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Biomechanical analysis of sub-elite performers in the women's long jump

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ABSTRACT

Biomechanical analysis of sub-elite competitions enriches the pool of knowledge about technique in athletics events. The purpose of this study was to describe the kinematics of the approach and take-off of competitors in the women's long jump competition at the 2006 European Cup 1st League-Group B. It was found that all the participants utilise the "longer penultimate-shorter last stride" ratio previously described for top-level performers. All but one increased their horizontal velocity during the last stride. Mean horizontal and vertical take-off velocities were 8.71m/sec (standard deviation: 0.26) and 2.45m/sec (0.12) respectively, resulting in a mean take-off angle of projection of 18.1 degrees (0.7). The values of the selected biomechanical parameters were either in range (i.e. loss of horizontal velocity during contact with the board, energy loss in take-off) or lower (i.e. take-off velocity, angle of projection) than results obtained at higher-level events such as the World Championships or Olympic Games.

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Introduction

A large amount of information concerning the long jump has been acquired from biomechanical analysis of elite competitors at major athletics events around the world. Data is available for competitors at the Olympic Games[13-14], IAAF World Championships in Athletics[15-16], IAAF World Junior Championships[4], World Student Games[6,17], USA national championships[18-19] and the UK national championships[20-21]. However, there is a lack of data concerning the technique employed by sub-elite long jumpers competing in international events. This missing information is important as sub-elite athletes can be assisted in their preparations by knowledge that allows comparisons with the world's best.

The aims of this study are: a) to describe the kinematics of the participant's run-up and the take-off by presenting biomechanical parameters exhibited in the women's long jump competition at the 1st league of the 2006 European Cup, and b) to comment on the results when they are compared with findings from the literature[4, 6, 13-21].

The technical factors affecting performance in the long jump include the accuracy of the approach, the technique used during the final strides of the approach, the role of elastic energy in the take-off, the initiation and control of the jumper's angular momentum, and the technique used in the landing[1].

The horizontal velocity of the approach is strongly correlated with the jump distance[2] and thus the jumper's aim is to develop and maintain horizontal velocity for as long as possible when reaching the take-off board. To fulfil this requirement, elite long jumpers adjust their body position in order to prepare for take-off during the penultimate stride simply by increasing their stride length and by decreasing the height of their body's centre of mass (CM)[3]. The last stride is thus quite a bit shorter, leading to the so-called "longer penultimate-shorter last stride" ratio. The lowering of the height of the CM leads to a larger vertical displacement of the CM during contact at the board, resulting in a greater vertical take-off velocity and a smaller loss of horizontal velocity[4].

Transformation of the initial kinetic energy is needed in order to perform the take-off[5]. Some loss of the jumper's total energy is expected during this process[6] but there is an optimum limit to this loss in an effective jump[7]. The efficient re-utilisation of elastic energy, stored in the leg extensor muscles in the early stages of the contact[8-10], assists in generating an additional amount of vertical velocity at take-off[6].

Placement of the foot on the board leads to a high braking force, which causes a forward rotation about a transverse axis through the CM[11]. This forward angular momentum must be controlled in order to avoid a loss in the distance of the jump[2]. Therefore, long jumpers must counteract the effects of the forward rotation and maintain their body orientation during the flight by executing appropriate arm and leg movements[12]. The most common flight techniques are the $2^1/_2$ hitch-kick, $3^1/_2$ hitch-kick and the hang.

Methods

The women's long jump competition at the 2006 European Cup 1st League-Group B Event, held in Thessaloniki, Greece, on 18 June 2006 was studied. The jumps were recorded with a digital JVC GR-DVL 9600EG (Victor Co., Japan) video camera operating at a sampling frequency of 100 fields/sec. The camera was placed perpendicular to the plane of motion and recorded the last two strides of the approach and the take-off from the board. A second digital JVC GR-DVL 9600EG video camera, also operating at 100 fields/sec, captured the flight and the landing in the pit. The latter was used for a qualitative analysis of the flight phase, utilising the Analysis Sheet proposed by TIDOW[22].

Calibration for the 2D-DLT kinematic analysis was conducted by placing a 2.5m x 2.5m frame with 16 control markers perpendicular to the camera axis[23]. The X-axis represented the direction of the runway. Y-axis was vertical and perpendicular to the x-axis.

All trials were recorded but the best valid jump for each athlete was selected for further analysis. Digitisation, smoothing and analyses were conducted using the APAS XP software (Ariel Dynamics Inc., Trabuco Canyon, CA).

Results

Definitions

Long jump distances discussed in this study are defined as follows:

- Official distance (OFD, IAAF rule 185§3): the horizontal distance from the pit edge the take-off board to the nearest break in the landing area made by any part of the body[24]
- Toe-to-board distance (TTB): the horizontal distance from the take-off foot's toe to the pit edge of the take-off board[16]
- Effective distance (EFD): the sum OFD + TTB4
- Effective take-off distance (EFto): the horizontal distance from the athlete's CM to the toe of the take-off foot at take-off[18]
- Time instant of touchdown: the first video field in which the landing foot clearly contacts the ground
- Time instant of takeoff: the first video field in which the foot has clearly left the ground
- Take-off: the push-off phase from the take-off board

Competition Results

The mean OFD was 6.27m (range: 6.71m – 5.81m; standard deviation: 0.34m), with the winner Deventzi achieving a new personal best of 6.71m (Table 1). Although the mean OD was lower than the 6.64m (0.16) of the top eight at the 2006 European Athletics Championships in Gothenburg or to 6.51m (0.20) of the top eight of the 2006 IAAF World Cup in Athens, the competition was of high standard, since the athletes achieved 97.1% of their personal bests at that time[25]. Furthermore, three of the analysed athletes went on to win silver medals at the European Athletics Championships later in the season: Gomez in the long jump, Deventzi in the triple jump, Ruckstuhl in the heptathlon.

Approach

All participants seemed to utilise the "long-short" ratio. In average, the last stride

Table 1: Participants, personal bests (PB) prior to the event*, result/official distance (OFD) and relative wind velocity for the analysed trials

Athlete	PB (m)	Result/OFD (m)	Wind (m/sec)	Trial
Hrisopiyi DEVENTZI (GRE)	6.56	6.71	0.60	4
Naide GOMEZ (POR)	6.72	6.70	1.20	1
Tünde VASZI (HUN)	6.86	6.52	1.80	3
Karin RUCKSTUHL (NED)	6.58	6.23	-0.50	4
Nina KOKOT (SLO)	6.23	6.19	-0.50	3
Tereza MARINOVA (BUL)	6.46	6.14	-1.00	2
Viktorija ZEMAITYTE (LTU)	6.23	5.89	-0.40	4
Mukadder ULUSOY (TUR)	6.07	5.81	1.40	3
mean	*6.46*	*6.27*		
std. dev.	*0.27*	*0.34*		

* as of 15 June 2006, according to www.thessaloniki2006.gr

Table 2: Length (S) and horizontal velocity (Vx) of the center of mass at take-off and the differences observed (¢) for the penultimate (2L) and the last stride (1L)

Athlete	OFD (m)	2LS (m)	1LS (m)	Δ S (m)	Vx2Lto (m/sec)	Vx1Lto (m/sec)	Δ Vx (m/sec)
DEVENTZI	6.71	2.34	2.15	-0.19	9.23	9.32	0.09
GOMEZ	6.70	2.38	2.06	-0.32	8.67	8.96	0.29
VASZI	6.52	2.26	1.81	-0.45	9.06	9.23	0.17
RUCKSTUHL	6.23	2.58	2.22	-0.36	8.79	9.21	0.42
KOKOT	6.19	2.34	1.99	-0.35	9.05	9.13	0.08
MARINOVA	6.14	2.48	2.15	-0.33	9.03	8.88	-0.15
ZEMAITYTE	5.89	2.39	2.25	-0.14	8.33	8.61	0.28
ULUSOY	5.81	2.34	2.15	-0.19	8.43	8.66	0.23
mean	*6.27*	*2.39*	*2.10*	*-0.29*	*8.82*	*9.00*	*0.18*
std. dev.	*0.34*	*0.10*	*0.14*	*0.11*	*0.32*	*0.27*	*0.17*

Table 3: Change of height of center of mass during the last strides and the contact on the board (to: take-off, td: touchdown)

Athlete	OFD (m)	2Lto→1Ltd (m)	1Ltd→1Lto (m)	1Lto→BOtd (m)	BOtd→BOto (m)
DEVENTZI	6.71	-0.01	-0.05	-0.02	0.22
GOMEZ	6.70	-0.04	-0.03	-0.05	0.20
VASZI	6.52	-0.04	-0.02	-0.05	0.19
RUCKSTUHL	6.23	-0.06	0.00	-0.06	0.18
KOKOT	6.19	-0.05	-0.04	-0.04	0.24
MARINOVA	6.14	-0.04	-0.03	-0.03	0.15
ZEMAITYTE	5.89	-0.02	-0.03	-0.04	0.21
ULUSOY	5.81	-0.04	-0.04	-0.05	0.22
mean	*6.27*	*-0.04*	*-0.03*	*-0.04*	*0.20*
std. dev.	*0.34*	*0.02*	*0.02*	*0.01*	*0.03*

was 0.29m (0.11) shorter than the penultimate (Table 2). Vaszi emphatically shortened her last stride length by 0.45m. Additionally, all the jumpers enhanced their horizontal velocity from the penultimate to the last stride by 0.18m/sec (0.17), with the excep-

tion of 6th placer Marinova, whose horizontal velocity decreased by 0.15m/sec. Slight velocity augmentations were recorded for Kokot (0.08m/sec) and Deventzi (0.09m/sec), while Ruckstuhl accelerated for the take-off (her velocity changed by 0.42m/sec).

The utilisation of the "longer penultimate-shorter last stride" ratio led to a constant lowering of the CM during the last two strides of the approach until touchdown on the board. It is worth mentioning that Deventzi lowered her CM height by only 0.08m, mainly during the contact phase for the last stride (0.05m).

On the contrary, Ruckstuhl lowered her CM height by 0.06m at each flight starting from the push-off for the penultimate stride until touchdown on the board, without any lowering during contact for the last stride (Figure 1). The highest values for CM lowering during the analysed strides were recorded for Kokot and Ulusoy (0.13m).

Take-off

The average toe-to-board distance was 0.10m (0.12). Devetzi, who as mentioned above won the competition with a new personal best, had a notable TTB of 0.01m. On the other hand, Ruckstuhl took off 0.40m prior to the board, thus losing third place and contributing to the large standard deviation value for this parameter. The mean value for the relative velocity of the support leg's ankle (compared to the body's CM) at touchdown on the board (-4.90m/sec) indicated an active landing on the board.

The mean horizontal touchdown velocity at the board was 8.71m/sec (0.26). Respectively, the mean horizontal and vertical take-off velocities were 7.46m/sec (0.23) and 2.45m/sec (0.12). An average decrement of

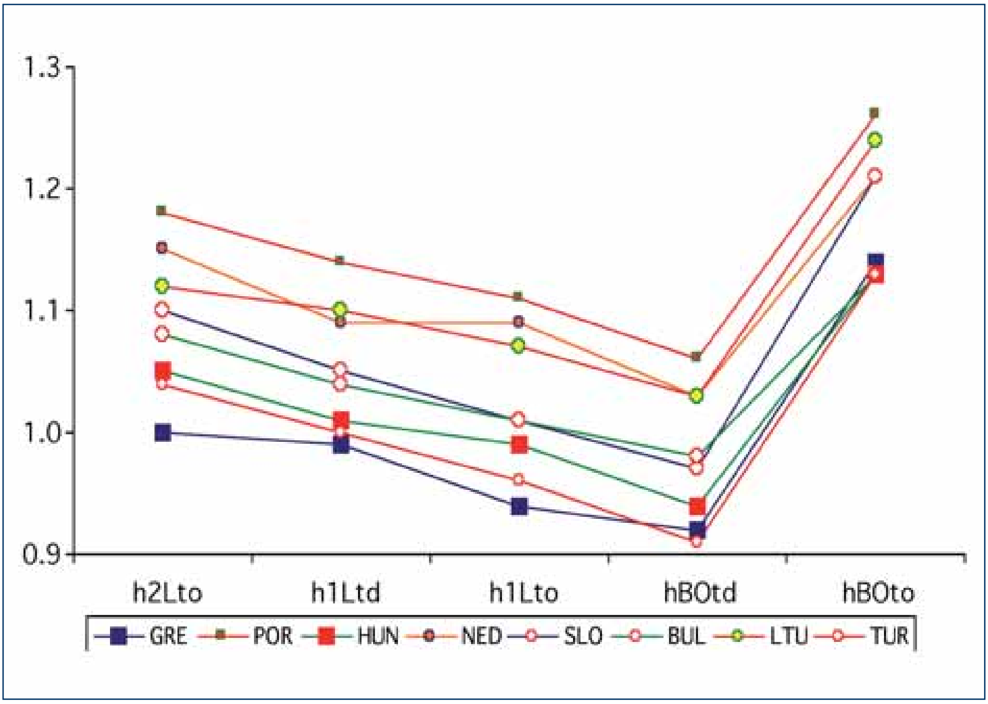

Figure 1: Height (H) of the center of mass uring touchdowns (td) and take-offs (to) for the penultimate stride (2L), last stride (1L) and contact on the take-off board (BO) (Note: the lines linking the data points are not intended to represent the actual BCM trajectory)

Table 4: Horizontal (Vx) and vertical (Vy) velocity of the center of mass at the instant of touchdown (td) and take-off (to) during contact on the board (BO); loss (Δ) of Vx, gain (Δ) of Vy and angle of projection (AngPr) during take-off

Athlete	OFD (m)	VxBOtd (m/sec)	VxBOto (m/sec)	Δ VxBO (m/sec)	VyBOtd (m/sec)	VyBOto (m/sec)	Δ VyBO (m/sec)	AngPr (°)
DEVENTZI	6.71	8.95	7.87	-1.08	-0.11	2.66	2.77	18.7
GOMEZ	6.70	8.79	7.34	-1.45	0.00	2.55	2.55	19.2
VASZI	6.52	8.90	7.69	-1.21	-0.10	2.47	2.57	17.8
RUCKSTUHL	6.23	8.88	7.54	-1.34	-0.13	2.37	2.50	17.4
KOKOT	6.19	8.88	7.30	-1.58	-0.11	2.44	2.55	18.5
MARINOVA	6.14	8.60	7.40	-1.20	-0.14	2.29	2.43	17.2
ZEMAITYTE	5.89	8.21	7.19	-1.02	-0.05	2.33	2.38	18.0
ULUSOY	5.81	8.48	7.34	-1.14	-0.26	2.45	2.71	18.5
mean	*6.27*	*8.71*	*7.46*	*-1.25*	*-0.11*	*2.45*	*2.56*	*18.1*
std. dev.	*0.34*	*0.26*	*0.23*	*0.19*	*0.08*	*0.12*	*0.13*	*0.7*

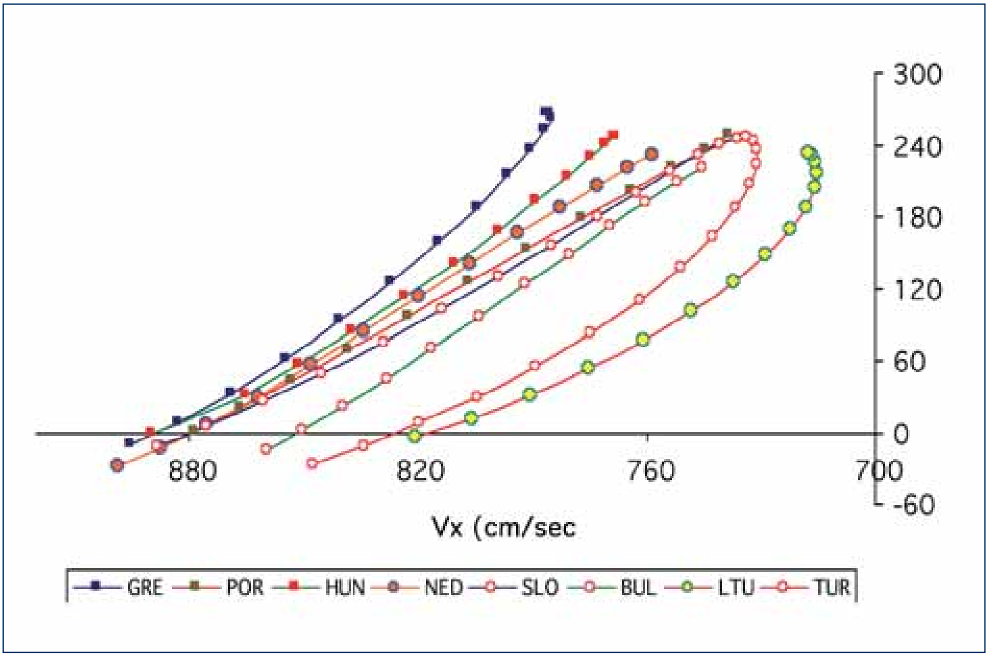

Figure 2: Horizontal (Vx) and vertical (Vy) velocity of the center of mass during contact on the board (Note: the distance between each data point represents 0.01sec)

horizontal velocity of 14.4% was observed during take-off (Table 3). A strong correlation (r= .94, p= .001) was observed between horizontal take-off velocity and effective distance.

Deventzi successfully combined the low decrement of her horizontal velocity during contact on the board (1.08m/sec, 12.1%) with the maximum gain in vertical velocity recorded in this study (2.66m/sec). Figure 2 presents the process of "converting" the horizontal velocity to vertical during contact on the board. Five of the athletes seem to have had a linear loss of horizontal velocity compared to the concurrent gain in vertical velocity. Conversely, Deventzi, Zemaityte and Ulusoy seemed to terminate the decrease of horizontal velocity and only a gain in vertical velocity was observed during the last stages of the take-off.

An average 0.20m (0.03) vertical elevation of the CM was recorded during contact on the board. It is worth mentioning that the largest vertical elevation of the CM was recorded for Kokot (24cm), who had the largest CM lowering during the last two strides. Effective take-off distance (Table 5) ranged from 0.44m (Gomez) to 0.30m (Deventzi, Ruckstuhl).

The average angle of projection for the take-off was 18.1° (0.7), with Gomez recording the largest value (19.2º).

Flight phase

Half the jumpers executed the jump using the $2^{1}/_{2}$ hitch-kick technique (Table 5). Ulusoy was the only one who used the hang technique. Mean flight time was 0.75sec (0.04), with athletes being in the final landing position[22] for an average 17.6% (4.9) of the flight. Deventzi, Gomez, Vaszi and Ulusof were in the landing position for over 20% of their flight time. On the contrary, Ruckstuhl

Table 5: Techniques (Techn)* used during the flight, toe-to-board distance (TTB), effective distance (EFD), effective take-off distance (EFto), relative to the body center of mass velocity of the ankle of the take-off leg at touchdown on the board (rV), time from take-off until first touch to the sand (tFL) and time from when landing position was taken until landing in the sand (tPosL)

Athlete	OFD (m)	Techn	TTB (m)	EFD (m)	EFto (m)	rV (m /sec)	tFL (sec)	tPosL
DEVENTZI	6.71	HK	0.01	6.72	0.30	-5.86	0.80	0.18
GOMEZ	6.70	HG	0.09	6.79	0.44	-4.26	0.81	0.18
VASZI	6.52	HK	0.04	6.56	0.35	-5.32	0.72	0.15
RUCKSTUHL	6.23	HG	0.40	6.63	0.30	-5.23	0.75	0.08
KOKOT	6.19	HK	0.05	6.24	0.39	-3.40	0.73	0.09
MARINOVA	6.14	HK	0.10	6.24	0.31	-5.55	0.73	0.10
ZEMAITYTE	5.89	HG	0.05	5.94	0.42	-4.89	0.73	0.12
ULUSOY	5.81	SL	0.07	5.88	0.39	-4.72	0.73	0.16
mean	*6.27*		*0.10*	*6.37*	*0.36*	*-4.90*	*0.75*	*0.13*
std. dev.	*0.34*		*0.12*	*0.35*	*0.06*	*0.79*	*0.04*	*0.04*

Table 6: Total mechanical energy (Et) during take-off of the penultimate (2L), the last (1L) stride and off the board (BO), its change (Δ) during the support phases, and energy transformation index for the take-off (Tindex)*

	Deventzi	Ruckstul
Et2L (J/kg)	52.01	49.51
Et1L (J/kg)	52.16	52.33
ΔEt1L (%)	-3.5	0.5
EtBO (J/kg)	45.14	42.66
ΔEtBO (%)	-7.3	-13.0
Tindex (deg/J/kg)	5.63	3.65

* as defined by ARAMPATZIS & BRÜGGEMANN [7].

was in that position for only 10.7% of her flight time.

Qualitative analysis of the flight phase

Absence of a forward bend of the trunk during contact with the sand, a technical criteria set by Tidow[22], was observed for Vaszi, Ruckstuhl, Marinova, Ulusof and possibly for Kokot. Other common errors were the incorrect timing and/or trajectory of the clockwise wind-milling arm movement for athletes using running-in-the-air techniques (Vaszi, Kokot, Ulusof) and the incorrect timing and/or trajectory of the "kneeling" action of the legs during the hang phase (Gomez, Ruckstuhl, Zemaityte). Another point was that Gomez, Vaszi and Ruckstuhl had a small backward trunk lean at take-off, while Deventzi and Marinova failed to fulfil reference #24 of TIDOW's Analysis Sheet, i.e the "3 o'clock" arm position prior the preparation for landing[22].

Mechanical energetic processes in the take-off

Anthropometric data were obtained for only two of the competitors (Table 6). As described above, Ruckstuhl's increase of horizontal velocity by 0.4m/sec during the last two strides without a lowering of the CM height during contact for the last stride contributed to a higher total mechanical energy just before touchdown on the board. On the other hand, Deventzi's lowering of the CM during the support and the flight of the last stride contributed to a decrease in total mechanical energy in the very last stage of the approach. As expected, energy was lost during take-off.

Discussion

As in biomechanical results from other women's long jump competitions, a "long-short" ratio was observed in the final strides. The mean decrement of stride length (0.29m) was similar to the women finalists of the 1988 Olympic Games[14]. However, the difference in length between the last two strides observed in the present study was approximately 2-6 times larger than in other studies[4,13,16].

Another similarity was the slight increase in horizontal velocity during these strides. In this study, the velocity increased by 0.18m/sec while there were corresponding increases of 0.25m/sec in the 1986 IAAF World Junior Championships[4] and 0.05m/sec in the 1997 IAAF World Championships in Athletics[16]. On the contrary, decrements of 0.35m/sec and 0.21m/sec were reported in the 1984 and 1988 Olympic Games[13-14], respectively.

The analysed athletes lowered their CM during the last two strides by 0.11m, a value exceeding the 0.04m and the 0.09m reported in the 1986 IAAF World Junior Championships[4] and the 1997 IAAF World Championships[16], respectively.

Horizontal take-off velocity (7.46m/sec) was similar to those recorded for the medallists of the 1986 IAAF World Junior Championships (7.53m/sec)[4] and for moderate-level female athletes (7.41m/sec)[26]. Horizontal take-off velocity in the other women's major competitions mentioned earlier was over 7.9m/sec. The 1.25m/sec loss in horizontal velocity during contact on the board is almost identical to the findings of MENDOZA et al.[26] and to the six finalists analysed in the 1992 UK national championships[20].

The relative velocity of the ankle of the take-off leg at touchdown on the board was 4.90m/sec (0.79), indicating an active landing on the board. This value is smaller than those reported in a study analysing the men's long jump[27].

Vertical take-off velocity (2.45m/sec) and gain in vertical velocity during contact on the board (2.56m/sec) were lower than any other study. Average angle of projection (18.1°) at take-off was also lower than the range of 18.8° to 21.9° found in the literature. Toe-to-board distance (0.10m) was larger than those reported in the past[14,16,19]. Finally, the effective take-off distance (0.36m) and its amount in comparison to the official distance (5.8%) were smaller than those reported (0.46m and 7%, respectively) by HAY et al.[13]

Energy loss during take-off for Deventzi and Ruckstuhl was within the range of values reported in the 1997 IAAF World Championships[16]. Although the energy transformation index for the take-off for Deventzi was higher than observed in the 1997 IAAF World Championships in Athletics[7], both athletes had lower mechanical energy at take-off from the board.

Conclusion

Although the European Cup league matches are not considered major competitions such as the European Championships, World Championships or Olympic Games, the women long jumpers in Thessaloniki exhibited the techniques described in text books and scientific research project reports from major competitions[4,14,16]. Adjustments (i.e. a constant increase of horizontal velocity until touchdown on the board, the "longer penultimate-shorter last stride" ratio) were in agreement with those described in the literature. The values of the selected biomechanical parameters were either in range (i.e. loss of horizontal velocity during contact to the board, energy loss in take-off) or lower (i.e. take-off velocity, angle of projection) compared to results obtained from higher level competitions. The latter can be attributed to the level of the athletes participating and to the time of the season when the European Cup matches are held (usually in mid-June).

Biomechanical analysis of competitions such as the European Cup enrich information concerning the long jump, since a wider range of athletic levels can be analysed. Furthermore, a database can be established for the athletes' long jump approach, take-off, flight and landing biomechanical parameters. The interpretation of the seasonal development in these parameters can be used as feedback for the training process.

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