# A THREE-DIMENSIONAL ANALYSIS OF ANGULAR VELOCITIES OF SEGMENTS IN JAVELIN THROWING

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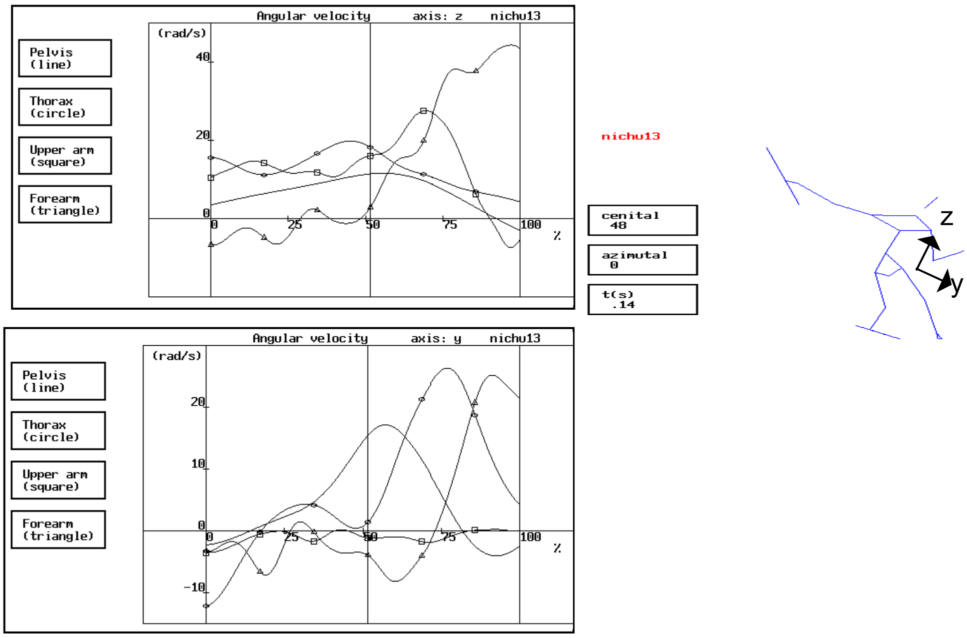
**INTRODUCTION:** The pattern of movement of the throwing phase (last double feet contact) based on the energy transmission between segments has been proved for numerous researchers through the observation and processing of the sequence of linear velocities or kinetic energy of the segments. (Bartlett, 1988, 1996). This sequence of speed maximums is the result of the rotational movements of segments about their anatomical axis. However, a lack of information exists in relation to the angular velocities. At the beginning of the throwing phase, elite throwers have their shoulder axes aligned approximately parallel to the throwing direction. Morris (1995) reported values of 143º for the horizontal angle between the shoulder axe and the mid-line of the throwing sector with the hips 38º further around in the throwing direction while the elbow of throwing arm was extended to a mean angle of 130º. That is, the relative attitude of segments is such that the segments which are farther from the implement are more rotated about the longitudinal axis of the body than those nearer, because these segments (lower members) will act before those which are more proximal to the javelin (shoulder; upper body). The blocking action of the left knee - in right throwers - to enable the athlete to use the left hip as a pivot about which the right hip can rotate (Morris, 1996). Following with the description of the movements, it is compulsory to remark 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 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, Navarro, 1994)). Morris (95) reported durations of as little as 0.08 s for the time taken for elite throwers to laterally rotate the shoulders into a position parallel with the hips (in the horizontal plane); these data agree with those of Navarro (1994) in which the time to reach the arched position - maximum external rotation of upper arm - was 0.073 s (subject A, 16 throws) and 0.092 (subject B, 20 throws). However, there is a lack of information in relation to the angular velocities of the body about the longitudinal axis of the trunk in javelin throwing. When the thrower starts the second part - acceleration part - the shoulder and hip lines are aligned. During this period the trunk, which was arched, performs a flexion about the transversal and anteroposterior axis while the upper arm rotates internally about the longitudinal axis and the elbow is extended. According to Ikegami et al. (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 – the acceleration phase. Data have not been found in relation to the movement of the trunk about the transversal axis. Although the importance of the left lateral flexion - right thrower - of the trunk in the frontal plane, only indirect information has been reported; in accord with Mero (1993) the lateral distance between the grip and the left foot was 0.5 m. The objective of this work is to analyze the movements of rotation of the segments about their three anatomical axes.

**METHODS AND PROCEDURE:** *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). The bars are defined by two points; thorax and pelvis by three; the upper arm and thigh are defined by two points and one third point belonging to the next distal segment linked to it through a joint of 1 degree of freedom (elbow and knee). Therefore, the system was determined by 26 markers, so that movement was determined through 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. A local reference system was defined in each solid rigid (the bars were determined by a unitary vector).
2. The rotation matrix relative to an Inertial Reference System were calculated in each photogram from the 3D co-ordinates of three points which defined each segment - solid rigid.
3. Interpolated (no smoothing) quintic spline functions were obtained for each component of three unit vectors (**i**, **j**, **k**).
4. The absolute angular velocity expressed in relation to the local reference system of the segment was calculated through $\mathbf{w}_x = (d\mathbf{j}/dt)\bullet\mathbf{k}$, $\mathbf{w}_y = -(d\mathbf{i}/dt)\bullet\mathbf{k}$ and $\mathbf{w}_z = (d\mathbf{i}/dt)\bullet\mathbf{j}$·(**•:** scalar product).
5. In this work, we focused on the angular velocity of thorax, pelvis, upper arm and forearm as follows:

- Thorax and Pelvis: absolute angular velocity expressed about their Local Reference System.
- Upper arm and Forearm: Absolute angular velocity expressed about the Local Reference System of thorax.

*Experimental procedures*. The technique was the 3D-photogrammetry (DLT algorithm). A total of 36 throws of two national level throwers were analyzed. Two cine cameras were used at 200 Hz. The data were smoothed by quintic spline functions. The time was normalized (0%: left foot contact, 100%: release).

**RESULTS AND DISCUSSION:** During the acceleration phase, the average peaks of angular velocity about anteroposterior axis (x) proved the existence of important movements of left lateral flexion of the thorax (-3.4 rad/s; SD=1.8, n=16) and upper arm (-11.89 rad/s, SD=2.6, n=16) in the frontal plane -data for subject A-. Also in accordance with the literature, at the release instant the thorax presented an average negative angular velocity of -1.8 rad/s (SD=1.3, n=16) and -2.5 rad/s (SD=1.8, n=20) for subject B. The average data for the upper arm were -7.7 rad/s (SD=2.7) and -6.7 rad/s (SD=4) for subject A and B respectively. As we can see, the latter data presented a high standard deviations, that is, the left lateral flexion seems to be an unstable factor of the technique. This is in accordance with the data of Morris (1995), who reported values for the maximum lateral displacement of the javelin during the delivery of 0.63 m and 0.09 for two throwers.




Also average maximums of angular velocity about transversal axis (y) demonstrated large movements of flexion in both subjects. As we can see in Table 1 the segments reach the maximums consecutively beginning with the proximal segments (pelvis). A significant linear coefficient between the decrease of angular velocity of the pelvis and increase of the thorax (in the period between the pelvis and trunk maximums) has been found in both subjects (A: r=-0.8, p<0.001; B:r=-0.54, p<0.05).

**Table 1**

| | Normalized time (%) | | | Wy (rad/s) | | |
|---|---|---|---|---|---|---|
| | Pelvis | Thorax | Forearm | Pelvis | Thorax | Forearm |
| A | 63.9 | 76.4 | 97.3 | 16.5 | 21.1 | 20.5 |
| B | 61.0 | 78.0 | 97.0 | 9.8 | 13.7 | 17.6 |

Table 2 shows the results corresponding to the angular velocity about the z axis. The peaks of the angular velocity about the longitudinal axis of the trunk reach the maximum in the next sequence: trunk-pelvis-upper arm-forearm. That is, the thorax maximum occurs before the pelvis maximum. An analysis of linear correlation was carried out between the increments of angular velocity of the segments in the three intervals defined by the instant of the maximums (Table 2). In subject A: in 1-2 interval, the decrease of the thorax was related to the increase of the upper arm (r=-0.5, p<0.05) and forearm (r=-0.65, p<0.01); during the second interval inverse correlations between pelvis and upper arm (r=-76, p<0.001) and forearm (r=-0.63, p<0.01) were found. Also, the decrease of the thorax was related to the increase of upper arm and forearm (r=-0.66, p<0.01; r=-0.63, p<0.01). The results for subject B were similar: at 1-2 interval the thorax decrease had an inverse correlation with the upper arm (-0.61, p<0.01) and forearm (r=-0.56, p<0.05). In the interval 2-3, an inverse correlation was found between pelvis and upper arm (r=-0.88, p<0.001) and between thorax and forearm (r=0.77, p<0.001). Therefore, the movement of rotation of the segments about the longitudinal axis of the trunk behaves in accordance with the pattern of movement based on the kinetic energy transmission between segments.

**Table 2**

| | Normalized time (%) | | | | Wz (rad/s) | | | |
|---|---|---|---|---|---|---|---|---|
| | Thorax (1) | Pelvis (2) | U.arm(2) | Forearm(3) | Thorax | Pelvis | U.arm | Forearm |
| A | 44.4 | 59.9 | 67.4 | 92.6 | 18.5 | 11.8 | 24.5 | 39.9 |
| B | 48.0 | 62.2 | 67.6 | 96.1 | 16.6 | 12.5 | 22.0 | 41.3 |

**CONCLUSIONS:** A procedure has been developed for calculating the angular velocities of the segments. Large angular velocities of the segments about the anteroposterior, transversal and longitudinal axis of the trunk has been found. It has been proved that the segments reach the maximum angular velocity about the transversal and longitudinal axes consecutively, beginning with those segments which are farther from the javelin. The importance of taking into account the angular velocities of the segments for assessing the sport technique in javelin throwing has been demonstrated.

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