A Comparison of Kinematics Between Overarm Throwing With 20% Underweight, Regular, and 20% Overweight Balls

Roland van den Tillaar and Gertjan Ettema

The aim of this study was to compare the kinematics in throwing with a regular weighted handball with 20% lighter and heavier balls in female experienced handball players. In total, eight joint movements during the throw were analyzed. The analysis consisted of maximal angles, angles at ball release, and maximal angular velocities of the joint movements and their timings during the throw. Results on 24 experienced female team handball players (mean age 18.2 ± 2.1 years) showed that the difference in ball weight affected the maximal ball velocity. The difference in ball release velocity was probably a result of the significant differences in kinematics of the major contributors to overarm throwing: elbow extension and internal rotation of the shoulder. These were altered when changing the ball weight, which resulted in differences in ball release velocity.

Keywords: ball velocity, team handball, coordination

In sports like baseball, javelin, water polo, and handball, overarm throwing velocity is an important factor for performance. To improve the throwing velocity, various training methods based upon the principles of overload, either by strength or speed of the exercise, are used (van den Tillaar, 2004; Ettema et al., 2008). Training with overweight or underweight implements in throwing can be seen as speed-strength-specific training programs, in which throwing with underweight implements you train the arm with faster speeds whereas with overweight implements you will train the arm with higher loads. These speed-strength-specific training programs were much used in the former Soviet Union and in European countries (Escamilla et al., 2000). Athletes from these countries have been training with overweight and underweight implements for several decades. Vasiliev (1983) and Jarver (1973) found that resistance variations in specific throwing training should range between 5 and 20% of normal resistance. These studies were based upon training in javelin, shot put, and discus throwing. Later studies in handball (Edwards van Muijen et al., 1991; van den Tillaar et al., 2002), and baseball (DeRenne et al., 1985, 1990, 1994; DeRenne & House, 1993; Escamilla et al., 2000; Fleisig et al., 2006) showed that training with 20% over- and underweighted implements could positively influence throwing velocity. All the experiments focused on the performance increase after training with different ball weights. However, none of the studies reported the kinematics during throwing with these different balls. To understand what happens with the different joints when throwing with different ball weights, it is of importance to measure the kinematics during throwing with these different ball weights.

Several studies have already investigated the kinematics of overarm throwing in handball (Fradet et al., 2004; van den Tillaar and Ettema, 2004, 2007, 2009). Fradet et al. (2004) and van den Tillaar and Ettema (2009) showed that in overarm throwing only a temporal proximal-to-distal sequence was exhibited for the initiation of the joint movements and no such sequence was found for the maximal velocity of the joints and distal end points of segments. Furthermore, van den Tillaar et al. (2004, 2007) found that the internal rotation of the shoulder and the elbow extension were the main contributors for the maximal ball velocity at release. The better throwers throw with a higher internal rotation of the shoulder and elbow extension than the poorer throwers. Van den Tillaar and Ettema (2004) also found that varying throwing weights (from 0.2 to 0.8 kg) influences the maximal velocity of internal rotation, elbow extension, and the ball velocity. However, in specific strength training for throwing, these weights are not used, but only weights that differ in small amounts from the regular weight, that is, between 0.288 and 0.5 kg (van den Tillaar, 2004). It is not known if these small weight changes around the regularly used throwing weight also can influence the kinematics of the throw.

Therefore the aim of this study was to investigate if any difference of throwing with 20% heavier, lighter
weights, and regular ball weights on the kinematics and performance in overarm throwing is detectable. In such cases, we hypothesized that the effects are in accordance with findings as found with larger weight differences. Information about the kinematics of the throws with the different small ball weight changes could give us more knowledge about what is trained differently when throwing with these different ball weights.

**Methods**

Twenty-four female handball players volunteered for this study. The subjects were experienced handball players playing in the second and third highest divisions of the Norwegian national competition (age 18.2 ± 2.1 years, mass 68 ± 7 kg, height 1.69 ± 0.04 m, training experience 10.7 ± 1.9 years). Before participating, the players signed informed consent forms prepared in accordance with the recommendations of local ethical committee and current Norwegian law and regulation.

**Procedure**

The general procedure was similar to that presented in Tillaar and Ettema (2003, 2004, 2007, 2009). After a general warm-up of 15 min, which consisted of jogging and throwing drills to warm up the throwing arm, throwing performance was tested in a penalty throw situation, that is, an overarm throw toward a target 7 m away. The participants performed a standing throw, keeping the front foot on the ground at all times. They were instructed to throw in a random order with each ball weight (light ball, 0.288 kg; regular ball, 0.360 kg; heavy ball: 0.432 kg) as fast as possible and try to hit the target, aiming at a 0.5 × 0.5 m square target at a 1.65 m height located in the middle of a handball goal (2 × 3 m). Once three successful attempts were captured for each ball weight, testing was completed. The average of these three hits was used for further analysis. The subjects were not informed about the total amount of throws that they had to throw. This was done to preserve them for not trying to throw as fast as possible but only aiming for the target. Between each throw, approximately 1 min of rest was allowed to avoid fatigue. Before testing, the participants were familiarized with throwing the different ball weights by a training session before the test session.

**Measurements**

Velocity of the different joints was measured using a 3-D motion capture system (Qualysis, Sävedalen, Sweden) of five cameras (240 Hz) that measured the position of the reflective markers (2.6 cm in diameter) on the following anatomical landmarks: (a) hip: trochanter major on both sides, (b) shoulder: lateral tip of the acromion on both sides, (c) elbow: lateral epicondyle of the throwing arm, (d) wrist: styloid process of the ulna and radius of the throwing arm, and (e) ball: on top of the ball. Computation of velocity of the different joints and the ball was done using a five-point differential filter in Matlab 6.1. The angles and angular movement of the joints were derived from relative positions between the different markers. For example, external and internal rotations of the shoulder were derived from positions of shoulder, elbow, and wrist markers; the orthogonal coordinate system was first translated to center the system in the shoulder (origin); subsequently, it was rotated to align the shoulder-elbow line with the x-axis; the shoulder rotation angle was calculated as the angle between the shoulder-elbow-wrist plane and the horizontal plane. The angular displacements and velocities of the joints were calculated with the same methods as published by Feltner and Dapena (1989) and van den Tillaar and Ettema (2007).

The angle at ball release, the maximal angle, and angular velocity and the timing of maximal joint angle and joint velocity in the following movements were calculated: elbow extension/flexion, external/internal rotation shoulder, shoulder extension/flexion, shoulder ad-/abduction, trunk tilt, trunk tilt sideways, upper-torso rotation, and pelvis rotation (Figure 1). Timing was measured as time before ball release.

**Statistical Analysis**

To assess differences of the parameters of the joint movements as a result of the three ball weights, a one-way ANOVA for repeated measures was used. A post hoc test using Bonferroni probability adjustments was used to locate significant differences. A significance level of 0.05 was used to identify differences.

**Results**

A significant difference in throwing velocity was observed between the three different ball weights (Table 1). Tables 1 and 2 show the angles at ball release, maximal angles, and velocities and their timings of the different joint movements during the throws with different ball masses.

Both the maximal internal rotation velocity of the shoulder ($p = .013$; effect size = .44) and maximal elbow extension velocity ($p = .003$; effect size = .65) changed significantly when throwing with the different ball weights (Table 1). Post hoc comparison showed that the maximal velocity of the elbow extension and internal rotation of the shoulder decreased significantly when throwing with the heavier ball, when compared with the throws with the other balls. Also, the timing of the maximal elbow extension velocity changed significantly ($p = .003$; effect size = .26) when throwing with the different balls (Table 1). No other significant differences in the other maximal joint movement velocities and their timings were found (Table 1).

At ball release, the external rotation angle of the shoulder ($p = .008$; effect size = .37) and trunk tilt sideways angle ($p = .013$; effect size = .33) were significantly different between the ball weights. Post hoc comparison revealed that the external rotation angle was smaller when...
Figure 1 — Definition of the kinematic parameters: (a) shoulder extension/flexion, (b) external/internal rotation shoulder, (c) shoulder ad-/abduction, (d) upper-torso rotation and pelvis rotation, (e) elbow extension/flexion, (f) trunk tilt, and (g) trunk tilt sideways. Adapted from van den Tillaar and Ettema (2007), “Three-dimensional analysis of overarm throwing in experienced handball players,” Journal of Applied Biomechanics 23, 12–19.

Table 1 Maximal velocities (mean ± SD) and their timings during the throws with the light ball (0.288 kg), regular ball (0.36 kg), and the heavy ball (0.432 kg)

<table>
<thead>
<tr>
<th>Maximal Velocity (rad s⁻¹)</th>
<th>Timing Max Velocity (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Light ball</td>
</tr>
<tr>
<td>Ball velocity (m·s⁻¹)</td>
<td>19.3 ± 0.7</td>
</tr>
<tr>
<td>Elbow extension</td>
<td>21.9 ± 2.5</td>
</tr>
<tr>
<td>Shoulder flexion</td>
<td>4.4 ± 1.3</td>
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<tr>
<td>Internal rotation</td>
<td>44.4 ± 6.8</td>
</tr>
<tr>
<td>Shoulder abduction</td>
<td>6.0 ± 1.2</td>
</tr>
<tr>
<td>Trunk tilt forward</td>
<td>7.1 ± 0.4</td>
</tr>
<tr>
<td>Trunk tilt sideways</td>
<td>5.5 ± 0.5</td>
</tr>
<tr>
<td>Upper-torso rotation</td>
<td>18.5 ± 1.4</td>
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<tr>
<td>Pelvis rotation</td>
<td>9.7 ± 0.9</td>
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</table>

Note. Significance level of \( p < 0.05 \).

*Significant difference between all balls.
†Significant difference between heavy and other balls.
Table 2  Angles at ball release and the maximal angles and their timings (mean ± SD) during throws with the light ball (0.288 kg), regular ball (0.36 kg), and heavy ball (0.432 kg)

<table>
<thead>
<tr>
<th>Angle at Ball Release (°)</th>
<th>Angle at Ball Release (°)</th>
<th>Maximal Angle (°)</th>
<th>Maximal Angle (°)</th>
<th>Maximal Angle (°)</th>
<th>Timing Max Angle (s)</th>
<th>Timing Max Angle (s)</th>
<th>Timing Max Angle (s)</th>
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<tr>
<td></td>
<td>Light ball</td>
<td>Regular ball</td>
<td>Heavy ball</td>
<td>Light ball</td>
<td>Regular ball</td>
<td>Heavy ball</td>
<td>Light ball</td>
</tr>
<tr>
<td>Elbow flexion</td>
<td>67.5 ± 5.5</td>
<td>66.7 ± 4.3</td>
<td>67.6 ± 4.1</td>
<td>107.9 ± 5.5</td>
<td>107.4 ± 4.4</td>
<td>107.1 ± 3.9</td>
<td>–0.061 ± 0.010</td>
</tr>
<tr>
<td>Shoulder flexion</td>
<td>4.6 ± 2.8</td>
<td>5.9 ± 2.7</td>
<td>5.8 ± 2.7</td>
<td>–10.7 ± 2.7</td>
<td>–10.8 ± 2.9</td>
<td>–10.9 ± 3.6</td>
<td>–0.324 ± 0.002</td>
</tr>
<tr>
<td>Shoulder external rotation</td>
<td>99.6 ± 8.1</td>
<td>95.1 ± 8.5*</td>
<td>100.4 ± 8.8</td>
<td>139 ± 4.7</td>
<td>142 ± 6.2</td>
<td>143 ± 4.5</td>
<td>–0.085 ± 0.017*</td>
</tr>
<tr>
<td>Shoulder abduction</td>
<td>77.1 ± 2.8</td>
<td>76.2 ± 4.4</td>
<td>75.0 ± 4.8</td>
<td>84.2 ± 2.7</td>
<td>83.0 ± 3.1</td>
<td>83.6 ± 2.2</td>
<td>–0.015 ± 0.004</td>
</tr>
<tr>
<td>Trunk tilt forward</td>
<td>61.1 ± 2.8</td>
<td>61.1 ± 2.5</td>
<td>60.5 ± 3.6</td>
<td>87.3 ± 2.9</td>
<td>87.6 ± 3.2</td>
<td>87.6 ± 3.7</td>
<td>–0.377 ± 0.053</td>
</tr>
<tr>
<td>Trunk tilt sideways</td>
<td>62.1 ± 3.0*</td>
<td>61.1 ± 2.1</td>
<td>60.6 ± 2.5</td>
<td>87.0 ± 3.2</td>
<td>86.7 ± 3.3</td>
<td>87.0 ± 2.7</td>
<td>–0.365 ± 0.121</td>
</tr>
<tr>
<td>Upper-torso rotation</td>
<td>51.9 ± 3.7</td>
<td>50.6 ± 4.0</td>
<td>49.8 ± 4.0</td>
<td>190.0 ± 4.6</td>
<td>189.6 ± 3.4</td>
<td>190.1 ± 3.6</td>
<td>–0.281 ± 0.052</td>
</tr>
<tr>
<td>Pelvis rotation</td>
<td>72.6 ± 3.6</td>
<td>71.6 ± 4.1</td>
<td>73.7 ± 4.4</td>
<td>160.7 ± 4.3</td>
<td>159.8 ± 4.9</td>
<td>161.1 ± 4.3</td>
<td>–0.422 ± 0.120</td>
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</tbody>
</table>

Note. Significance level of $p < 0.05$.

*Significant difference with the other balls.
throwing with the regular ball and that the trunk tilt side-ways angle was higher when throwing with the light ball when comparing to the other balls. A significant difference in timing of the maximal external rotation angle of the shoulder was found \( p = .021 \) (effect size = .30); that is, the maximal external rotation of the shoulder occurred closer to ball release when throwing with the light ball compared with the other balls (Table 2).

No other significant differences for the maximal angles, angles at ball release, and their timings during the throws with the different balls were found (Table 2).

**Discussion**

The objective of this study was to investigate the difference of throwing with slightly heavier and lighter than regular balls on the kinematics and performance in overarm throwing. With a 20% difference in weight, differences in ball release velocity and the maximal velocity of the major contributors (elbow extension and internal rotation of the shoulder) were found.

The ball release velocities with the regular ball were in the same range (17–19 m/s) as those found in earlier studies on experienced female handball players studies (Jöris et al., 1985; Edwards van Muijen et al., 1991; Hoff & Almåsbakk, 1995).

Several studies have examined the effect of throwing training with these weight differences (DeRenne et al., 1985, 1990, 1994; Jöris et al., 1985). However, none of the studies reported the throwing velocities for the different ball weights during training. Our results indicate that 20% differences in ball weight result in differences in maximal ball velocity of 4.3% compared with the throws with the regular weighted ball.

The difference in ball release velocity is mainly the result of the differences in maximal elbow extension velocity and internal rotation of the shoulder. These two joint movements were the only ones that changed with the different weights. Van den Tillaar and Ettema (2004) found that these two joint movements were the main contributors for the development of the total ball release velocity. They also indicated that by extreme ball weight changes these two parameters also changed. Our study showed that this is also the case when changing the weight with small amounts. In other words, throwing kinematics is highly sensitive for ball weight changes. The importance of the internal rotation of the shoulder and the elbow extension was also shown by the difference in timing of the maximal elbow extension velocity (Table 1) and external rotation angle of the shoulder and the angle at ball release of the internal rotation of the shoulder (Table 2). The changes in these parameters can contribute in altering the ball release velocity.

No significant differences were found for maximal velocities of the elbow extension and internal rotation of the shoulder between the throws with the light ball and the regular ball. However, the difference in maximal velocities of the elbow extension showed the same clear trend between light and regular ball \( p = .05 \) as between regular and heavy ball. It indicates that a relatively small change in weight noticeably affects the movement velocities of the main contributors in overarm throwing in handball, namely, elbow extension and internal rotation of the shoulder.

The size and form of the balls were the same in our study, and the subjects did not receive any information about with which ball they had to throw. However, the subjects could sometimes feel the difference between the balls and thereby adapt their kinematics perhaps explicitly, which is a limitation of our study.

Thus, throwing with small weight differences in overarm throwing in female experienced handball players can influence the kinematics of the throw in training, which may have implications for the training results.

**References**


