KINEMATICS ANALYSIS OF POLE VAULT DURING NATIONAL INDOOR ATHLETICS CHAMPIONSHIPS

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There should be a minimal level of individual variation presented by athletes in high level competitions, reflecting a high degree of consistency in the form of execution. By registering and subsequently analysing kinematic and kinetic data, obtained during athletic exercises, it is possible to verify such differences. The objective of this work was to collect kinematic data in order to quantify and verify these differences. Parameters such as amplitude, frequency, velocity, inter-segmental angles and kinetic energy were quantified, in order to understand the variations found in the different parameters. One should assume that an athlete that presents major variations from the above-mentioned parameters is not at his or her best form. We analysed 16 exercises of 3 athletes in the Portugal Indoor Championship in the year of the Sydney Olympic Games. This analysis enabled trainers to gain access to information on stability of technique in the exercise of each jump.

KEY WORDS: pole vault, velocity, presentation angle, inter segmental angles, kinetic energy.

INTRODUCTION: Biomechanical analysis of data obtained during execution is vitally important in order to enable trainers to gain detailed, rigorous and specific information on their athletes' performance in order to intervene during the training process. Simple direct or visual observation is not enough for certain levels of execution in order to detect errors. Considering that sporting techniques are also an exteriorisation in terms of the organisation of motor tasks, aiming to obtain a specific objective (i.e. to jump higher), an elite athlete must present small variations in the manner in which technique is exteriorised. The manner of execution may be assessed via kinematic analysis and the causes of variations may be provoked by variation in certain kinematic quantities. In light of the problem raised, and in accordance with an interview made with pole-vault trainers and using a model presented by Hay (1993) (figure 1), it was possible to determine the key parameters for this study. The study aims to calculate the confidence interval (variability) of the three best Portuguese pole-vault athletes in the Portugal Indoor Championship, in the following parameters:

- ✓ Amplitude and frequency in the last four strides.
- ✓ Angle of delivery
- ✓ Inter-segmental angles (arm – forearm, arm – trunk, thigh – leg). (figure 2)
- ✓ Kinetic energy.

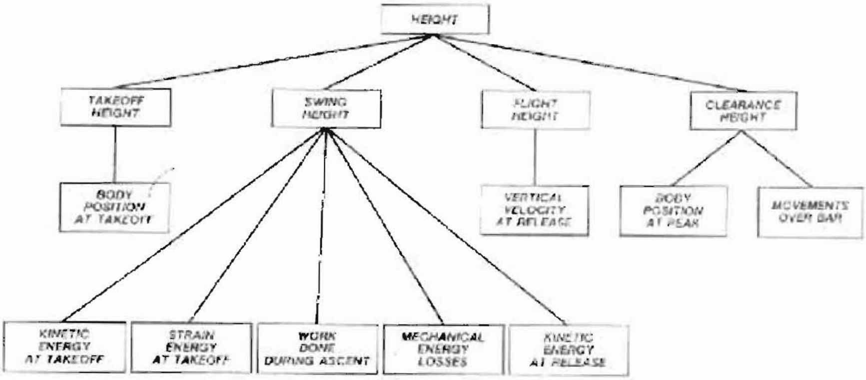

Figure 1. Basic factors in pole vaulting (Hay, 1993).

Due to the position and placement of cameras we chose to calculate average velocity in the last four strides using the method presented by Hay (1993) as a procedure. The velocity values obtained were compared with the values for the last five metres of the run-up of five elite athletes.

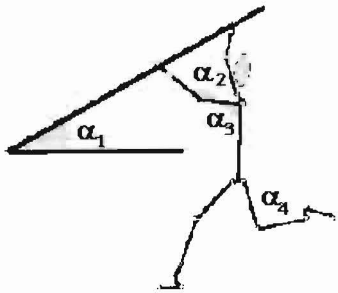

Figure 2. Inter-segmental angles and angle of delivery.

METHODS: In order to record the images we used two Sony cameras - model CCD-VX1EHi8, 8mm. One was placed perpendicularly to the runway at a distance of 20 metres and the second camera placed in front of the runway - 30 metres from the centre of the landing mat. Both recorded images at 50 frames/second. The recording of the jumps was subsequently codified in *.avi files for data processing. The digitalisation of articulated centres and extremities, in order to calculate centre of mass, was achieved via the AnaMovH programme (Programme developed in the Biomechanical Laboratory of the Faculdade de Motricidade Humana (Faculty of Human Motricity), Lisbon, Portugal), using the 21 points presented by Abrantes (1986). Calibration for the horizontal component was achieved using the marks placed in the exterior part of the runway, more or less 2 metres from the runway's external borders, thus serving to gauge the distances between each stride with greater precision. For the vertical component beyond the bar's support points, whose height was known, in function of the height to be jumped, the results marker was used - measured before the trial with considerable care, throughout the runway. The measurements for the amplitude of the stride, in the last 4 strides, were initially tested by measuring 15 executions of the same athlete, with calibration volume in x de 8 m, presenting an error of 13,24 mm and standard deviation of ±10 mm. The same 15 executions, using only a volume of 4 m+4 m, presented an error of 23.12 mm and standard deviation of ±15 mm. The kinetic energy of the athletes was gauged on the basis of the velocity resulting from the centre of mass (horizontal and vertical velocity), through complete digitalisation of the body. For this purpose, we used approximately 10 images before and 10 images after the moment at which the athlete probably made his take-off. The velocity used in order to calculate the kinetic energy was the maximum velocity value recorded at take-off. The variation in the different kinematic parameters was quantified using the statistical technique described below. Andrade, R., Calapez, T., Melo, P., Reis, E. (1997, 111) refer that "in estimation by intervals, instead of indicating a specific value for a certain population parameter, an interval is built that contains this parameter with a certain level of certainty as previously stipulated". According to Silva, C. (1994, 24) for small samples (n<30) and "considering that the distribution of the variable in X is normal or approximately normal", in the event that the standard deviation is not known, as is the case, "in order to estimate the population's standard deviation, the following equation should be used:

$$S_{n-1} = \sqrt{\frac{\sum\left(X_i - \overline{X}\right)^2}{n-1}}$$

given that it is an estimator with more suitable properties than the standard deviation S_n. "It is thus demonstrated that the variable

$$T = \frac{\overline{X} - \mu}{\frac{S_{n-1}}{\sqrt{n}}}$$

has a Student distribution with (n-1) degrees of freedom.". The confidence interval for the average of this population will be

$$\left]\overline{X} - t.\frac{S_{n-1}}{\sqrt{n}}, \overline{X} + t.\frac{S_{n-1}}{\sqrt{n}}\right[$$

where t is the value of the inverse distribution of the T- student for n-1 degrees of freedom and corresponding to the confidence level established. "The t interval will be read in the percentile table of the Student distribution with a no. of degrees of freedom equal to (n-1)". In this way, we aim to calculate confidence levels, for a confidence level of α=0.95, for the different kinematic parameters. This means that the probability that the confidence interval contains the true average value of a specific parameter is 95%. The samples to be used in this study are the three finalists of the Portugal Indoor Championship, in the pole-vaulting category, for executions of height equal to or above 5.00 m. The size of the sample is n=6, for the athletes JA and PP, and n=4 for the athlete NF.

RESULTS AND DISCUSSION: *Amplitude and Frequency in the last four strides* – For the best jump of each athlete the following results were *obtained*: In function to these results it was possible to calculate the average velocity, in the last five strides, using the procedure presented by Hay (1993), in which the average velocity is the result of the product of the amplitude (A) multiplied by the frequency (Fr). The velocities obtained for this process were compared with the velocities of world elite pole-vaulters, in a study made in the Seoul Olympic Games using photo-electric cells, in which the velocity of the athletes varied between 9.9 m.s-1 for the best athlete and 9,1 m.s-1 for the fifth athlete classified. The results obtained enable us to conclude that the athletes of the Portuguese elite are less rapid in the moments before the jump itself.

Table 2. Results obtained for Amplitude (A) and Frequency (Fr) in the last four strides, in the best jump of each athlete the average and standard deviation of each jump.

	NF 5.45		**JA 5.24**		**PP 5.24**	
	A	Fr	A	Fr	A	Fr
4 LS	2.29	3.75	1.94	5	2.27	4.29
3 LS	2.47	3.75	2.08	4.29	2.1	4.29
2 LS	2.2	4.29	1.99	5	2.17	4.29
LS	2.06	4.29	1.94	3.75	1.96	4.29
Avrg	2.26	4.02	1.99	4.51	2.13	4.29
Sdev	0.17	0.31	0.07	0.61	0.13	0.00

Table 1. Velocity results (A*Fr) ($m.s^{-1}$) in the last four strides, in the best jump of each athlete, with the average and standard deviation of each jump.

	NF	**JA**	**PP**
4 LS	8.59	9.70	9.74
3 LS	9.26	8.92	9.01
2 LS	9.44	9.95	9.31
LS	8.84	7.28	8.41
Avrg	9.03	8.96	9.12
Sdev	0.39	1.21	0.56

Angle of delivery and inter-segmental angles – for the angular kinematic parameters (angle of delivery and inter-segmental angles) the results are displayed in the table 3. The parameters, inter-segmental angles and grip-height, help to characterise the different positions at the moment of take-off. The different confidence intervals presented lead us to conclude that the athlete PP presents a greater variability in the angles that, according to the trainer, are decisive for undertaking the jump – e.g. the left Arm-Forearm and the Left Arm-Trunk. These are angles that characterise the position of the athlete in the moment before the pole starts to bend. *Kinetic Energy* – Another of the parameters analysed was that of kinetic energy. The results are displayed in Table 4. The results demonstrate that the Portuguese athletes present, on average, lower levels of kinetic energy at the moment of take-off. We also observe a greater variability of the maximum and minimum levels of kinetic energy, in elite athletes. However, this only occurs, due to the fact that the confidence level is for the five athletes.

Table 4. Upper and Lower Limit for the inter-segmental angles (degrees °) and grip-height (cm), for each athlete.

		AP 1	BA_D 2	BT_D 3	BA_E 2	BT_E 3	TCx_E	PCx_E 4
NF	Upper Limit	33.1	165.2	161.5	180.8	110.1	177.9	162.0
	Lower Limit	28.3	95.7	88.3	116.3	92.9	159.7	149.0
JA	Upper Limit	33.0	152.1	160.0	177.9	185.8	178.5	178.1
	Lower Limit	33.2	131.3	128.1	161.8	119.3	148.1	157.1
PP	Upper Limit	34.3	166.9	168.6	179.2	140.9	169.5	174.0
	Lower Limit	30.0	136.8	140.9	125.8	99.1	163.2	154.2

Table 3. Upper and Lower Limit of Kinetic Energy (Joules J), of the Portuguese Athletes.

	NF	JA	PP
Lower Limit	2190.98	1765.75	1815.96
Upper Limit	2366.37	2040.98	1915.29

Legend: BA-D – Right Arm-Forearm. **BA-E** – Left Arm-Forearm. **BT-D** – Right Arm-Trunk. **BA-E** – Left Arm-Forearm. **TCx_D** – Right Trunk-Thigh. **AP** – Angle of delivery.

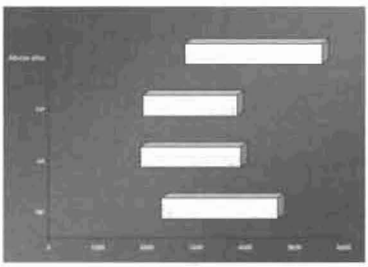

Figure 3. Graph of the Confidence Interval for Kinetic Energy, of elite athletes and Portuguese athletes.

CONCLUSION: the analysis of the results obtained enables the trainer to qualify his athlete's performance and know the parameters that need to be collected. Despite the quality of the material, the sharpness of the images delivered by filming from the bench, made it possible to obtain coherent and relevant data.

REFERENCES:

Abrantes, J. (1997). Biomecânica. Cruz-Quebrada. *Edições da Faculdade de Motricidade Humana.*

Andrade, R., Calapez, T., Melo, P., Reis, E. (1997). Estatística Aplicada Vol. 2. Lisboa. Edições Sílabo

Angulo-Kinzler, R., Kinzler, S., Balius, X., Turro, C., Caubet, J., Escoda, J. & Prat, A. (1994). Biomechanical Analysis of the Pole Vault Event. *Journal of Applied Biomechanics,* **10**, 147-165.

Gros, H., Kunkel, V. (1988). Pole Vault. Video of the IAAF. Seoul Olympic Games

Knudson, D., Morrison, C. (1997). Qualitative Analysis of Human Movement. Champaign. Human Kinetics Books.

Hay, J. (1993). The Biomechanics os Sports Techniques. New Jersey. Prentice Hall.

Hall, S. (1993). Biomecânica Básica. Rio de Janeiro. Guanabara koogan.

Hay, James & Reid, J. Gavin (1982). Anatomy, Mechanics and Human Motion. New Jersey. Prentice Hall.

Linthorne, N. (1994). Mathematical Model of the Takeoff Phase in the Pole Vault. *Journal of Applied Biomechanics*, **10**, 323-333.