INFLUENCE OF KINEMATIC PARAMETERS ON BALL VELOCITY OF THE HANDBALL PENALTY THROW

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ABSTRACT
The aim of this study was to investigate the influence of some kinematics parameters (upper extremity, trunk position) on ball velocity of the handball penalty throw. Thirty female elite handball players (height: 1.73 ± 0.08 m; mass: 69 ± 8.9 kg; BMI 22.9 ± 2; training experience: 12.3 ± 6.2 yrs), playing in the first Serbian Handball League from two different clubs volunteered to participate in the present study. The research was of transversal character, during the competition period. An angle of upper body relative to the ground (deg); Shoulder internal rotation (deg); Elbow flexion (deg), that is, the angle closing the longitudinal axis of the upper arm with the longitudinal axis of the forearm was analyzed by Kinovea 0.8.2 kinematic analysis software. Pearson linear correlations were used to calculate the influence of kinematic parameters to throwing ball velocity. A strong negative correlation was calculated between the angle of upper body relative to the ground with the throwing ball velocity (r=‐0.496) whereby the big angles relative to the ground was followed by the reduction throwing ball velocity. It has been proven existence of the mean negative correlation between variables shoulder internal rotation and the throwing ball velocity (r=‐0.299). Between variables the elbow flexion and the throwing ball velocity there was mean positive correlation (r=0.402), which means that by increasing the angle of elbow flexion increases ball velocity. It can be concluded that the tested kinematic parameters have an influence on the throwing ball velocity in performing a penalty throw in team handball.

Keywords: team handball, throwing velocity, ball velocity, kinematics, penalty throw

INTRODUCTION
Competitive success in team handball depends of the numerous factors such as the anthropometric characteristics, the technical skills and tactics and highs levels of power, force and throwing velocity (Hoff, & Almåsbakk, 1995). In competition, 6-9% during the game constitute penalty throw (Wagner & Müller, 2008). The aim of the offensive handball players is to throw a ball on goal from a position from 7 m distance without being tackled or obstructed by the opposing goalkeeper. An important fact is that the faster the ball is thrown at the goal, the less time defenders and goalkeeper have to save the shot what is important aspect for success (Marković, S., & Marković, K, 2018).

The overarm throw is an example of a complex, discrete and fast movement with a clear beginning and end. It can be divided into six phases: wind-up, stride, arm cocking, arm acceleration, arm deceleration, and follow-through (Werner, Fleisig, Dillman, & Andrews, 1993; Van den Tillaar & Ettema, 2007). Maximal internal rotation, maximal elbow flexion and ball release speed are some of characteristic points, which identify the phases of overarm throw. Van den Tillaar & Ettema, 2004 used a model that predicted that 73% of the contribution to the ball velocity was explained by the maximal elbow extension velocity and the maximal internal rotation velocity shoulder during the throw.

The velocity of handball throw is dependent on the aspects such as body segments coordination and the technical skills not only on the on the muscular strength (Marković, S., & Marković, K, 2018). Some authors described differences in ball velocity of elite team-handball players revealing that greatest ball velocity was achieved in the standing throw with run-up (26.3 ± 3.2 m·s⁻¹) rather than the standing throw without run-up (23.5 ± 2.2 m·s⁻¹) (Bayios & Boudolos, 1998). This fact indicates that the throwing ball velocity depends on the technique performance, the way the feet, body and arm are positioned. It is not determined how much all throwing kinematics parameters separately have an
influence on throwing ball velocity, which is an extremely difficult research task since the shot is a complex kinetic chain whose parts are almost impossible to isolate and decompose individually.

The aim of this study was to investigate the influence of some kinematics parameters (upper extremity, trunk position) on ball velocity of the handball penalty throw.

METHODS

Subjects

Thirty female elite handball players (height: 1.73 ± 0.08 m; mass: 69 ± 8.9 kg; BMI 22.9 ± 2; training experience: 12.3 ± 6.2 yrs), playing in the first Serbian Handball League from two different clubs volunteered to participate in the present study. All participants had a certificate from the physician that they were healthy and able to fulfill the requirements that were expected of them, at the time of testing.

Procedure

The research was of transversal character, during the competition period. The testing procedure was standardized (Van den Tillar & Ettema, 2007). The subjects had a warm-up period of 30 min, which needed to be prepared for the optimal organism condition, to have the best respond to the tasks. Each subject performed a shot 3 times from the ground at a distance of 7 m from the goal. A Casio Exillim F1 camera was placed on the side of the throwing arm, recording all three attempts. The task was to hit the target as strong as possible, that is, the upper half of the standard size handball goal (2 m x 3 m). Behind the goal was an interrogator who measured the speed of each shot by radar (Pocket Radar). When the testing was completed, the shot that had the highest velocity of all three attempts was analyzed by Kinovea 0.8.2 kinematic analysis software. For the throwing kinematics parameters were tested three variables: An angle of upper body relative to the ground (deg); Shoulder internal rotation (deg) and Elbow flexion (deg), that is, the angle closing the longitudinal axis of the upper arm. The point describing the center of this angle is the region of the lateral epicondylus (lat. epicondylus lateralis).

Maximal throwing ball velocity was also one of the analyzed variables. The phase of ball throwing was analyzed, that is, the moment when the ball leaves the hand of the subject.

Statistical analysis

Statistical analysis was conducted via IBM SPSS Statistics 19 (Statistical Package for Social Sciences, v19.0, SPSS Inc., Chicago, IL, USA) software. To provide basic summaries about the sample and tested variables descriptive statistics was used: average value (MEAN), standard deviation (SD), coefficient of variation (cV%), Minimum (MIN) and Maximum (MAX). Pearson linear correlations were used to calculate the influence of kinematic parameters to ball velocity.

RESULTS

Table 1 shows the basic statistical parameters for kinematic variables and ball velocity.

<table>
<thead>
<tr>
<th>Variables</th>
<th>N</th>
<th>MEAN</th>
<th>MIN</th>
<th>MAX</th>
<th>Std. Deviation</th>
<th>Coefficient of variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>An angle of upper body</td>
<td>30</td>
<td>69.17</td>
<td>50.00</td>
<td>83.00</td>
<td>7.38</td>
<td>54.49</td>
</tr>
<tr>
<td>Shoulder internal rotation</td>
<td>30</td>
<td>49.53</td>
<td>5.00</td>
<td>98.00</td>
<td>17.54</td>
<td>307.64</td>
</tr>
<tr>
<td>Elbow flexion</td>
<td>30</td>
<td>130.37</td>
<td>91.00</td>
<td>168.00</td>
<td>16.23</td>
<td>263.34</td>
</tr>
<tr>
<td>Ball velocity</td>
<td>30</td>
<td>75.87</td>
<td>61.00</td>
<td>93.00</td>
<td>9.29</td>
<td>86.26</td>
</tr>
</tbody>
</table>

Descriptive values of kinematic variables (angles) are shown in degrees (°), while ball velocity values are expressed in km/h. Average value of the angle of upper body relative to the ground was 69.17±7.38, average value of the angle of shoulder internal rotation was 49.53±17.54, average value of the angle of elbow flexion was 130.37±16.23 and average value of ball velocity was 75.87±9.29. Minimal value of ball velocity variable was 61 and maximal was 93.
Relationship between tested kinematic parameters of penalty throw and the ball velocity was express by Pearson linear correlation. Satisfaction with the assumptions of normality, linearity and homogeneity of variance was confirmed by preliminary analyzes. A strong negative correlation was calculated between the angle of upper body relative to the ground with the throwing ball velocity ($r=0.496$) whereby the big angles relative to the ground was followed by the reduction throwing ball velocity. It has been proven existence of the average negative correlation between variables shoulder internal rotation and the throwing ball velocity ($r=-0.299$). Between variables the elbow flexion and the throwing ball velocity there was average positive correlation ($r=0.402$), which means that by increasing the angle of elbow flexion increases ball velocity.

**DISCUSSION**

Earlier research has found that the highest velocity of the ball is achieved by shot from the ground from the run-up (100%), then from the ground without run-up (93%) and jump shot (92%) (Wagner, Pfusterschmied, Von Duvillard & Müller, 2011). This study examined the correlation between the selected kinematic parameters to the throwing ball velocity. Kinematic parameters described the angles in the elbow and shoulder joint and the angle of the upper body relative to the ground at the ball release time. According to Van den Tillaar & Ettema, 2007 it is considered that two main contributors to the total ball velocity (73%) are the internal rotation of the shoulder together with the extension of the elbow. They found that those subjects who had a smaller angle at the elbow joint at the time of the ball release had achieved higher ball velocity (angle that engages the outside of the forearm with an imaginary axis that is an extension of the upper arm). Our results indicate that subjects who achieved higher ball velocity also had a greater angle at the elbow joint (the angle closing the longitudinal axis of the upper arm with the longitudinal axis of the forearm). Such data confirm the fact that greater acceleration can be achieved if there is greater leverage. Both studies show a significant correlation of extension range with shot efficiency even though the tested sample was of different sex. The highest ranked handball players who competed in the national competition, some of whom were also representative, took part in this research. The angle of the shoulder internal rotation achieved by the handball players was 49.53 $\pm$ 17.54 $^\circ$, while for the handball players in the study of Van den Tillaar & Ettema, 2007 it was about 65 $^\circ$ and subjects who had a faster shot also had a greater angular velocity of shoulder internal rotation. We did not prove that these results were consistent with this study, but we found that by increasing the angle of shoulder internal rotation, the throwing ball velocity decreases and vice versa.

According to some studies about kinematics parameters of shot from the ground 7 m distance from the goal it is proved that elite female handball players had the angle of upper body relative to the ground 65.8$\pm$7.9$^\circ$. Such data can be considered as s model considering that the subjects were the female handball players of the Norwegian national selection (Van den Tillaar & Cabri, 2012). Average value of the angle of upper body relative to the ground was 69.17$\pm$7.38 what was a little difference which may be justified by different body structure. Considering that the results do not differ significantly, it can be concluded that there is a great similarity in the technique of taking a shot from the ground 7 meters distance from the goal in top handball players regardless of nationality. Statistical processing has found that the big angles relative to the ground was followed by the reduction throwing ball velocity. This can be explained by the fact that the standing throw involves keeping the lead foot on the floor during the throw and is typical for the penalty throw in team handball (Wagner, Pfusterschmied, Von Duvillard & Müller, 2011). The fact is that the throwing ball velocity also depends on the muscular strength of the abdominal musculature when it comes to this segment of the body, so the results can be explained if the subject flexes the body more during the shot, giving a stronger impulse, the faster the ball throw.

**CONCLUSION**

Based on the obtained results, it can be concluded that the kinematic parameters at the moment of ball

### Table 2 Pearson linear correlation coefficients, P-values between kinematic parameters and ball velocity and coefficient of determination (the percentage of variance)

<table>
<thead>
<tr>
<th>Variables</th>
<th>N</th>
<th>Ball velocity</th>
<th>p</th>
<th>%Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>An angle of upper body</td>
<td>30</td>
<td>-0.496*</td>
<td>0.005</td>
<td>25</td>
</tr>
<tr>
<td>Shoulder internal rotation</td>
<td>30</td>
<td>-0.299</td>
<td>0.109</td>
<td>5</td>
</tr>
<tr>
<td>Elbow flexion</td>
<td>30</td>
<td>0.402*</td>
<td>0.028</td>
<td>16</td>
</tr>
</tbody>
</table>

*"p<0.01 (2-tailed).
release (the moment when the ball left the hand of the subject) have an influence on the throwing ball velocity, at a shot 7 m distance from the goal. This data indicates that coaches should pay attention to the method of taking a shot from 7 meters, in the training cycle, as it is often a crucial factor for winning games. Each team should have its own statistician who will keep an eye on the number of missed and scored penalties in the match so that the records can contribute to the improvement in the realization of the same and, consequently, to the reduction of the number of errors. Higher throwing ball velocity in the top handball players of this research is conditioned by decrease of the upper body angle in relation to the ground, decrease of the angle of shoulder internal rotation and increase of the range of extension in the elbow joint. If the lever of the throwing arm is higher and a stronger force is created that will cause increased flexion in the hip joint (reduced upper body angles relative to the ground), the throwing ball velocity will be higher.

The information obtained can be useful for coaches in planning training programs, especially in the period when new handball players are created. Future research in the field of kinematic analysis of handball throwing should be based on current knowledge. A suggestion for further research is to examine whether the longitudinal dimensionality of certain parts of the hand (arm length, forearm, or upper arm) and the whole arm affect the velocity of ball release. It is also advisable to carry out similar research with the male population of elite handball players.

REFERENCES
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