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THREE-DIMENSIONAL KINEMATIC ANALYSIS OF ELITE JAVELIN THROWERS AT THE WORLD ATHLETICS CHAMPIONSHIP "SEVILLA'99".

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ABSTRACT

A Biomechanical analysis of Javelin Throw in the Sevilla'99 World Athletics Championships , was carried out by the University of Valencia (Department of Physical Education and Sports). This paper presents the results of a study of the male finalists. The methodology used is based on 3D Video Photogrammetry at 50 Hz.

The results show the characteristics of the throwers' individual model at the event, which for practical purposes can be compared with the performance of the same throwers in other competitions. Detailed information on the kinematic parameters is provided. The most significant differences between the patterns used by the throwers are located in the kinematic chain in the preparatory and final phases, and in the instant of javelin release and the vertical and horizontal velocity combinations of the javelin at delivery.

1.- INTRODUCTION

A description of the technique used by elite throwers gives insight into individual forms of organization used to obtain high performance. These models eventually become references that help coaches and athletes to organize their own strategies to achieve maximum mechanical efficiency.

The pattern of motion used in javelin throw is similar to that used in other movements when striking or throwing an object. These movements are characterized by the fact that the body segments act sequentially to attain the maximum speed in the most distal segment of the system in the instant when the object is struck or thrown (Atwater, 1979; Menzel, 1987). Many studies have described the javelin throwing technique, including those by Hay (1993), Whiting et al (1991), Best et al (1993), Mero et al (1994) and Bartlett et al (1996).

The present paper also describes the technical models used by a group of athletes who were finalists in the "Sevilla 99" World Athletics Championship. The aim of the study is to compare the throwers' individual models in the light of the documented data available on the biomechanical analysis of javelin throw.

2.- METHODS:

3D photogrammetric analysis was used. During the finals all throws were filmed and the best attempts of each athlete were subsequently analyzed . The cameras were phase-locked and aligned with their optical axis at approximately 90º. (side and back views):

- Two synchronized SVHS Panasonic video cameras, operating at 50 fps.
- Modulated reference system (Two integrated cubes of 2x2 m. each) for spatial calibration.
- Kinescan 8.3 (IBV)software for the digitizing process.

All coordinates were smoothed using quintic spline. The DLT (Direct linear transformation) algorithm was used to calculate the 3D marker coordinates (Abdel-Azir

& Karara, 1971). The kinematic parameters obtained on the marker coordinates (x,y,z) were transformed as variables of the study

3.- ANALYSIS PROCEDURES.

The biomechanical analysis for each athlete focused on the period illustrated for the preparatory and final throwing phases. The most important factors for javelin release occur during these decisive periods, which offer the best conditions for comparing athletes' techniques.

The main time periods were the following:

- **t_1**: right foot lands (support leg for right-handed thrower) on the ground at the beginning of the preparatory throwing phase.
- **t_2**: left foot lands (pressure leg for right-handed thrower) on the ground at the beginning of the double-support phase.
- **t_3**: javelin release (instant of delivery).

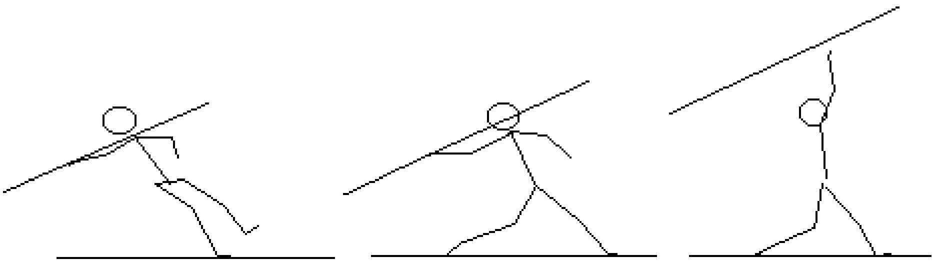


Figure 1: Time periods T1, T2 and T3.

All the throwers were right-handed except the Cuban thrower Emeterio González. Each thrower's best attempt was analyzed except for the German thrower Hecht whose second best throw was studied. None of the Norwegian athlete Fagernes' throws were analyzed due to image recording problems. The results for 7 of the male finalists are shown in table 1.

Table 1: List of the analyzed throws.

Thrower	**Result**		**Filmed and Analyzed**
Parvianen, Aki	89.52		Best
Gatsioudis, Kostas	89.18		Best
Zelezny, Jan	87.67		Best
Hecht, Raymond	85.24		2nd Best
Henry, Boris	85.43		Best
González, Emeterio	84.32	NR	Best
Backley, Steve	83.84		Best

4.- RESULTS

4.1.- Phase Timing

<u>*A/. Duration of Preparatory and Final throwing phases*</u>

The throw was split into two sub-phases in the reference instants mentioned above (t1, t2 and t3)

- Preparatory phase: period between instants t1 and t2.

- Release phase: period between instants t2 and t3.

The results show that the greatest differences between athletes occur in the preparatory phase. Times recorded for the duration of the Preparatory Phase (t_1–t_2) ranged from 140 to 260 milliseconds, and from 100 to 140 milliseconds for the Final Phase (t_2 –t_3).

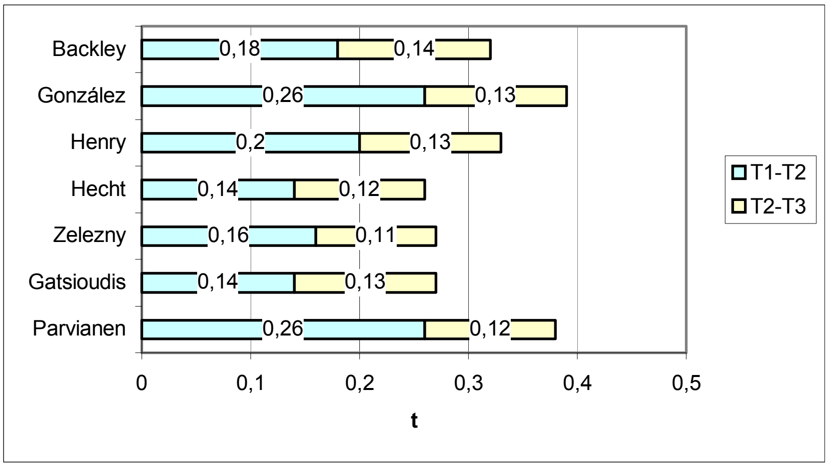
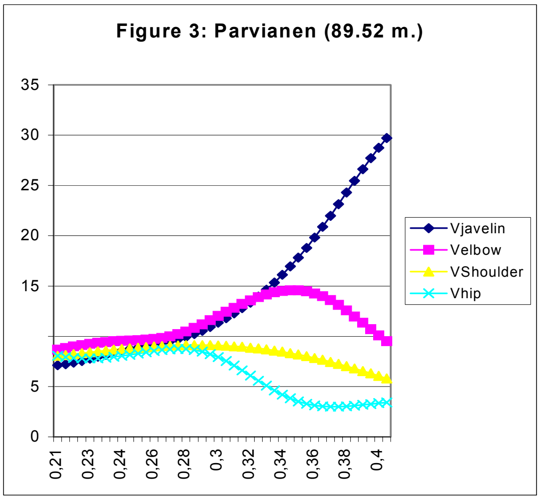


Figure 2: Times for the preparatory (T1-T2) and final phases (s).

Two time models can be distinguished in the preparatory phase (T1-T2). One is the model used by throwers Parvianen, González and Henry who base their throwing tempo on an extended preparatory phase (over 200 milliseconds), while throwers Gatsioudis, Zelezny and Hecht base their tempo on a shorter preparatory phase.
There is less difference between the throwers in the final phase (T2-T3) with values ranging from 100 to140ms.

B/. Duration between Maximum peak joint speed and instant of release
A factor that influences the quality of energy transfer to the javelin is the coordinated motion of the upper limb starting from the acceleration-deceleration of the sequences in the upper kinetic chain. These sequential motions from the proximal to the distal segments are one of the fundamental keys to performance in overarm throwing (Atwater, 1979; Whiting et al., 1991; Mero et al., 1994). Hip, shoulder, elbow, hand and javelin velocities are taken into account to analyze these power transmission sequences in the Final Phase. Figure 3 shows hip, shoulder, elbow, and javelin velocities in the Finnish thrower Parvianen's winning 89.52m throw in the final, and it can be seen that the general throwing model is repeated (Menzel, 1987).



The analysis of how the maximum peak velocities for each marker are reached at the instant of release (T3) provides a more detailed description of the timing used by the throwers to structure their individual motion models for the upper limb.

Table 3 show the data of time duration from maximum peak hip, shoulder and elbow velocities to delivery with average times of 130 ms for time from maximum peak hip velocity to release, 90 ms from maximum peak shoulder velocity to release, and 60 ms from maximum peakelbow velocity to release.

Table 3: Time duration from maximum peak hip, shoulder and elbow velocities to delivery.

Thrower	T3-Vmhip	T3-Vmshoul	T3-Vmelb
Parviainen	0,12	0,10	0,06
Gatsioudis	0,14	0,08	0,05
Zelezny	0,12	0,08	0,06
Hecht	0,12	0,10	0,05
Henry	0,16	0,10	0,06
González	0,14	0,08	0,05
Backley	0,14	0,10	0,06
Mean	0,13	0,09	0,06
SD	0,01	0,02	0,01
CV	0,11	0,16	0,10

The data confirm that throwers is greater than 10% in all cases. The higgest level for coefficient of variation is for the period from the maximum peak shoulder velocity to release (16%), while variability for hip an elbow are very similar with 11% and 10% resopectively.
Moreover, the tendency observed for hip motion may be worthy of note. Taking the period between instants t1 and t2 as a reference, it is shown that all throwers, except Backley, reach maximum hip velocity before instant t2. Advance times are quite variable ranging from 10 to 80 ms. In case of Backley, this thrower reach maximum hip velocity 20 ms after instant t2. These differences in starting hip motion confirm findings by Best (1993) to the effect that this parameter depends on individual technique and that its effect on performance should be considered in relative terms.

Table 2: Time of maximum hip velocity with regard to instant t2

Thrower	T3-Vmhip (s)
Parviainen	- 0,020
Gatsioudis	- 0,020
Zelezny	- 0,020
Hecht	- 0,022
Henry	- 0,080
González	- 0,010
Backley	+ 0,020

4.2.- Velocity Variables .

A/. Velocity of Release.

Throw velocity is known to be the parameter that bears most relation to distance (Ikegami (1981), Mero (1993), Menzel (1987), Morris, Barlett & Fowler (1997). The linear velocity of the javelin at release depends on the quality of power transmission from the body to the upper limb and then to the javelin.
The results show throw velocities that range from 28.1 m/s in Henry's 85.43 throw and 29.71 m/s in Parvianen's 89.52 m throw. With regard to the relation between distance and throw velocity, the correlation index was high (r: .714) but not statistically significant (p: .072).

Table 3: Distance and velocity of release

Thrower	**Distance (m)**	**VT3(m/s)**
Parvianen	89.52	29.7
Gatsioudis	89.18	29.7
Zelezny	87.67	29.2
Hecht	85.24	28.5
Henry	85.43	28.1
González	84.32	29.4
Backley	83.84	28.5
r: .714 p: .072		

B/ Horizontal (Vy) and Vertical (Vz) velocity components of the Javelin at Release (t3).
The magnitudes of two javelin velocity components at release have also been considered in order to interpret the final throwing action and its influence on javelin behaviour in the airborne phase. Figure 4 shows the values of these horizontal (Vy) and vertical (Vz) components.

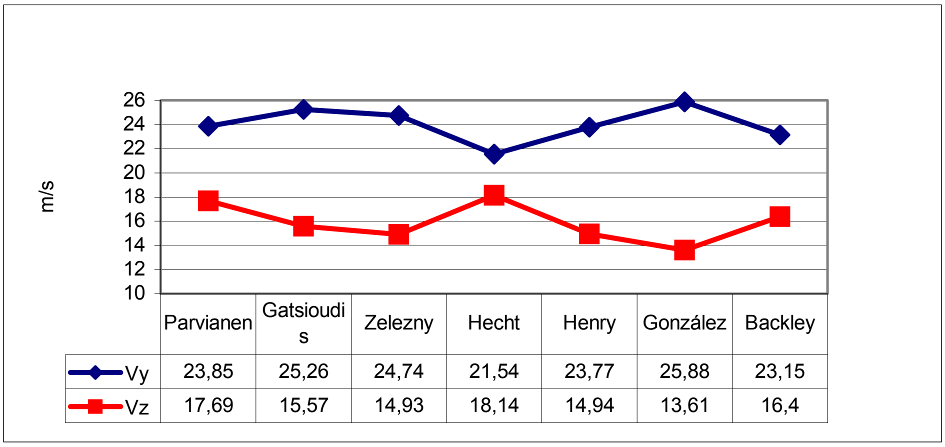


Figure 5: Vertical (Vz) and horizontal (Vy) velocity at T3

The differences between the two components in each of the throws under study ranged from Hecht's 3.4 m/s to González's 12.27 m/s respectively. In absolute values the horizontal component in the men's throws ranged from Hecht's 21.54 m/s to González's 25.88 m/s, and the vertical component from González's 13.61 m/s to Hecht's 18.14 m/s. The Cuban athlete E. Gonzalez was the athlete with the highest vertical component and the lowest horizontal component, whereas Hecht had the lowest horizontal component (18.14 m/s) and the highest vertical component (18.54 m/s) of all the athletes.
It is interesting to note that in throws like those made by athletes Parvianen and Gatsioudis where both distance and release velocity are similar, different models are used to direct forces to the javelin.

4.3.- Release conditions. (Height; Angle of Release and Angle of Attack)
Release height is a measure of ballistic efficiency and is conditioned by the thrower's height, lateral bending of the trunk and front leg knee angle at release. Throwers should aim to throw as high as their height allows while maintaining foot contact on the

ground. The results show release heights that range from 1.80 m to 2.14 m in throws by Zelezny and Parvianen respectively.

The parameters relative to the position of the javelin at release should include javelin position angle, release angle and, as a consequence of these, attack angle. Attitude angle is the angle formed by the velocity vector and the horizontal, and the attack angle is formed by the difference between attitude angle and release angle. Theoretical references suggest that the release angle should be 32º - 37º and the attack angle not over ± 8º to perform an effective throw. In a study based on a simulation Hubbard and Alway (1987) reported that optimum conditions for throws with velocities of 23-35 m/s require an attack angle of 0-2.5º.

Table 4: Release variables.

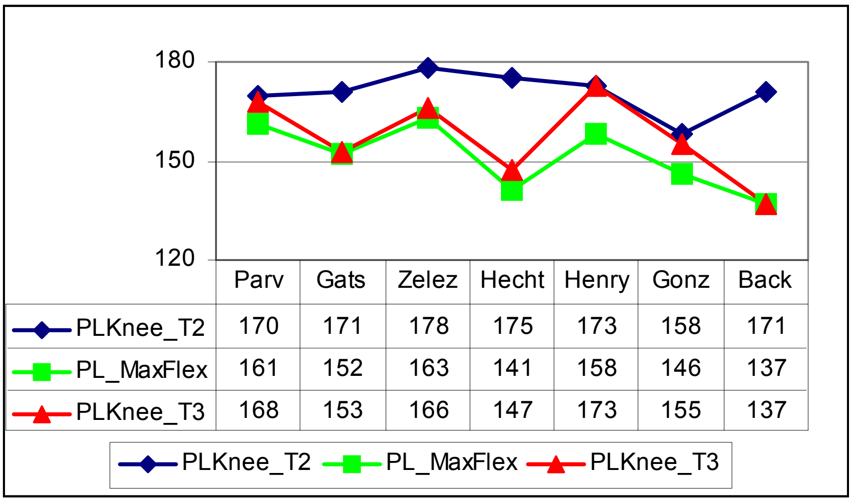
Thrower	Distance	Release Velocity	Height Delivery	Attitude Angle	Release Angle	Attack Angle
Parvianen	89.52	29.7	2.14	35.7	36.6	-0.9
Gatsioudis	89.18	29.6	1.9	37.5	31.6	5.9
Zelezny	87.67	29.2	1.8	36.9	31.1	5.8
Hecht	85.24	28.5	2.09	41.7	40.1	1.6
Henry	85.43	28.1	1.99	25.3	32.1	-6.8
González	84.32	29.4	1.83	36.5	27.7	8.8
Backley	83.84	28.5	2.08	40.8	35.3	5.5

The German thrower Hecht used the largest release angle (40.1º) and the Cuban Menéndez the smallest (27.7º). Menéndez had the largest resulting attack angle (8.8º) and Parvianen (0.9º) and Hecht (1.6º) the smallest. Overall, table 4 show that the athlete who came closest to the reference values was the World Champion, the Finn Parvianen, who was capable of throwing at a release velocity of over 29.5 m/s. with a release angle of 36.6º, resulting in a negative attack angle of almost zero.

4.4.- Knee Angle of the pressure and support legs (Final Phase t2-t3)

The bracing and blocking action of the pressure leg must also be taken into account in order to reach maximum release velocity, as it greatly reduces the horizontal velocity of the thrower-plus-javelin system. The knee angle of the pressure leg is an indicator of the athlete's ability to transfer kinetic energy to the javelin. This blocking action favours kinetic energy transfer from the upper part of the body to the javelin (Morris, Bartlett, Navarro, 2001). It seems evident that this action is decisive, considering that in elite throwers 60% of the javelin's kinetic energy is generated in the last 50 ms before release (Morris, Bartlett, 1995).

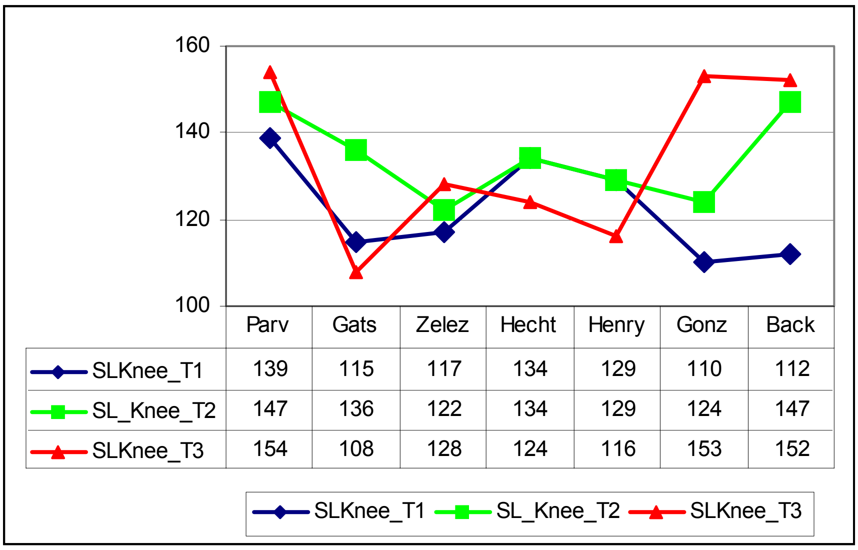
Theoretical principles for an effective throw state the need to maintain a flexion-extension angle of 160º-180º, so that the largest degree of extension occurs at javelin release. Table 6 shows pressure leg knee angle values at t2 and t3 and maximum flexion in the final release phase (t2-t3).



	Parv	Gats	Zelez	Hecht	Henry	Gonz	Back
PLKnee_T2	170	171	178	175	173	158	171
PL_MaxFlex	161	152	163	141	158	146	137
PLKnee_T3	168	153	166	147	173	155	137

Figure 6: Knee angle of the pressure leg (PL) at t1, maximum flexion and t3.

All the finalists except Backley and Gatsioudis showed a behaviour of increasing extension of the pressure leg knee in the final release phase. Therefore, pressure leg knee extension at release is higher than the maximum for the whole of the final phase. In Backley's case, however, the knee does not return to extension because maximum knee flexion (137º) is reached at release, showing a behaviour of progressive flexion that leads to a loss of support at javelin release. The same behaviour is seen in Gatsioudis' performance, but in this case extension is higher (152º-153º). In short, Parvianen, Zelezny and Henry were the most orthodox throwers in this action and Gatsioudis, Hecht and Backley were less effective in relation to support.
Support leg knee behaviour is not a frequently used parameter in reported studies, but support leg knee flexion-extension is decisive to drive the action and the thrower-plus-javelin system forward and direct it "against" the pressure leg. The results are shown in table 7.



	Parv	Gats	Zelez	Hecht	Henry	Gonz	Back
SLKnee_T1	139	115	117	134	129	110	112
SL_Knee_T2	147	136	122	134	129	124	147
SLKnee_T3	154	108	128	124	116	153	152

Figure 7: Knee angle of the support leg (SL) at t1, t2 and t3.

The results show knee extension in all the throwers in the t1-t2 phase, i.e. between support leg foot contact and pressure leg foot contact respectively. However, differentiated patterns were found in the phase between t2 and release (t3). One group (Parvianen, Zelezny, González and Backley) tends to extend the support leg knee and the other group (Gatsioudis, Hecht and Henry) tends to do the opposite.
The authors consider that this kinematic measure should not be studied separately but together with the bracing and blocking action performed by the pressure leg and hip rotation on the horizontal plane.

4.5.- Hip and Shoulder axis rotation on the horizontal plane.

Rotation of the hip and shoulder lines on the horizontal plane are two important measures that show the thrower's ability to make a wide and continuous movement in the final release phase to help throw the javelin further. Table 5 shows the measurements recorded for each athlete at the t1 and t2 reference times. Thus, the 90º position is the athlete's anatomical position facing the throw area and 180º is the position where the axes would be parallel with the Y axis, i.e. the position at t1 where the hip and shoulder axes are in maximum rotation and aligned with the release axis.

Table 5: Relation between Hip and Shoulder axis rotation

Athlete	**Hip Axis Rotation (º)**		**Shoulder Axis Rotation (º)**		**Difference Shoulder/ Hip (º)**	**Difference Shoulder/ Hip (º)**
	T1	**T2**	**T1**	**T2**	**T1**	**T2**
Parvianen	141	107	165	133	24	26
Gatsioudis	182	114	180	135	-2	21
Zelezny	170	114	181	132	11	18
Hecht	151	135	194	156	43	21
Henry	148	138	171	139	23	1
González	124	122	188	154	64	32
Backley	135	111	162	143	27	32

.

Gatsioudis and Zelezny were the athletes with the highest hip axis rotation values at t1 and González and Backley those with the most advanced hip axis. Gatsioudis and Zelezny were also the throwers with most hip movement from t1 to t2. Conversely, Hecht, Henry y González showed the most passive hip action.
With regard to shoulder motion, most of the athletes kept the shoulder axis at an angle of about 140º in double-support (t2), which is in line with a study by Morris y Bartlett (1996) on elite throwers. In addition, there was greater variability in the difference between shoulder and hip axes angles at t1 than at t2. There were differences ranging from 18 to 32 degrees between the two axes at instant of double-support (t3), except for Henry who had a difference of only 1º that shows early advance of the shoulder axis.

4.6.- Throwing arm elbow angle

Elbow angle is another kinematic measure frequently reported in the literature. From the technical viewpoint the throwing arm should be extended as much as possible until double-support in order to attain maximum javelin acceleration run-up.
All the throwers except Zelezny held the elbow quite extended at t1. The greatest differences between throwers were found at t2, although they all bent the elbow in relation to the position held at t1, with differences that ranged from 19º to 44º.

Gatsioudis was the thrower with the highest elbow angle and González and Backley had the lowest angle change between t1 and t2 (19º and 20º respectively). Lastly, all the throwers had similar elbow angles at t3, ranging from 151º to 160º.

Table 8: Throwing arm elbow angle at t1, t2, t3

Athlete	Elb_t1	Elb_t2	Elb_t3
Parvianen	158	119	159
Gatsioudis	172	128	159
Zelezny	140	105	160
Hecht	157	118	151
Henry	162	130	156
González	166	147	160
Backley	168	148	160

4.7.- Path of Acceleration.

The javelin acceleration path has been used as a performance measure in javelin throw. A long approach run facilitates optimum application of the forces and enables better use of the stretch-shortening muscle cycle. The importance of a longer run-up is stressed in the literature, including two proposals for approach run assessment under the heading "Acceleration Path". This is defined by Bartlett et al (1996) as the horizontal distance from the right hip to the center of mass of the javelin at the start of the delivery stride. Mero et al (1994) define the acceleration path as the horizontal distance from the grip of the javelin to the right hip at final foot strike.

As both proposals refer to two of the instants used in this kinetic study, it was decided to analyze both versions of the acceleration path, i.e. the horizontal distance from the javelin's center of mass to the hip at instants t1 and t2.

Figure 9: Representation for Path acceleration at t1 and t2.

All the athletes reached a longer acceleration path at t1, which is understandable because at that instant the hip is advanced as a consequence of the cross-over step. The range was 0.73-0.96 m and Parvianen had the longest acceleration path and Gatsioudis the shortest.

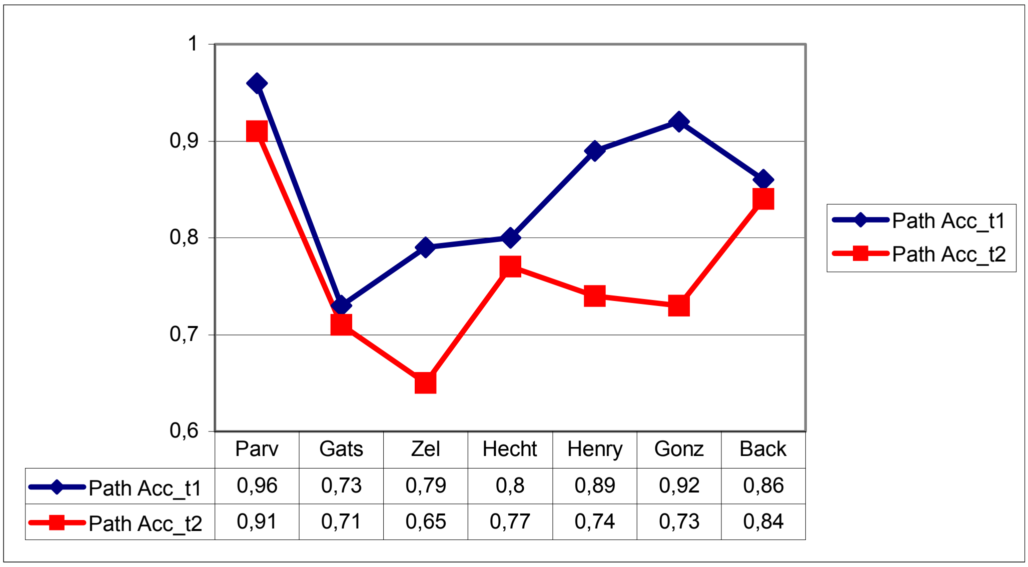


Figure 10: Path acceleratiion at T1 and T2

T2 values ranged from 0.65 to 0.91 m and Parvianen again had the longest acceleration path. As an overall criterion it was observed that the acceleration path decreased just before release, which means a loss of power in the most decisive phase. Zelezny (14 cm), Henry (15 cm), and González (19 cm) showed the largest losses. In any case, it must be noted that the acceleration path is conditioned by other factors like elbow angle. Thus, the acceleration path value is the result of several actions which should all be aimed at achieving the maximum efficacy possible. The analysis of acceleration path loss between t1 and t2 should therefore call for a review of all of the parameters analyzed.

5.- CONCLUSIONS.

As noted in the conclusions of previous studies it has been observed that each thrower maintains an individual throwing pattern in relation to timing and in the values obtained in the different kinematic parameters under study.

Nevertheless, these individual patterns are conditioned by what could be called efficiency filters. These are the minimum requirements needed to throw the javelin at a long distance which affect the position of the kinetic chain in the final release phase as well as the coordination of the body segments for ballistic movement.

The aspects that distinguished Parvianen from the rest of the throwers were that his throw was more rectilinear and he throws from a higher position, with a longer acceleration path and more favourable release conditions (V: 29.62 m/s; Attack angle: -0,9º; Height: 2.14 m.)..

Athletes' individual models are an example of motor complexity and numerous methodologies are required to analyze them. Descriptive studies such as the present work help to understand the dimensions involved in achieving performance in sport but their repeatability is relative.

However, we hope the information presented herein will be useful for javelin throw coaches and athletes and contribute to the understanding of this sport.

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