2005 IAAF World Championships in Athletics

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Extracts from the Final Report

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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 event in the decathlon. Their study included the highlight of the three competitions – the women's world record 5.01m set by Yelena Isinbayeva (RUS). A preliminary report was published in NSA in 2006. This article, extracted from the final report, provides an overview of the main results obtained and focuses on a) approach velocity, b) forces exerted at the end of the pole in the planting box during the vault and c) mechanical energy parameters of the vaulter and angular momentum during the vault, including a comparison of the male and female finalists and the decathletes on the basis of energy considerations and angular momentum.

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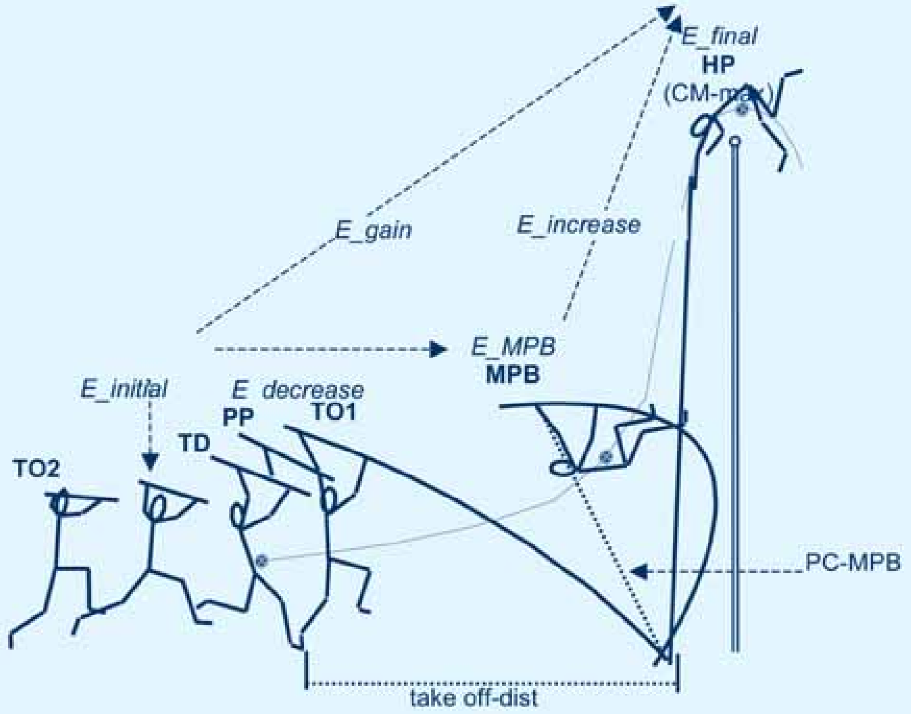
Introduction

To improve understanding of the biomechanics of elite pole-vaulting, the IAAF commissioned a study of the event as an element of its Biomechanical Research Project at the 2005 IAAF World Championships in Athletics in Helsinki, Finland. In a preliminary report on the study, published in New Studies in Athletics (issue 2, 2006), we explained that we had selected an energy-oriented approach, detailed the meth-



The pole vault movement and selected parameters

TO2=end of penultimate ground contact; TD=beginning of last ground contact; PP=pole plant (pole hits planting box); TO1=end of last ground contact; MPB=maximum pole bend; HP=instant of maximum centre of mass (CM) height; E_initial=total energy of the athlete in the middle of the last flight phase of the approach run; E_MPB=athlete's total mechanical energy at MPB; E_final=athlete's total mechanical energy at the moment of the highest position of the CM; E_decrease=decrease of athlete's energy in the first pole phase (E_initial minus E_MPB); E_increase=increase of athlete's energy in the second pole phase (E_final minus E_MPB); E_gain=net work performed by the vaulter during the whole pole phase; CM-max=maximum centre of mass height; take-off dist (take-off distance)=horizontal distance between the tip of the take off foot and the end of the planting box (zero line) at take-off; PC-MPB: length of pole chord at MPB (distance between the middle of upper grip hand and deepest point in the planting box) (from SCHADE et al. 2006)

ods used for data collection, gave the formulas used for calculation and provided the initial results obtained to that point.

To summarise, in Helsinki we collected data on the men's and women's finalists as well as one of the groups of the decathlon (see Table 1, Table 2 and Table 3 for results and details of the competitions). Data on the approach velocity was collected with a laser distance measurement device. Data on the ground reaction forces exerted by the pole was collected using force sensors under the vaulting box. Other data was obtained from video recordings, which were subsequently digitised and analysed.

This article provides an overview of the results we obtained in the following three areas:

- Approach velocity
- Forces exerted at the end of the pole in the planting box during the vault
- Mechanical energy parameters of the vaulter and angular momentum during the vault (including a comparison of the male and female finalists and the decathletes on the basis of energy considerations and angular momentum).

Table 1: Official results of the men's pole vault final at the 2005 IAAF World Championships in Athletics (analysed trials are marked bold)

Position	Name		5.35	5.50	5.65	5.75	5.80	5.85
1	Rens BLOM	NED	-	xxo	xo	xo	**o**	x
2	Brad WALKER	USA	-	xxo	xo	**xo**	x-	xx
3	Pavel GERASIMOV	RUS	-	o	**xo**	xxx		
4	Igor PAVLOV	RUS	-	o	**xxo**	xxx		
5	Guiseppe GIBILISCO	ITA	-	**o**	xxx			
5	Nick HYSONG	USA	-	**o**	xxx			
5	Tim Lobinger	GER	-	**o**	xxx			
8	Daichi SAWANO	JPN	xo	**o**	xxx			
9	Patrik KRISTIANSON	SWE	-	**xxo**	xxx			
10	Kevin RANS	BEL	**o**	xxx				
NM	Danny ECKER	GER	-	xxx				
NM	Dimitri MARKOV	AUS	-	xxx				

Table 2: Official results of the women's pole vault final at the 2005 IAAF World Championships in Athletics (analysed trials are marked bold)

Position	Name		4.00	4.20	4.35	4.50	4.60	4.70	4.75	5.01
1	Yelena ISINBAYEVA	RUS	-	-	-	o	o	o	-	**xo**
2	Monika PYREK	POL	-	o	o	xo	**o**	xx-	x	
3	Pavla HAMACKOVA	CZE	-	xo	o	**o**	xxx			
4	Tatyana POLNOVA	RUS	-	o	o	**xxo**	xxx			
5	Shuying GAO	CHN	xo	o	xo	**xxo**	xxx			
6	Dana ELLIS	CAN	-	o	**o**	xxx				
6	Anna ROGOWSKA	POL	-	-	**o**	xxx				
8	Vanessa BOSLAK	FRA	-	xo	**xo**	xxx				
9	Naroa AGIRRE	ESP	o	o	**xxo**	xxx				
10	Carolin HINGST	GER	xo	o	**xxo**	xxx				
11	Jillian SCHWART	USA	-	**xo**						
12	Tatiana GRIGORIEVA	AUS	**o**	xxx						
NM	Tracy O'HARA	USA	-	xxx						

Table 3: Official results of the decathletes competing at facility A at the 2005 IAAF World Championships in Athletics (analysed trials are marked bold)

Position	Name		4.20	4.30	4.40	4.50	4.60	4.70	4.80	4.90	5.00	5.10
1	Paul TEREK	USA	-	-	-	-	xxo	-	-	xo	xo	xxx
2	Roland SCHWARZL	AUT	-	-	-	xxo	-	xo	o	o	xxx	
3	Hamdi DHOUIBI	TUN	-	-	o	-	-	o	o	xxx		
4	Frederic XHONNEUX	BEL	o	-	xo	o	xo	o	xxx			
5	Oscar GONZALEZ	ESP	o	-	xo	-	xxo	xxx				
6	Jaakko OJANIEMI	FIN	o	o	xo	xo	xxx					
7	Thomas DVORAK	CZE	o	-	xxx							
NM	Phil McMULLEN	USA	-	-	-	xxx						
NM	Aleksey SYSOYEV	RUS	xxx									
NM	Eugene MARTNIEAU	NED	-	xxx								

Approach velocity

The aim of the approach run is to generate kinetic energy that can be used during the interaction with the pole. Three aspects should be highlighted. First: the athlete has to perform an approach run that enables him/her to make a jump and plant action that optimises energy transfer during the take-off (legs) and the pole plant (arms/trunk). Second: this can only be achieved by hitting the take-off point accurately; an accuracy of ± 8cm approximately will not influence the jump and plant action, regardless the chosen jump and plant technique (SCHADE et al., 2006). Third: the athlete should achieve the highest kinetic energy possible at foot plant for take-off, having fulfilled the preconditions of the two points mentioned above. In other words, the athlete has to achieve the maximum level of controlled velocity at the instant of touchdown for take-off.

Tables 4 and Table 5 show the mean approach velocity between 16 and 11m and between 11 and 6m for the male specialists and the decathletes. From a methodological point of view, the last interval measured should be as close to the take-off point as possible without being influenced by the planting action. Because the take-off point for women is generally closer than for men, their mean approach velocity was determined between 15 and 10m and between 10 and 5m respectively (Table 6). As approach velocity strongly depends on the weather and wind conditions and with the circumstances during the competitions at the Helsinki 2005 World Championships in mind, the presented data should be interpreted with care.

The male pole vault specialists showed approach velocities (V11-6m) between 8.88m/s and 9.43m/s, with the slowest approach shown by the world champion Blom and the highest velocity shown by Kristianson, who placed 9th. Compared, for example, to the approach velocities measured 18 years earlier at the 1987 IAAF World Championships in Athletics (GROS and KUNKEL, 1988), the vaulters studied here clearly had slower approaches. The female vaults showed approach velocities (V10-5m) between 7.51m/s and 8.53m/s, with the slowest by Polnova (4th place) and the fastest by Rogowska (6th place). Isinbayeva's slowest approach velocity, compared to her other fair vaults, was on her world record jump (8.31m/s). As expected, the decathletes showed an extremely wide range in approach velocity (7.63m/s to 9.17m/s)

The difference between the fastest female vaulter and the slowest male vaulter (Table 7

Table 4: Mean approach velocity between 16 and 11m (V16-11m) and 11 and 6m (V11-6m) for the successful trials of the finalists in the men's pole vault at the 2005 IAAF World Championships in Athletics (Data calculated from laser distance measurement, the distances refer to the zero-line. A few data are missing due to signal irritation by participants crossing the runway).

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

and Table 8) was 0.35m/s, with a difference in bar height of 1.45m. Even the difference in maximum centre of mass (CM) height (1.16m) cannot be explained by the difference in approach velocity, indicating that there are other differences between the pole vaulting of men and women.

Most of the vaulters showed a clear increase in approach velocity between the measured intervals, which is generally accepted to be ideal. Only Blom maintained his velocity. Interestingly, Isinbayeva showed a relatively small increase in her world record vault (Table 5) compared to her other successful trials. The time histories of the approach velocities reveal different structuring of the approach run (Figure 1 and Figure 2). For example, both Blom and Walker (2nd place) were both successful in the event but Blom's time history shows a smooth increase in velocity while Walker's history shows a faster acceleration.

Forces in the planting box

The time history of the reaction forces at the end of the pole measured in the planting box during the vault reflect the changes in the velocity of the vaulter/pole system. This is, in fact, the result of the vaulter's action and the application of force to the pole respectively. Figure 3 and Figure 4 show the absolute reaction forces in the planting box of Isinbayeva's world record and Blom's winning vault. Both athletes show similar force time histories in the three components measured:

- Reaction forces in horizontal direction of the runway (Fx)
- Vertical reaction force (Fy)
- Reaction force perpendicular to Fx (Fz)

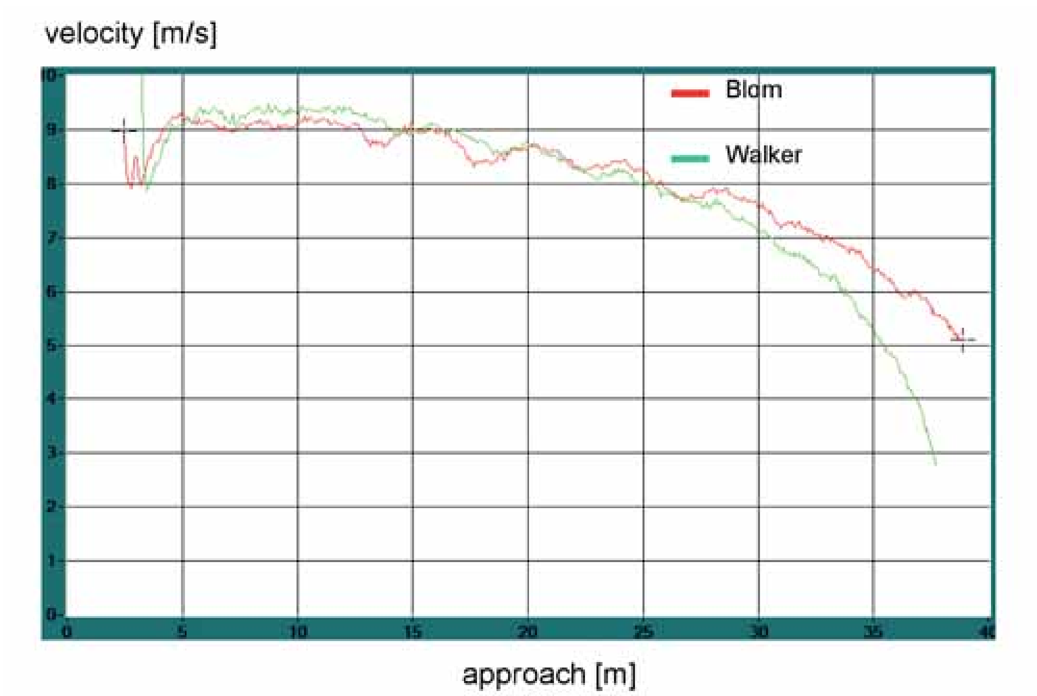


Figure 1: Development of approach velocity in vaults by Blom (5.80m) and Walker (5.75m) at the 2005 IAAF World Championships in Athletics

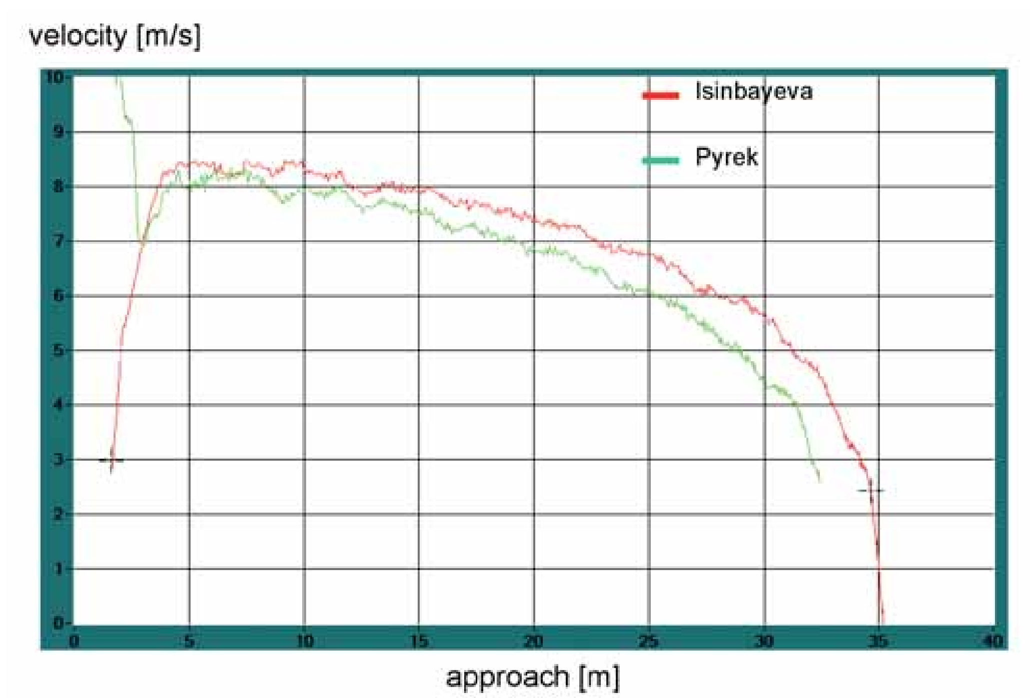


Figure 2: Development of approach velocity in vaults by Isinbayeva (5.01m) and Pyrek (4.60m) at the 2005 IAAF World Championships in Athletics

Table 5: Mean approach velocity between 15 and 10m (V15-10m) and 10 and 5m (V10-5m) for the successful trials of the finalists in the women's pole vault at the 2005 IAAF World Championships in Athletics (Data calculated from laser distance measurement, the distances refer to the zero-line. A few data are missing due to signal irritation by participants crossing the runway).

Name	Bar height [m]	Trial	V15-10m [m/s]	V10-5m [m/s]	Difference [m/s]
Agirre	4.00	1	7.65	7.66	0.01
Agirre	4.20	1	7.52	7.76	0.25
Agirre	4.35	3	7.69	7.86	0.17
Boslak	4.20	2	7.95	7.94	-0.01
Boslak	4.35	2	7.99	8.05	0.06
Ellis	4.20	1	7.52	7.76	0.25
Ellis	4.35	1	7.49	7.70	0.22
Gao	4.00	2	7.85	7.97	0.13
Gao	4.20	1	7.82	7.97	0.15
Gao	4.35	2	7.72	7.91	0.20
Gao	4.50	3	7.75	8.00	0.25
Grigo	4.00	1	7.84	8.08	0.24
Hamack	4.20	2	7.58	7.73	0.15
Hamack	4.35	1	7.66	7.75	0.09
Hamack	4.50	1	7.60	7.72	0.12
Hingst	4.00	2	7.54	7.81	0.27
Hingst	4.20	1	7.58	7.84	0.26
Hingst	4.35	3	7.73	7.76	0.04
Isinbayeva	4.50	1	8.28	8.33	0.06
Isinbayeva	4.60	1	8.10	8.49	0.39
Isinbayeva	4.70	1	8.09	8.47	0.38
Isinbayeva	5.01	2	8.10	8.31	0.20
Polnova	4.20	1	7.29	7.51	0.22
Polnova	4.35	1	7.23	7.54	0.32
Polnova	4.50	3	7.39	7.52	0.13
Pyrek	4.20	1	7.69	7.84	0.14
Pyrek	4.35	1	7.84	8.03	0.19
Pyrek	4.50	2	7.74	8.08	0.34
Pyrek	4.60	1	7.80	8.01	0.21
Rogowska	4.35	1	8.33	8.53	0.20
Schwartz	4.20	2	7.89	8.03	0.14

Table 6: Mean approach velocity between 16 and 11m (V16-11m) and 11 and 6m (V11-6m) for the successful trials (plus one failure, marked x) in the decathlon pole vault (Facility A) at the 2005 IAAF World Championships in Athletics (Data calculated from laser distance measurement, the distances refer to the zero-line. A few data are missing due to signal irritation by participants crossing the runway).

Name	Bar height [m]	Trial	V16-11m [m/s]	V11-6m [m/s]	Difference [m/s]
Dhouibi	4.40	1	8.79	9.09	0.30
Dhouibi	4.70	1	8.94	9.14	0.20
Dhouibi	4.80	1	9.07	9.17	0.10
Dvorak	4.20	1	7.62	8.13	0.51
Gonzales	4.40	1	7.23	7.78	0.55
Gonzales	4.60	3	7.18	7.63	0.45
Ojaniemie	4.30	1	8.14	8.43	0.29
Ojaniemie	4.40	2	8.04	8.29	0.25
Ojaniemie	4.50	2	8.14	8.56	0.42
Schwarzl	4.50	3	7.91	8.13	0.22
Schwarzl	4.70	2	7.92	8.24	0.31
Schwarzl	4.80	1	7.89	8.21	0.32
Schwarzl	4.90	1	7.89	8.29	0.41
Terek	4.60	3	8.55	8.73	0.18
Terek	4.90	2	8.62	8.87	0.24
Terek	5.00	2	8.49	8.77	0.28
Terek	5.10	3	8.61	8.85	0.24
Xhonneux	4.20	1	8.18	8.46	0.28
Xhonneux	4.40	2	8.42	8.67	0.25
Xhonneux	4.50	1	8.47	8.55	0.07
Xhonneux	4.60	2	8.33	8.43	0.10
Xhonneux	4.70	1	8.45	8.52	0.07

The reaction forces in the horizontal direction of the runway are characterised by a clear peak at the beginning of the vault, when the pole hits the back of the planting box. Due to his greater body mass, approach velocity and pole stiffness, Blom (Figure 3) produces a clearly higher peak. This peak is followed by a second maximum, which occurs approximately when his CM passes the pole chord. From that point Fx decreases up to the pole straight position, where it is close to zero and remains on this level.

The vertical reaction force (Fy) for Blom increases steadily and achieves its maximum after the maximum pole bend position and prior to the maximum of the athlete's kinetic energy that occurs between maximum

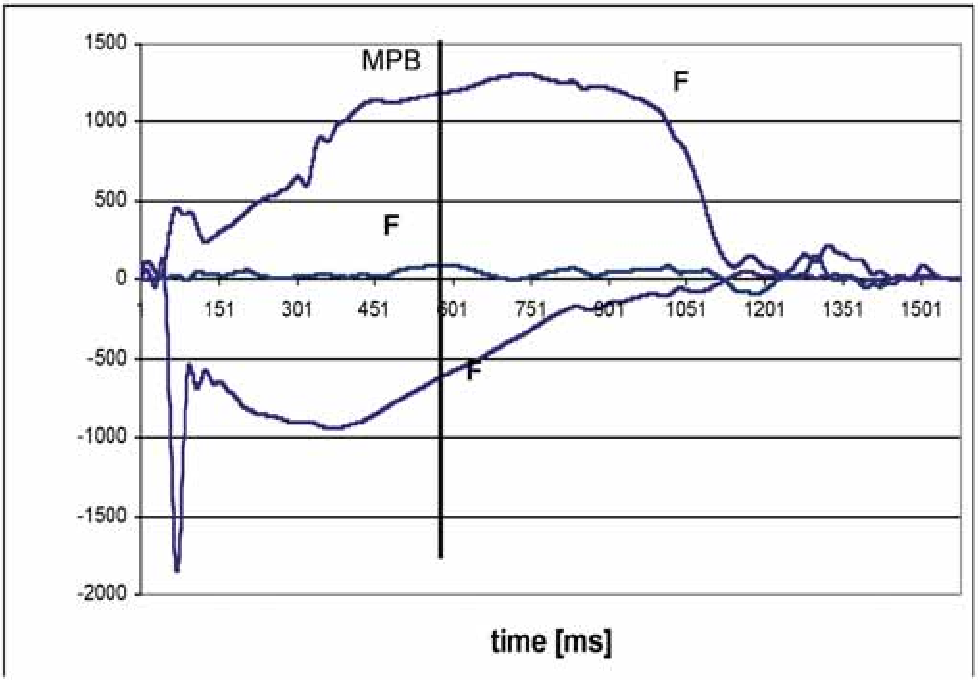


Figure 3: Reaction forces measured in the planting box for Blom's 5.80m vault at the 2005 IAAF World Championships in Athletics (x is in direction of the approach run, y is in vertical direction, z is perpendicular to the two)

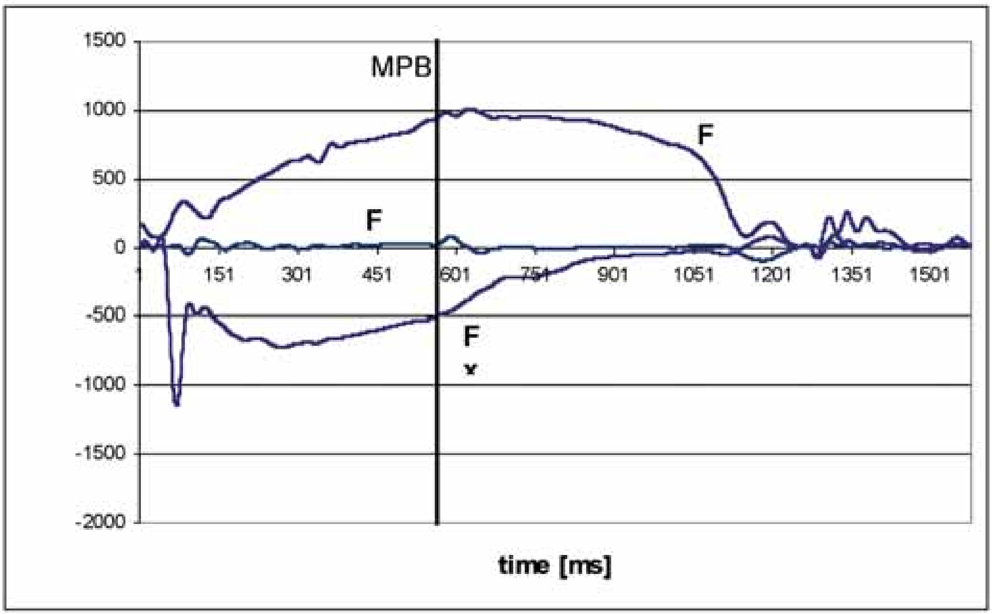


Figure 4: Reaction forces measured in the planting box for Isinbayeva's 5.01m vault at the 2005 IAAF World Championships in Athletics (x is in direction of the approach run, y is in vertical direction, z is perpendicular to the two)

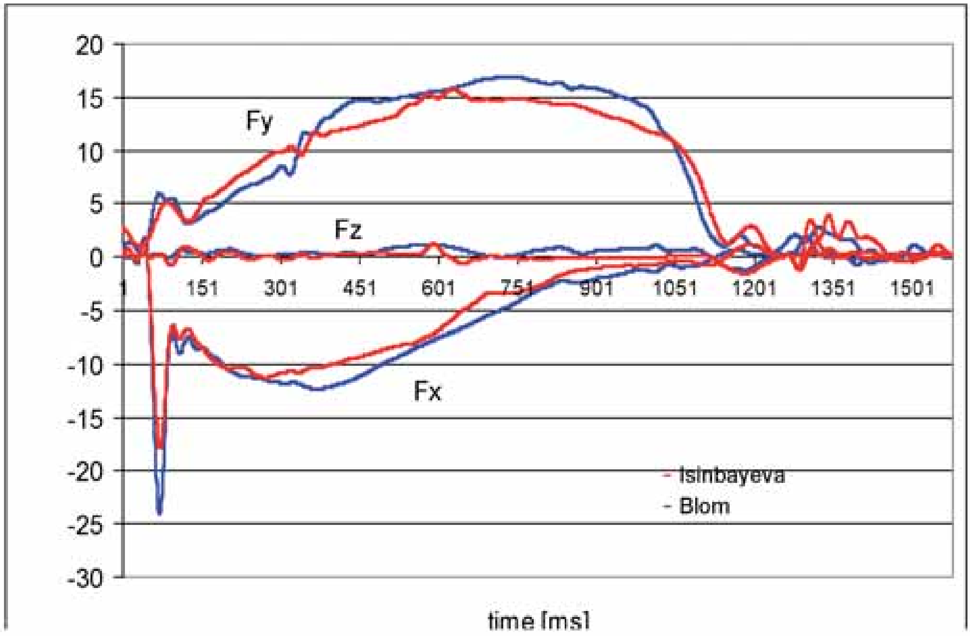


Figure 5: Reaction forces measured in the planting box relative to body weight for vaults by Isinbayeva (5.01m) and Blom (5.80m) at the 2005 IAAF World Championships in Athletics (x is in direction of the approach run, y is in vertical direction, z is perpendicular to the two)

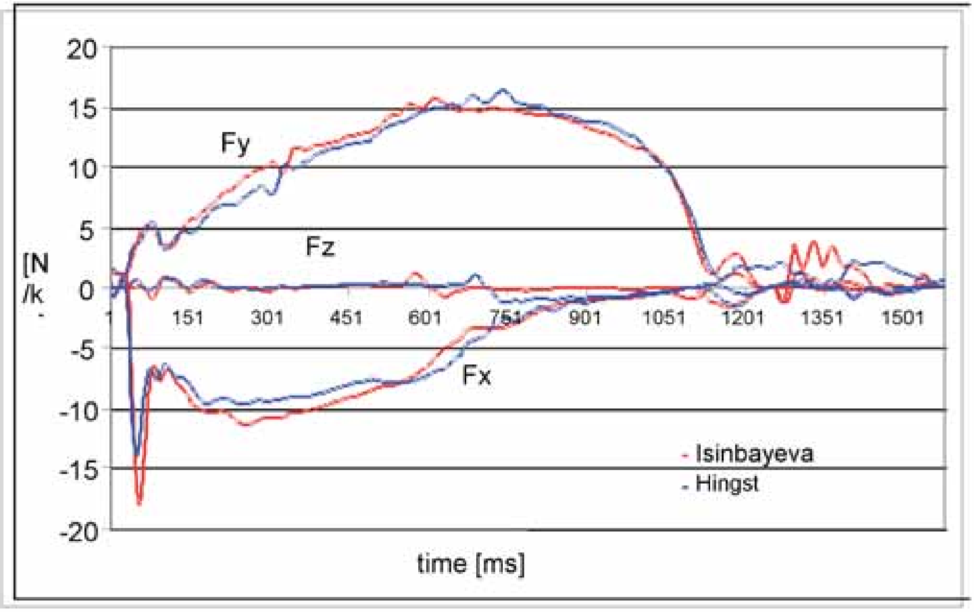


Figure 6 Reaction forces measured in the planting box) relative to body weight for vaults by Isinbayeva (5.01m) and Hingst (4.35m) at the 2005 IAAF World Championships in Athletics (x is in direction of the approach run, y is in vertical direction, z is perpendicular to the two)

pole bend (MPB) position and pole straight (PS) position. It decreases to zero approximately, close to the PS position. Actively pushing of the pole at pole release (PR) leads to a second, small increase in Fy. This push can lead to a gain in CM height of approximately 14cm (SCHADE et al., 2004).

The reaction force perpendicular to Fx (Fz) is close to zero throughout the whole vault for the successful vaults of elite vaulters, indicating that most of the action occurs in the main plane of movement (see also SCHADE et al., 2000). Figures 5 and 6 give examples of the reaction forces in the planting box relative to body weight. Even in relation to body weight, Blom shows a higher initial peak in Fx than Isinbayeva, which is the result of a higher approach velocity and, with this, greater horizontal breaking forces. Interestingly Isinbayeva produces higher vertical reaction forces (Fy) than Blom between take-off and the instant when the CM crosses the pole chord, whereas the reaction forces Fx and Fy are higher for Blom throughout the remainder of the vault.

Comparison of male and female specialists and decathletes

The maximum CM height of the top ten male vaulters (Table 7) ranged between 5.58m and 5.91m (5.78 ±0.09m), which is a homogenous but, compared to the 2000 Olympic Games in Sydney for example (5.93 ±0.09m; SCHADE et al., 2004), weak result. The top ten female vaulters (Table 8) achieved maximum CM heights between

Table 7: Selected parameters of vaults by the top 10 finalists in the men's pole vault at the 2005 IAAF World Championships in Athletics

Vaulter	Bar height [m]	Trial	Grip height [m]	Take off distance [m]	Maximum CM height [m]	Distance CM_max [m]	Pole chord length at MPB [m]	Shortening of pole chord length at MPB as % of grip heigth [m]
Rans	5.35	1	4.81	3.78	5.58	0.70	3.56	26.0
Lobinger	5.50	1	4.92	3.8	5.76	0.87	3.39	31.0
Gibilisco	5.50	1	4.86	4.23	5.82	0.66	3.46	28.8
Hysong	5.50	1	4.87	4.05	5.70	0.59	3.55	27.1
Sawano	5.50	1	4.89	4.35	5.74	1.07	3.47	29.0
Kristianson	5.50	3	4.86	4.15	5.80	0.76	3.58	26.3
Gerasimov	5.65	2	4.95	4.24	5.79	0.48	3.64	26.4
Pavlov	5.65	3	4.96	4.38	5.82	0.74	3.56	28.2
Walker	5.75	2	4.94	3.93	5.89	0.73	3.69	25.4
Blom	5.80	1	4.81	3.75	5.91	0.61	3.45	28.3
Mean	*5.57*		*4.89*	*4.07*	*5.78*	*0.72*	*3.54*	*27.7*
s	*0.14*		*0.05*	*0.24*	*0.09*	*0.16*	*0.09*	*1.7*

Note: Grip height was defined as the distance between the middle of the upper grip hand on the pole and the deepest point of the planting box at the moment of the pole straight position. The distance CM_max describes the horizontal distance between the CM at the moment of maximum CM height (HP) and the zero line of the facility. Pole chord length at MPB is defined as the distance between the middle of the upper grip hand at the pole and the deepest point of the planting box at the moment of maximum pole bend.

Table 8: Selected parameters of vaults by the top 10 finalists in the women's pole vault at the 2005 IAAF World Championships in Athletics

Vaulter	Bar height [m]	Trial	Grip height [m]	Take off distance [m]	Maximum CM height [m]	Distance CM_max [m]	Pole chord length at MPB [m]	Shortening of pole chord length at MPB as % of grip heigth [m]
Hingst	4.35	3	4.14	3.22	4.50	0.56	3.03	26.9
Agirre	4.35	3	4.22	3.39	4.43	0.45	3.38	20.0
Boslak	4.20	2	4.17	3.33	4.55	0.84	3.02	27.5
Ellis	4.35	1	4.06	3.18	4.38	0.61	2.99	26.3
Rogowska	4.35	1	4.22	3.48	4.75	0.74	3.13	25.8
Gao	4.50	3	4.26	3.54	4.58	0.68	3.17	25.5
Polnova	4.50	3	4.04	3.33	4.61	0.47	3.02	25.2
Hamackova	4.50	1	4.29	3.19	4.54	0.57	2.96	31.1
Pyrek	4.60	1	4.24	3.46	4.80	0.61	3.33	21.6
Isinbayeva	5.01	2	4.37	3.41	5.19	0.66	2.98	31.7
Mean	*4.47*		*4.21*	*3.35*	*4.63*	*0.62*	*3.11*	*26.1*
s	*0.22*		*0.1*	*0.13*	*0.24*	*0.12*	*0.15*	*3.6*

Table 9: Selected parameters of vaults by decathletes competing at facility A at the 2005 IAAF World Championships in Athletics

Vaulter	Bar height [m]	Trial	Grip height [m]	Take off distance [m]	Maximum CM height [m]	Distance CM_max [m]	Pole chord length at MPB [m]	Shortening of pole chord length at MPB as % of grip heigth [m]
Dvorak	4.20	1	4.48	3.56	4.75	0.75	3.26	27.3
Ojaniemi	4.50	2	4.59	3.55	4.80	0.30	3.60	21.6
Gonzalez	4.60	3	4.68	3.57	4.70	0.56	3.52	24.8
Xhonneux	4.70	1	4.59	3.92	4.92	0.41	3.37	26.6
Dhouibi	4.80	1	4.85	4.12	5.36	1.13	3.36	30.7
Schwarzl	4.90	1	4.84	3.73	5.19	1.02	3.25	32.8
Terek	5.10	3	4.75	3.69	5.23	0.40	3.31	30.4
Mean	*4.69*		*4.68*	*3.73*	*4.99*	*0.65*	*3.38*	*27.7*
s	*0.29*		*0.14*	*0.21*	*0.26*	*0.32*	*0.13*	*3.9*

4.43m and 5.19m (4.63 ±0.4m), which is at the level as Sydney 2000 (4.58 ±0.08m; SCHADE et al., 2004), but more heterogeneous, largely due to Isinbayeva's world record vault. The top seven highest vaulters at facility A of the decathlon (Table 9) achieved maximum CM heights between 4.70m abd 5.36m (4.99 ±0.26m).

The individual time histories of the total mechanical energy, total kinetic energy and potential energy of Blom's and Isinbayeva's winning vaults are shown in Figure 7. With the beginning of the take-off support phase (TD), total mechanical energy of the vaulter and total kinetic energy decrease as an expression of energy transformation that occurs a) in the legs during the take-off action, b) in the trunk, arms and arm/trunk connection during the pole plant and initial pole bending, and c) during the rock back action until MPB (LINTHORNE, 2000; SCHADE et al., 2004). While a) is a transformation within the athlete (active system) (ARAMPATZIS et al., 1999), b) and c) refer to the interaction between the active system and the pole (passive system), which results in an increase in the strain energy of the pole. The total body energy decreases until approximately the MPB position, while the kinetic energy reaches its minimum after the MPB position. The total body energy shows a clear increase up to the PS position. The potential energy increases continuously after the pole plant until the HP position.

Comparing the development of the mechanical energy of Blom and Isinbayeva, similar characteristics are found. But initial and final total energy were much higher for Blom. Male vaulters show a greater decrease in total energy until the maximum pole bend position. The increase in total energy after the maximum pole bend position is also greater for the male vaulters (Figure 8).

Compared with the other female finalists, Isinbayeva had by far the highest increase in total mechanical energy between MPB and HP. She also had a high value for maximum shortening of the pole chord (31.7%). In other words she bends the pole to a high extent (Table 8). It can be concluded that she performs the most effective interaction with the pole. Among the female finalists, Polnova achieved the best energy gain for the whole vault (8.44J/kg). Considering her low approach velocity (Table 5) this could have been expected because energy loss during jump and plant transformations increases with increasing approach velocity, which makes it more difficult to achieve high energy gain when approaching with higher velocity. Isinbayeva showed the second best energy gain (7.98J/kg), which, together with

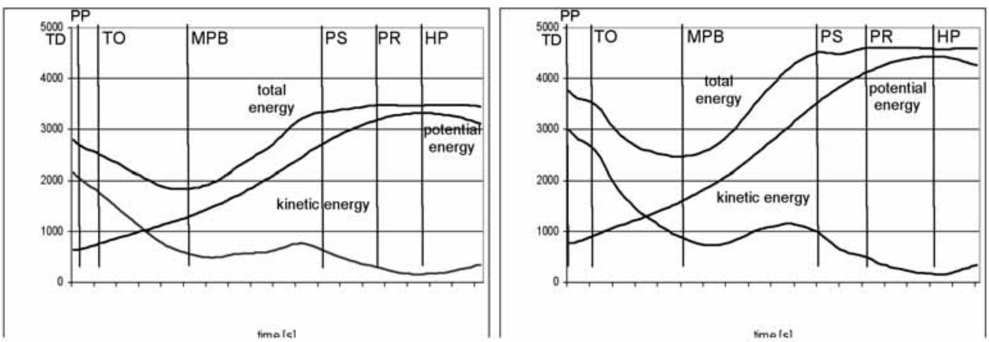


Figure 7: Individual time histories of the vaulter's total mechanical energy, total kinetic energy and potential energy of vaults by Blom (5.80m) and Isinbayeva (5.01m) at the 2005 IAAF World Championships in Athletics (See boxon page 30 for explanation of abbreviations)

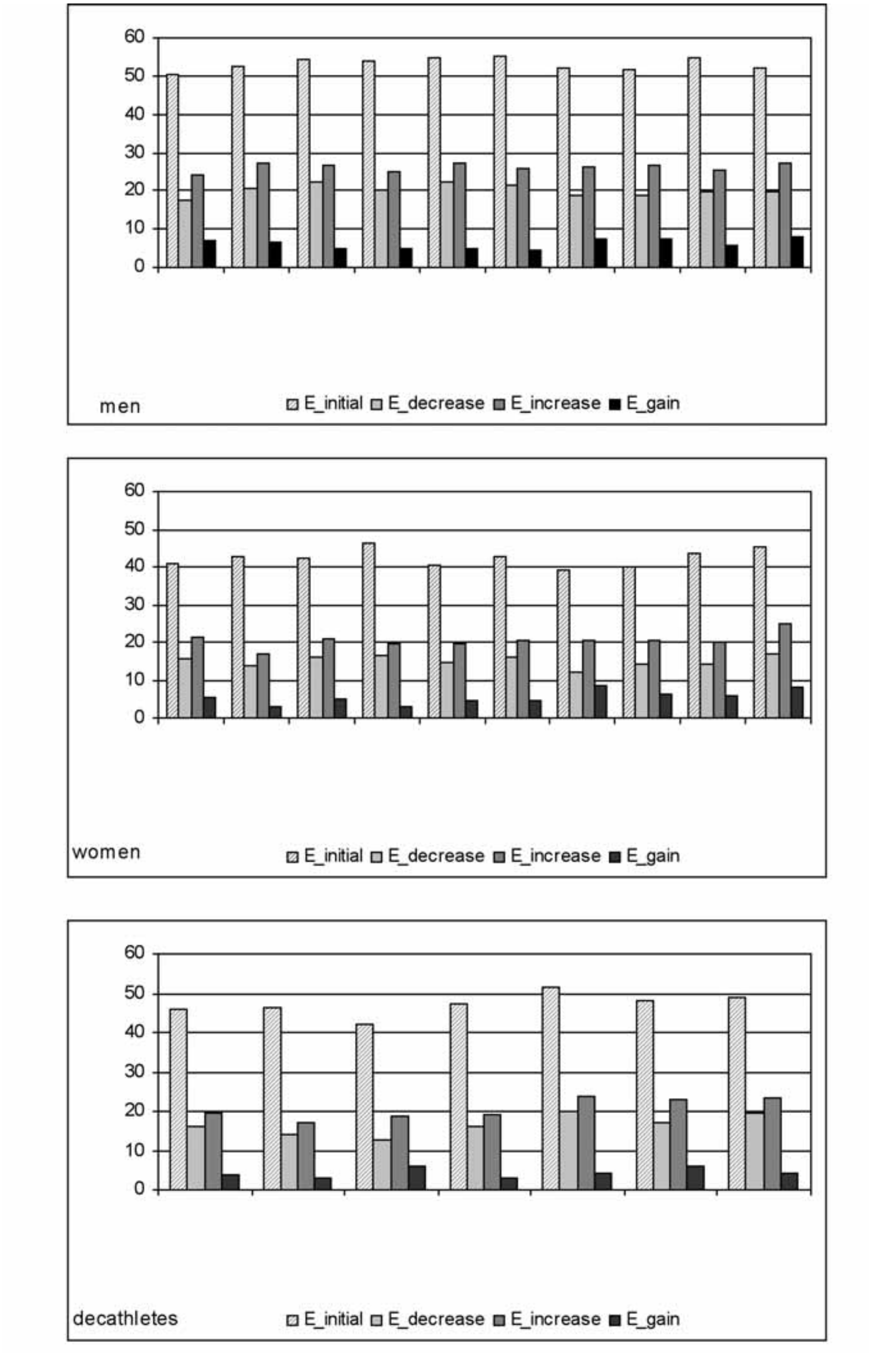


Figure 8: Selected energy parameters of male and female pole vault finalists and decathlon vaulters at the 2005 IAAF World Championships in Athletics (E_initial = vaulter's total mechanical energy in the middle of the last flight phase prior to take off; E-decrease = decrease of vaulter's total mechanical energy from the middle of the last flight phase (E_initial) up to maximum pole bend position (MPB); E_increase = increase of vaulter`s total mechanical energy from MPB up to the instant of maximum center of mass height (HP); E_gain: difference between E_initial and E_final (total mechanical energy of the vaulter at HP))

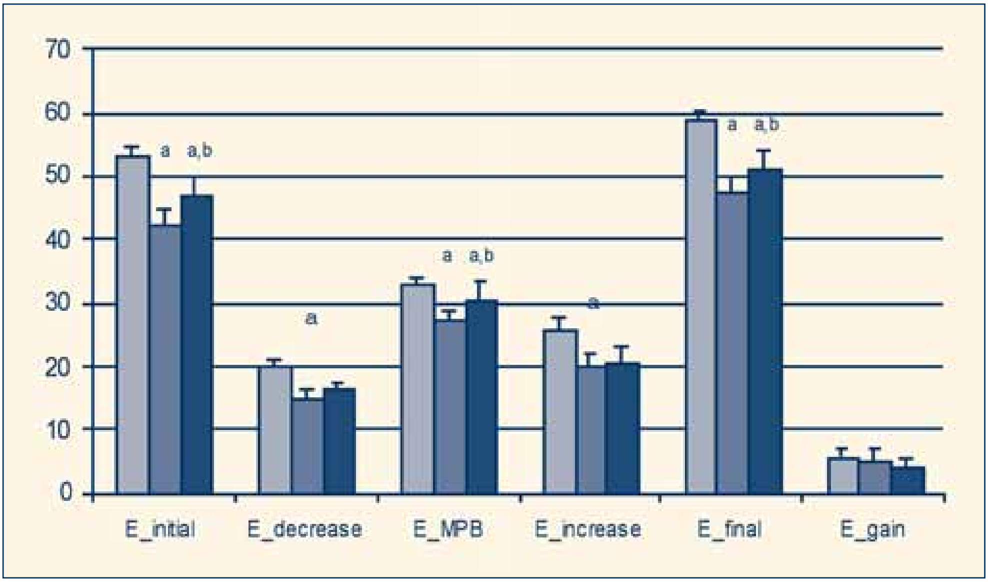


Figure 9: Comparison of energy parameters in the pole vault competitions at the 2005 IAAF World Championships in Athletics: a significant different ($p < 0.05$) to male specialists ($n = 10$), b significant difference ($p < 0.05$) between female specialists ($n = 10$) and decathletes ($n = 7$)

her high approach velocity, is a strong hint at her extraordinary skills. In fact, in her winning vault she had a maximum CM height of 5.19m (Table 8) and on her first attempt she even achieved 5.22m, but at a depth of 0.90m to the zero line approximately.

The men's winner Blom achieved the best maximum CM height among the male specialists (5.91m, Table 7). In addition, he also showed the highest energy gain (7,75J/kg) with Pavlov (7.60J/kg) having the second best. Considering his low approach velocity (Table 4) it can be stated that Blom won the competition because he was able to individually optimise approach velocity and interaction with the pole (energy gain).

The decathletes again show heterogeneous results. Within the seven analysed, the three best performers differ from the others. They bend their poles to a higher extent and also show higher E_decrease and E_increase (Figure 8), indicating a different strategy of interacting with the pole. The highest energy gain was achieved by Gonzalez, who also showed the lowest approach velocity. But he only achieved a maximum CM height of 4.70m (Table 9). His potential to improve his vaulting performance can be found in the approach velocity.

Comparing selected energy parameters of male and female specialists and decathletes, significant differences between the three groups ($p<0.05$) are found concerning the initial energy (E_initial), the energy at MPB (E_MPB) and the final energy (E_final; Figure 8 and Figure 9). The highest values were found in the male specialists and the lowest in the female vaulters. The range between E_decrease and E_increase are similar for the decathletes and the female specialists and both are significantly different from the male specialists. E_gain is not significantly different between the three groups. This could mean that the decathletes might improve performance by enhancing their approach velocity without losing additional energy within the jump and plant action, which in fact means improving the energy transforma-

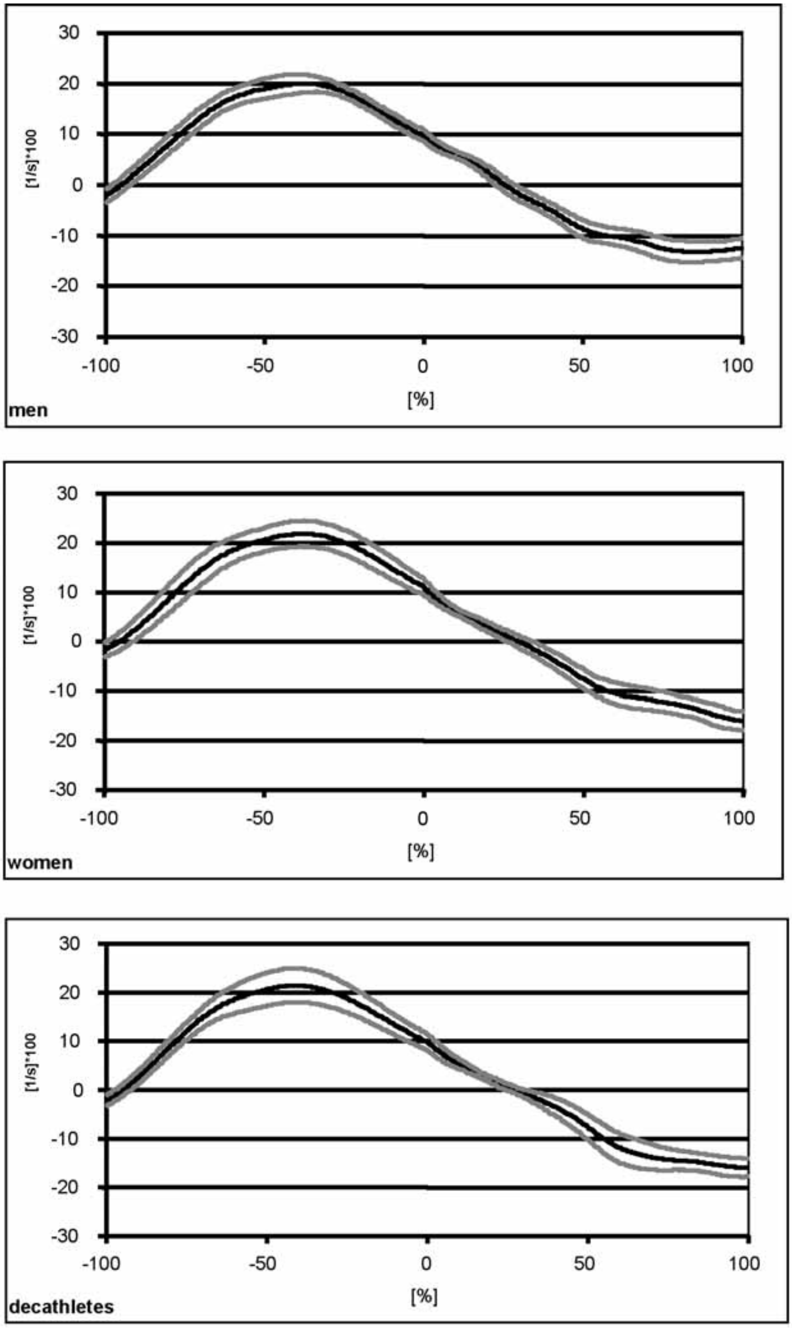


Figure 10: Normalised mean angular momentum about the transverse axis through the centre of mass and corresponding standard deviation for male (n = 10) and female (n = 10) specialists and decathletes (n = 7). The angular momentum has been divided by the product of body mass and the square of body height. The x-axis is normalised as follows (Schade et al. 2004): -100% to 0% represents the phase between the pole plant (pole hits back of the box) and the MPB position; 0% up to 100% represents the phase between the MPB position and the instant of maximum CM height.

tion in this phase of the vault. At the 2000 Olympic Games in Sydney, there also was no significant difference in E_gain between the male and female finalists (SCHADE et al., 2004).

Figure 10 shows the normalised mean angular momentum about the transverse axis through the CM and the corresponding standard deviation for male and female specialists and decathletes. No differences can be seen between the groups, except for the bar clearance, with the male specialists showing the lowest negative values. This can be explained by the fact that most of the decathletes and female specialists do not show a clear free upward flight phase. They were still in contact with the pole when crossing the bar, using it as an abutment to increase angular momentum. Interestingly, there are no differences within the first phase of the vault (PP up to the instant when CM crosses the pole chord). In the 2004 Olympic Games in Sydney, the female vaulters had a higher angular momentum about the transverse axis immediately after pole plant than the men, indicating a passive upward swing, rather than an active pole bending action (SCHADE et al., 2004). Taking into account that the female vaulters increased their maximum pole bending, it can be stated that the techniques of elite men and women have come closer in the period between Sydney 2000 and Helsinki 2005. The above findings indicate that female vaulters have started to make better use of the elastic qualities of the pole by increasing the energy exchange between athlete and pole.

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