Stroboscopic computerized determination of humeral rotation in overarm throwing

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Analysis of the final phase of the overarm handball throw was carried out by a computerized treatment of photographic images taken simultaneously in two grid layouts. Reflective stickers on the joints of the throwing arm (shoulder, elbow, wrist) allowed the coordinates of these three points to be measured against a reference on the wall. Using a mathematical treatment and Euler matrices, the movement could be studied in space. The results confirmed that humeral rotation occurs during the overarm handball throw. Initial external rotation was immediately followed with internal rotation about 40 ms before ball release.

Keywords: Humeral rotation, overarm throwing, stroboscopic images

Most studies of sports movements describe only one plane or analyse three planes using cameras1,2. The method described here enabled us to investigate the overarm handball throw simultaneously in the three planes using only a stroboscopic light and two sets of photographic apparatus. Previous studies have analysed this movement from projections in the sagittal plane, and suggest that the throw involves bending the trunk and simultaneous rotation of the humerus.

Techniques

Rotation of the humerus relative to the trunk in the end phase of the throw was followed by marking the wrist, elbow and shoulder joints of the throwing arm with reflecting stickers. The axis of the trunk was marked by a reflecting solid rod fixed along the internal side of the scapula and in alignment with the shoulder joint marker. A stroboscopic light at 25 Hz gave the best picture definition. The subject was photographed in top view and profile for sagittal and horizontal planes. Coordinates X, Y, Z of the chosen points in the reference frame were obtained every 40 ms.

The experimental set-up is shown in Figure 1. The player stood 4 m from the target and under a mirror 3 m long. At the start of each trial the subject was still, trunk vertical, arm in 90° abduction and forearm flexed at 90°. Only the throw phase was photographed avoiding superposition of the images from the top view, induced by the slight displacement of the ball and the wrist at the beginning of the forearm throw.

The players did warm-up exercises, and then took a few practice throws. A trial was used if the ball reached the target and if the photographs included the grouping of points necessary for kinematical analysis.

Developed slides were projected onto a screen. The measured coordinates X, Y, Z were corrected for distance of the different grids from the equipment. The diameter of the ball constitutes an interesting element of reference, since the positions of the target and of the player were determined so that the ball only moved in the sagittal plane. The data were analysed using a computer program (mainly with Euler matrices used by Haynes and Hildebrand for another problem). These transformation matrices were characterized by three rotation angles α, β, γ, and three movements of translation XA, YA, ZA (Figure 2).

The kinematic analysis of the throw based on the absolute coordinates XA, YA, ZA was mainly aimed at studying the rotation of the humerus. Two grids, one formed by the humerus and the forearm (grid A) and the other by the humerus and the trunk axis (grid B), defined rotation angle θh (Figure 3). A third vertical grid (V) again contained the humerus. Angle θh could thus be determined in relation to the bending of the trunk. θw was defined as the angle formed by grids A and V. So we can write that:

θh = θw + θr

The calculation of these angles was simplified by adopting a new reference point E, Y, Z closely linked to the humerus with: origin E merged with the elbow, axis Y confirmed by the humerus, axis Z placed in the vertical grid V. Two movements of translation and one rotation defined this basic change. The first movement of translation (T1) carried the absolute coordinates over
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Figure 1. Experimental apparatus – reflective stickers (▲) and dorsal rod (▼)

the reference point $X_S$, $Y_S$, $Z_S$ of which the origin was merged with the articulation of the shoulder. The second movement of translation (T2), followed by a rotation (R), made it possible to work in the desired reference point $X_E$, $Y_E$, $Z_E$. Both translation matrices were united and could be calculated easily, since both origins, shoulder and elbows belonged to the characteristic points measured on each player.

To obtain the rotation matrix, we used the Euler matrices joined to angles $\alpha$, $\beta$, $\gamma$. Axes $Y_E$, $Z_E$ however, which belonged to grid V, just like axis $Z_S$, implied that axis $X_E$ was parallel with grid ($X_S$, $Y_S$). Angle $\gamma$, therefore, was zero, and angles $\alpha$, $\beta$ could be calculated easily. Finally, using these absolute coordinates $X_A$, $Y_A$, $Z_A$, new coordinates $X_E$, $Y_E$, $Z_E$ of the characteristic points were written as:

$$
\begin{align*}
X_E & = \begin{bmatrix} \cos \alpha & -\sin \alpha & 0 \end{bmatrix}
Y_E & = \begin{bmatrix} \sin \alpha \times \cos \beta & \cos \alpha \times \cos \beta & -\sin \beta \end{bmatrix}
Z_E & = \begin{bmatrix} \sin \alpha \times \sin \beta & \cos \alpha \times \sin \beta \cos \beta \end{bmatrix}
\end{align*}
$$

$$
\begin{align*}
X_A - X_B & = X_E - X_A
Y_A - Y_B & = Y_E - Y_A
Z_A - Z_B & = Z_E - Z_A
\end{align*}
$$

Figure 2. Euler transformation

Figure 3. Sagittal view showing successive changes of coordinates (T1, T2, R), humeral rotation ($\theta_h$) and trunk bending ($\theta_t$)
where $X_d$, $Y_d$, $Z_d$ represent the union of the two movements of translation. After having carried out the basic change, determining angles $\theta_w$ and $\theta_d$ was easy, e.g. to obtain angle $\theta_w$ only wrist coordinates $X_d$ and $Z_d$ need to be found. An analogous study made it possible to obtain the bending of the trunk characterized by angle $\theta_t$.

The calculations were done on microcomputer, and the program automatically selected the angular solutions compatible with the anatomical facts. The Mann–Whitney $U$ test was used to determine any statistically significant difference.

Results

The data presented are for five subjects (S1, S2, S3, S4, S5) playing in a national handball competition. For each player, the values used were the average of five trials. Table 1 gives the morphological characteristics of the subjects.

The data were collected every 40 ms, i.e. between two successive stroboscopic flashes. These results confirmed that the end phase of the overarm handball throw includes trunk bending and humerus rotation around its longitudinal axis.

Trunk bending

Figure 4 shows trunk bending during the five throws of S3. Good reproducibility of this mobilization was confirmed statistically for each subject. Mean values for trunk bending of each subject were obtained every 40 ms. At 120 ms before the release, all the subjects stood vertically. Then, forward flexion of the trunk started earlier or later depending on subject. Degree of flexion increased until the ball was released reaching 20.8–46.4° (Figure 5).

Humeral rotation

As shown in Figure 6, the results for each trial were in good agreement. Therefore, mean data were calculated at each moment during the last phase of the throw. Figure 7 shows humerus rotation around its axis for each player. The positive values of $\theta_h$ reflect an internal rotation of the arm, whereas the negative values indicate an external rotation. At 120 ms before

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Table 1. Morphological characteristics of the five handball players

<table>
<thead>
<tr>
<th>Player</th>
<th>Age (years)</th>
<th>Size (cm)</th>
<th>Weight (kg)</th>
<th>Span (cm)</th>
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<tr>
<td>S1</td>
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<td>185</td>
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<td>25</td>
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<td>S2</td>
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<td>S4</td>
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</tr>
<tr>
<td>S5</td>
<td>18</td>
<td>185</td>
<td>75</td>
<td>24</td>
</tr>
</tbody>
</table>

**Figure 4.** Trunk bending in S3 – results obtained in each of the five trials

**Figure 5.** Trunk bending for the five throwers (mean values). (— —) S1, (— —) S2, (— — —) S3, (— — —) S4, (— — —) S5

**Figure 6.** Humeral rotation in S5 – results obtained in each of the five trials
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![Graph showing humeral rotation over time](Image)

**Figure 7.** Humeral rotation for the five throwers (mean values), (---) S1, (-- -) S2, (-- - -) S3, (-- - - -) S4, (-----) S5

the release, the arm was either in internal or slightly external rotation, depending on subject. Before release two phases could be distinguished. The following motion consisted of an external then an internal rotation (Figure 7). In all subjects, the movement reversed at -40 ms. With regard to the release, all the players had their humerus in internal rotation.

**Discussion**

This method allowed us to demonstrate and measure the internal rotation of the arm around its axis, during the end phase of overarm handball throw. However, using stroboscopic pictures has some limitations. Not all segments studied displace at the same speed. For example, during external rotation of the arm, the wrist moved forward a little compared with the elbow, causing superposition of pictures. This made it necessary to use a lower stroboscopic frequency, which reduced both the number of points or images and the precision of the measures. Despite this, we emphasize that this method makes it possible for the subject to displace during the movement. From a biomechanical viewpoint, and taking into account the results of Jorris et al.\(^4\), this sequence is of fundamental interest for the handball player. Internal rotation of the humerus is accelerated, while translations of the elbow and wrist are slowed down. At the beginning of the movement progressive external rotation of the humerus corresponds to a movement toward the front of the elbow which reaches a maximum velocity at -60 ms. The wrist continues to swing towards the back taking advantage of the weight of the ball, to a time of -40 ms. This movement can be assimilated into a rotation, around a hypothetical horizontal axis, passing near the wrist area, as an apparent velocity of the ball less than of the wrist can testify, it being less than that of the elbow. At -40 ms rotation of the humerus has already started to reverse. Everything now happens as if the forearm was swinging in the other direction, around a hypothetical axis always near the wrist. This movement provokes an apparent slowing down of the elbow directing itself towards the back, while the ball accelerates, pushed by the hand. The speed of the wrist near the hypothetical axis declines weakly. At time zero, the deceleration of the elbow compared with the wrist is equal to the acceleration of the ball also relative to the wrist. This can only be explained by the existence of the hypothetical axis.

Final bending of the fingers is an important part of this final swinging movement. However, we have not demonstrated this bending of the hand before letting go of the ball.

**References**

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