Kinematic Structure of the Jump Shot in Handball Game

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The final effort of the handball game during the attack occurs in the form of throwing of different structure, which is performed to score the goal. In this context, several authors studied the usability and effectiveness of different options of shooting at the door [2,3]. From the wide variety of techniques used for shooting the most common throw is a jump shot. It occurs in two versions - forward and above. This way of shooting combines moving actions of cyclic and non-cyclical type - running, jumping, throwing. Their kinematic structure was studied in detail by [4] and others.

Having the main intention to help coaches in training their athletes to perform jump shooting more effectively through the optimal use of their personal physical capacity and rectify certain inaccuracies in the technique, we focused on researching the structure of the jump shot.

One of the ways to answer the questions is to conduct a biomechanical analysis based on the performance of a highly skilled athlete and adopts it as a model. This kind of analysis makes it possible to quantitatively describe the movement and to gather precise information on the parameters having importance for its effective implementation.

PURPOSE

In this work we set ourselves to investigate the kinematic structure of the jump shot with run-out in order to optimise the technical and physical training of athletes.

METHOD

Implementation of the study was the jump shooting with run-out of a highly skilled handball player aged 21, height 193cm and weight 82kg. Two standard digital VCRs provided the registration of movement. The data was processed through the original video computer system [1]. For a comprehensive analysis, three top executions (performances) with the highest linear velocity of the ball were selected, then the measurements were normalised in the time domain (phase of the overall movement) and averaged. A 14-segment model of the human body was used, defined by digitising the location coordinates of 17 specifically chosen points of the body and one more for the ball. To smooth the digitised data a digital low-pass filter with partial damping was used with a cut-off frequency equal to the sixth harmonic of the natural movement frequency. To more precisely determine the time structure, source data was reconstructed using modified cubic splines interpolation with a sampling rate set at 100Hz. Subsequently, the kinematic parameters of the movement were calculated from the so-processed output data.

RESULTS AND ANALYSIS

In accordance with the basic structure of the movement, it was divided into five separate phases (Fig. 1):
1) **Approach** - includes the initial acceleration of the athlete up to the touchdown of the take-off foot (30);
2) **Take-off** - is defined as the time where the take-off foot is in contact with the ground (35);
3) **Swing up** - defined by the time interval between the end of the take-off and the moment athlete’s centre of mass (COM) reaches its highest point (41,42);
4) **Throwing** - starts from the maximum height of players COM and ends at the separation of the ball from his hand;
5) **Landing** - beginning at the time of ball separation and continuing until the feet contact with the support (ground).
**Approach**

In the run-up phase the athlete must generate an optimum amount of kinetic energy, i.e. a high horizontal velocity, which will later be transformed into vertical during the jump itself. The run-up usually consists of two or three steps necessary to reach a certain amount of movement and to achieve optimal (maximum) height during the flight phase.

In our particular case the horizontal velocity of the experienced test person increased from 2.91±0.12 m/s to 4.18±0.15 m/s, reached before the take-off foot contacts the ground (Fig. 2).
Typical for this phase internal structure is that the length of strides is different (Table 1) and last step is usually lengthened – this is meant to prepare the change of movement.

<table>
<thead>
<tr>
<th>1-t stride [cm]</th>
<th>2-d stride [cm]</th>
<th>3-rd stride [cm]</th>
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<tbody>
<tr>
<td>121.1±6.3</td>
<td>163.4±7.6</td>
<td>238.6±4.1</td>
</tr>
</tbody>
</table>

Also, in the middle of the 3rd stride, for the athlete's COM height there is a local minimum registered (Fig. 3), which provides a smooth transition to the vertical movement during the take-off phase and minimisation of the impeding components of the supporting reaction. The results obtained show that the vertical velocity of the athlete’s COM reduced to -0.79±0.09 m/s, while the height of COM is lowered from 97.7±2.4 cm to 81.7±1.6 cm (Fig. 3). Then the velocity increased again to 2.15±0.07 m/s before take-off and the athlete’s COM height is 90.1±1.9 cm.

![Fig.3. Vertical movement (shift) of the athlete’s centre of mass](image)

**Take-off**

During this phase, the athlete must generate enough vertical momentum while limiting the loss of horizontal velocity and at the same time to bring the segments of his/her body in proper posture for energy transfer to the ball.

The take-off begins at the end of the third step at the time of contact of the jumping leg’s foot with support. A typical feature is that the foot is placed at an angle of 20±5 degree internal rotation, which provides an additional angle for the shooting acceleration, and the shoulder opposite to the throwing arm is leading.

Figure 2 illustrates very well that the horizontal velocity of the athlete’s COM has decreased from 4.18±0.1m/s to 3.51±0.1m/s, measured at the end of the take-off, which represents only 16% loss and is an excellent testimonial for the brilliant technique performed by this particular player at the end of previous and during this phase. Simultaneously, the vertical momentum created accelerates athlete’s COM to 2.25±0.08m/s in the vertical direction (Fig. 2). The duration of the take-off is 0.26±0.02s. About this time athletes COM raises to 131 cm, measured at the moment before the take-off foot separates from the support.

The results obtained for the knee joint angle (β) and "foot-shank" angle (γ) are given in Table 2. These angles behaviour determines the trajectory of the athlete’s COM, the transition of movement from horizontal to the vertical direction and the extent of kinetic energy loss. The data illustrates the smooth process of absorption and rise, the minimum for both angles being at 46% of the phase duration.
During take-off the athlete prepares his posture for shooting, such as twisting the torso and expanding the kinematic chain of throwing arm back and up over the shoulder. The take-off is also forced by means of swing leg knee joint flexion and an internal rotation of the hip. This combination displaces athlete’s COM up and later plays an important role in strengthening and stabilising the lower body against rotation - a necessary condition for a powerful throw. The free hand is folded in the elbow joint to the body, thereby reducing the moment of inertia about the longitudinal axis of rotation.

**Swing up**

Since the body flight phase (if we neglect air resistance) is defined as a parabolic movement, it is determined by horizontal and vertical velocity of the athlete’s COM at the end of the take-off.

During this phase the test person’s COM rises from 131±2.8 cm to 175±3.3 cm (Fig. 3) at the top of the trajectory. In addition, before the shooting, the athlete’s COM moves forward by 80±3.6cm. The duration of the swing up phase so far is 0.25±0.005s.

In the beginning of this phase an acceleration and guidance of the ball starts by twisting whip shaped torso and throwing arm rotation, stabilised by the opposite torque resulting from the swinging leg’s knee extension. The obtained results confirm the nature of the movement, as 0.16s after the phase start the elbow joint horizontal velocity gets ahead of the hand (8.58m/s; 6.28m/s) with more than 2m/s.

**Throwing**

Throwing the ball starts from the highest jump point, which in this study is 175±3.3cm for the athlete’s COM.

Figure 4 shows the joint centres’ and hand’s linear velocities. It illustrates the kinematic chain operation, based on energy transfer from proximal to distal end, which is a necessary condition for efficient energy transfer to the ball. The velocities’ peak values are consecutive over time, thus providing whip shaped movement.

<table>
<thead>
<tr>
<th>Frames</th>
<th>29</th>
<th>30</th>
<th>31</th>
<th>32</th>
<th>33</th>
<th>34</th>
<th>35</th>
<th>36</th>
</tr>
</thead>
<tbody>
<tr>
<td>β [degree]</td>
<td>142±2</td>
<td>149±1</td>
<td>130±2</td>
<td>127±1</td>
<td>139±1</td>
<td>153±11</td>
<td>178±2</td>
<td>170±3</td>
</tr>
<tr>
<td>γ [degree]</td>
<td>89±3</td>
<td>106±1</td>
<td>94±3</td>
<td>81±5</td>
<td>88±1</td>
<td>95±1</td>
<td>122±8</td>
<td>125±1</td>
</tr>
</tbody>
</table>
Table 3 and Figure 5 show the results for the maximum linear velocities of the same points and the time they have been reached since the swing up beginning.

Table 3: Parameters of the throwing kinematic chain points

<table>
<thead>
<tr>
<th>Points</th>
<th>Max. linear velocity [m/s]</th>
<th>Time * [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip</td>
<td>3.97±0.13</td>
<td>90±5</td>
</tr>
<tr>
<td>Shoulder</td>
<td>6.05±0.19</td>
<td>130±10</td>
</tr>
<tr>
<td>Elbow</td>
<td>11.29±0.27</td>
<td>190±7</td>
</tr>
<tr>
<td>Wrist</td>
<td>14.84±0.35</td>
<td>250±5</td>
</tr>
<tr>
<td>Hand</td>
<td>17.66±0.33</td>
<td>250±5</td>
</tr>
</tbody>
</table>

*Interval to peak velocity from swing up beginning

The results show a smooth distribution of force effort both in amplitude and time. The time interval of the peak rate to the time of the ball separation from the hand is 0.16±0.01s for the hip, for the shoulder it is 0.12±0.008s, for the elbow joint it is 0.06±0.005s, while for wrist and hand they are reached in same time. This simultaneity of the last two points is due to the hand’s flexion movement, which also further accelerates the ball letting it leave the hand at a speed of 27.05±0.21m/s from a height of 278.4±5cm.
The final hand acceleration reaches a maximum value 0.06±0.005s before the release of the ball (figure 6).

Fig.6. Throwing kinematic chain points acceleration in the horizontal direction

**Landing**

Once the ball is away, throwing hand continues to move forward and down and body prepares for landing. The jumping foot toes contact with the support first, followed by actions to absorb of impact with the ground and keep the balance.

**CONCLUSIONS AND RECOMMENDATIONS**

Based on the analysed performance of a jump shot with run-out, as performed by one of the best Bulgarian handball players, some of the main kinematic characteristics were defined. The phase structure parameters and internal phase characteristics of the run-up and take-off were analysed (the transformation of quantity of horizontal to vertical movement), as well as the unsupported phase height and length plus the implementation of throwing motion.

The analysis leads to the following most important conclusions:

1. The transition from run-up to take-off should be as smooth as possible, and the vertical velocity of the athlete’s COM must be positive at the moment the foot touches the support, i.e. the local minimum of COM height should preceded this moment and COM must have already started to move up.
2. The swinging leg knee flexion should be completed no later than the take-off end (while the body still has a supporting reaction) to create additional vertical momentum and be ready for extension early next phase.
3. The swinging leg extension’s angular velocity during the swing up phase must be synchronous with the throwing kinematic chain force effort of rotation to ensure maximum stability of the distal end of the chain.

Keeping in mind the objective results of this study, the following recommendations for the training process could be extremely effective:

1. The last step during the approach phase should be longer and the sole can be placed at an internal angle of about 20 degrees to the direction of run-up.
2. Take-off takes place at an angle at the supporting leg knee of approximately 130 degrees. This allows us to shape weight exercises predominantly within this range while training in the competitive period and the second half of the preparatory one.
3. The swinging leg active work should be improved by developing the power of hip-belts muscles.
4. Focus on the arm’s external rotation in the throwing drills, too.

REFERENCES

3. Yotov I., Comparative analysis of shots at the door of the Bulgarian national handball team - men in tournaments “Serdika”, Collection of scientific works, book 4, 1985