A PROCEDURE FOR DETERMINING THE ANGULAR VELOCITY OF THE UPPER ARM ABOUT ITS LONGITUDINAL AXIS RELATIVE TO THE THORAX IN JAVELIN THROWING

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INTRODUCTION: Javelin throwing is a movement whose objective is to reach the maximum velocity of the free end -javelin- of the human body chain at the instant of release. Obviously the release speed will be maximum depending on the preceding movements, especially of those defining the throwing phase. The throwing phase begins with the last double foot contact and finishes with the release of the javelin. The throwing phase time has been reported for men as 110-170 ms (Ikegami, 1981; Mero, 1993). As result of the rotational movements about their anatomical axis, a sequence of speed maximums of segments is produced during the throwing phase.

More in relation to performance, it is obligatory to note the importance that coaches give to the arched position. The arched position concept appears when the throwing phase is divided into two parts. During the first part, the thrower turns his hips and shoulders consecutively through the longitudinal axis of the trunk, while the javelin should remain to the rear, so that the right shoulder, upper arm and elbow move up and forward; at the end of this part an "arched position" must be reached (Koltai, 1985). According to Ikegami (1981), the kinetic energy of the thrower's body obtained during the approach run is stored as elastic energy during the first part (from the start of the throwing phase to the arched position); after that, the energy is restored during the latter part -acceleration phase.

Taking into account the real technique of javelin throwing, is obvious that a more detailed analysis of the coordination patterns and exact movements -translational and rotational movements-, predominantly of the upper arm and body, would be required to design a specific training program for each athlete (Morris, 1996). A lot of information exists about the linear movements of segments in javelin throwing, however, few data have been found in relation to the absolute angular velocities. One of the most important movements in throwing skills is the internal-external rotation of the upper arm about its longitudinal axis. Internal rotation of the humerus (and possibly pronation of the forearm) could contribute greatly to the acceleration of javelin throwing (Morris, 1996). Navarro (1994) calculated the absolute longitudinal angular velocity of the upper arm and defined the arched position instant as the maximum external rotation. Morris (95) reported durations of as little as 0.08 s for the time taken for elite throwers to laterally rotate their shoulders into a position parallel with their hips (in the horizontal plane); these data agree with those of Navarro (1994), in which the time to reach the arched position was 0.073 s (subject A, 16 throws) and 0.092 (subject B, 20 throws). In order to introduce a new factor into the evaluation of the javelin technique, the objective proposed in this work is to develop a procedure for determining the angular velocity of the upper arm about its longitudinal axis relative to the thorax.

METHODS AND PROCEDURES:

Mechanical model: The mechanical model (Navarro, 1995) considered the system (human body + javelin) composed of 6 rigid solids (thorax, pelvis, upper arms and thighs) and 11 bars (head, abdomen, forearms, hands, legs, feet and javelin). Therefore, the system was determined by 26 markers, so that movement was determined by 3D co-ordinates of 26 landmarks in accord with Zatsiorsky (1983) and Clauser (1969). The procedure for calculating the angular velocity of the segments was the following:

1. Thorax was modeled like a rigid solid (with three non-colinear points: right and left shoulder and substernal). The upper arm was defined as a solid rigid (two own points -right shoulder and elbow- and an external third point -wrist- through one degree of freedom joint -elbow-) (Figure 1).
2. A local reference system was defined both in the upper arm and thorax (x: anteroposterior, y: transversal, z: longitudinal).
3. The rotation matrix in relation to a Inertial Reference System were calculated at each photogram from the 3D co-ordinates of three points which defined each segment (${}^{0}\mathbf{A}_{t}$: Thorax, ${}^{0}\mathbf{A}_{ua}$: Upper arm).
4. The rotation matrix of the upper arm in relation to the local reference system of the thorax was calculated in each photogram by the expression: ${}^{t}\mathbf{A}_{ua}$: = $\{{}^{0}\mathbf{A}_{t}\}^{T}\cdot{}^{0}\mathbf{A}_{ua}$..
5. Interpolated (no smoothing) quintic spline functions were obtaining for each component of three unit vectors (**i**, **j**, **k**).
6. The angular velocity about the longitudinal axis of the upper arm was calculated by $\mathbf{w}_z = (d\mathbf{i}/dt)$⌧$\mathbf{j}$·(⌧**:** scalar product).

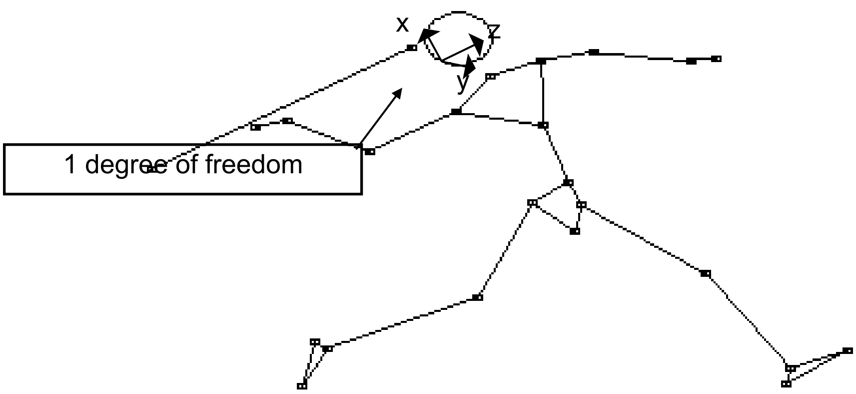

Figure 1

Experimental procedures: The experimental technique used was 3D-photogrammetry with high speed cine-cameras. The subjects were the two best Spanish javelin throwers. A total of 36 throws were analyzed. The distance range was 59-66 m for subject A (22 years old, 1.70 m of height and 75 Kg of mass) and 58-68.9 m for subject B (23 years old, 1.92 m of height and 101 Kg of mass). Two synchronized Photosonics 1PL cine-cameras were used at a frequency of 200 Hz. The cameras were located on the right side of the runway so that the optical axes between both were approximately 90^{o}. The two subjects were right-handed throwers. The throwing phase area was calibrated before and after the event using a cube frame (2m x 2m x 2m) with eight control points. The three-dimensional coordinates of the 26 points which defined the body model were obtained using DLT algorithm. After computation of the throwers' Center of Mass coordinates, the data was smoothed and velocities were calculated using quintic spline functions. The smoothing factor was calculated using the Mean-Squared Error Criteria (Craven & Wahba, 1979).

RESULTS AND DISCUSSION: Figure 1 presents the angular velocity of the upper arm about the longitudinal axis relative to the thorax expressed in relation to the Local Reference System of the segment. In both subjects the temporal functions of angular velocity (normalized time: 0%: left foot contact; 100%: release) showed a movement of external rotation first and external rotation in the final instants. However, the instant of maximum relative external rotation is produced after the arched position -central vertical bar in Figure 2- which has been calculated in accord with the criteria of Navarro (1994) -maximum absolute external rotation.

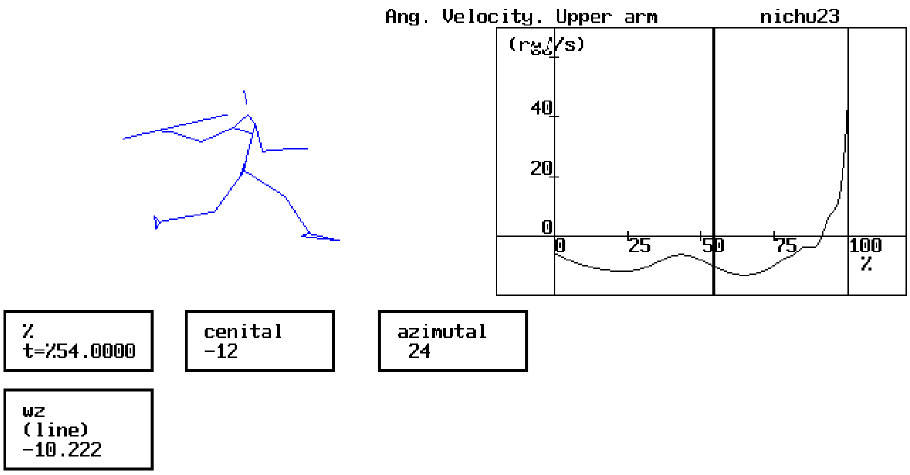

Figure 2

For subject A the average angular velocity at the release instant was 47.4 rad/s (SD=29.6 n=15; in subject B was 49.8 rad/s (SD=33.6, n=20). In both subjects (independent samples) we found a high standard deviation, that is the variability between throws is great. It must be taken into account that this variable expresses the angular velocity measured about the local reference system of the thorax; therefore the rotational movements of the thorax about the transversal and anteroposterior axes have an important effect on the relative velocity of the upper arm. A significant linear correlation coefficient between internal velocity of rotation of the upper arm and javelin speed at release has been found in both samples analyzed (Subject A:. r=0.57, $p<0.05$; Subject B: 0.54 $p<0.05$).

CONCLUSIONS: A procedure for obtaining the angular velocity of upper arm relative to thorax about the longitudinal axis has been developed. The increase of internal angular velocity of upper arm in the final moments seemed to produce higher release speed of javelin. This can suggest that internal rotation of upper arm relative to trunk is an important factor to be taken into account in the assessing of performance in javelin throwing.

REFERENCES:

Bartlett, R. M., Best, R. J. (1988). The Biomechanics of Javelin Throwing: A Review. *Journal of Sports Sciences. Sports* **6**, 1-38.
Bartlett, R. M., Müller, E., Lindinger, S., Brunner, F., Morris, C. J. (1996). Three-Dimensional Javelin Release Parameters for Throwers of Different Skills Levels. *Journal of Applied Biomechanics* **12**, 58-71.
Clauser, C. E., McConville, J. T., Young, J. W. (1969). Weight, Volume, and Center of Mass of Segments of the Human Body. Wright-Patterson Air Force Base, Ohio: Aerospace Medical Research Laboratory.
Craven, P., Wahba, G. (1979). Smoothing Noisy Data with Spline Functions. *Numerische Mathematik* **31**, 377-403.
Ikegami, Y., Miura, M., Matsui, H., Hashimoto, I. (1981). Biomechanical Analysis of the Javelin Throw. In A. Morecki, K. Fidelus (Eds.), *Biomechanics VII-B* (pp. 271-276). Baltimore: University Park Press.
Koltai, J. (1985). Javelin. In H. Payne (Ed.), *Athletes in Action: the Official IAAF Book on Track and Field Techniques* (pp. 263-293). London: Pelham.
Mero, A., Komi, P. V., Korjus, T., Gregor, R. J., Navarro, E. (1993). Body Segment Contribution to Javelin Throwing during Final Thrust Phases. *Journal of Applied Biomechancs* **10**, 166-177.
Morris, C., Bartlett, R. (1996). Biomechanical Factors Critical for Performance in Men's Javelin Throwing. *Sports Medicine* **21**(6), 439-445.
Morris, C., Bartlett, R. (1995). Biomechanical Analysis of Men's Javelin Throwing. In R. Bartlett (Ed.), *Biomechanical Analysis of the 1995 National Championships.* Vol 4. Alsager: British Athletic Federation.
Navarro, E., Campos, Vera., P., Chillaron, E. (1994). A Procedure for Determining the Acceleration Phase in Javelin Throwing. In A. Barabás, G. Fábián (Eds.), *Proceeding of the 12th International Symposium on Biomechanics on Sports* (pp. 357-359). Budapest: Hungarian University of Physical Education.
Navarro, E., Campos, J., Chillaron, E., Vera, P. (1995). A Kinetic Energy Model of Human Body Applied to 3D Analysis of Javelin Throwing. In K. Häkkinen, K. L. Keskinen, P. V. Komi, A. Mero (Eds.), *XVth Congress of the International Society of Biomechanics. Book of Abstracts* (pp. 668-669). Jyväskylä: University of Jyväskylä.
Zatsiorsky, V. M., Seluyanov, V. N. (1983). The Mass and Inertia Characteristics of the Main Segments of the Human Body. In H. Matsui, K. Kobayashi (Eds.), *Biomechanics VIII-B* (pp. 1152-1159). Champaign, Ill.: Human Kinetics Publisher.