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EFFECT OF TRAINING ON BALL RELEASE VELOCITY AND KINEMATICS IN OVERARM THROWING AMONG EXPERIENCED FEMALE HANDBALL PLAYERS

UČINEK VADBE NA IZMETNO HITROST ŽOGE IN KINEMATIKO META ŽOGE NAD GLAVO PRI IZKUŠENIH ROKOMETAŠICAH

ABSTRACT

The aim of this study was to compare the effect of different training programmes upon the kinematics and ball release velocity in overarm throwing among experienced female team handball players. No significant change in ball release velocity (p=0.25) was found after the different training programmes. However, the changes that did occur in ball release velocity were probably caused by changes in the maximal internal shoulder rotation after the training period, as indicated by the positive correlation. More studies that examine the kinematics in overarm throwing before and after a training period must be performed to investigate the statement that maximal internal shoulder rotation velocity is the main parameter responsible for the changes in ball release velocity after training.

Key words: performance, co-ordination, 3D analysis

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IZVLEČEK

Cilj raziskave je bil primerjati učinke različnih vadbenih programov na kinematiko in izmetno hitrost žoge pri metu nad glavo pri izkušenih ekipnih rokometašicah. Po zaključku različnih vadbenih programov nismo ugotovili značilnih sprememb v izmetni hitrosti žoge (p=0,25). Vendar pa so bile spremembe, opažene v izmetni hitrosti žoge, verjetno posledica sprememb v maksimalni interni rotaciji rame po obdobju vadbe, kot je pokazala pozitivna korelacija. Opraviti je treba več raziskav kinematike meta žoge nad glavo pred obdobjem vadbe in po njem, da se preveri izjava, da je hitrost maksimalne interne rotacije rame glavni parameter, ki je odgovoren za spremembe v izmetni hitrosti žoge po vadbi.

Ključne besede: uspešnost, koordinacija, 3D analiza

INTRODUCTION

Maximal velocity in overarm throwing is particularly important in many team sports such as baseball, cricket and team handball (Marques, van den Tillaar, Vescovi and González-Badillo, 2007). Several studies have examined the effect of different types of training to examine ball release velocity enhancement (see van den Tillaar 2004 for a review). In most of these studies, only ball release velocity was measured before and after a training period in order to verify the efficiency of the resistance training regimen (Marques & González-Badillo, 2006). Some studies have tried to explain the improvement of ball release velocity by testing participants in bench press or other strength tests to show increased strength in some muscle groups (Edwards van Muijen, Jöris, Kemper, & van Ingen Schenau, 1991, Hoff & Almåsbakk, 1995). Unfortunately, it is not known if and how these possible strength changes help to increase the throwing velocity. Where does the difference in throwing velocity come from, and is the increase in ball release velocity the result of strength of the distal joints or of the proximal joints or both? To better understand the possible changes caused by training programmes, kinematics should be measured to provide more information about the exact changes.

Many studies have examined the kinematics in overarm throwing in team handball (e.g. Fradet et al., 2004; van den Tilaar & Ettema, 2004; 2006; 2007; 2009a; 2009b; Wagner, Buckecker, von Duvillard, & Müller, 2010). Their main conclusions were that in overarm throwing only a temporal proximal-to-distal sequence is exhibited for the initiation of the joint movements and no such sequence is found for the maximal angular and linear velocity of the joints (Fradet et al., 2004; van den Tillaar & Ettema, 2009a). Further, the internal rotation of the shoulder and the elbow extension are the main contributors to the maximal ball release velocity (van den Tillaar & Ettema, 2004, 2007), i.e. better throwers perform with a higher internal rotation of the shoulder and elbow extension than poorer ones. Wagner, Buckecker, von Duvillard and Müller (2010) and Wagner, Pfusterschmied, von Duvillard and Müller (2011) showed that maximal pelvis and trunk rotation velocity and flexion correlated positively with ball release velocity, i.e. better throwers had a higher maximal pelvis and trunk rotation velocity. By varying throwing weights (from 0.2 to 0.8 kg), van den Tillaar and Ettema (2004) found that only the maximal velocity of the internal rotation, elbow extension and ball release velocity was influenced.

However, to the best of our knowledge no study prior to ours has examined differences in kinematics due to training. The knowledge gained about the kinematic changes could help trainers develop more detailed training programmes to help athletes to increase their throwing velocity. Therefore, the study's objective was to compare the kinematics before and after a training period in a so-called 7 m throwing situation involving experienced female handball players. It was hypothesised that the changes in ball release velocity were caused by changes in the kinematics of the major contributors: the internal shoulder rotation and the elbow extension.

METHOD

Participants

Twenty experienced female handball players volunteered for this study (mean age: 19.9 ± 2.1 years, mass: 67.3 ± 7.5 kg, height: 1.69 ± 0.03 m, training experience: 11 ± 1.5 years). The participants played in the first-fourth division of the national competition. Before participating in this study, each subject was fully informed about the protocol. Informed consent was obtained from all subjects prior to the testing, with the approval of the local ethics committee and in line with current ethical standards in sports and exercise research. All testing and training were performed during the competitive in-season (January–March).

Procedure

After a general warm-up of 15 minutes, the subjects performed a standing throw by holding their front foot on the floor during throwing, also called a 7 m throw. Pre- and post-tests were performed on maximal throwing velocity with weight-adjusted javelin balls (circumference 0.3m; regular handball weight 0.360kg). The instruction was to throw as fast as possible and try to hit the target, aiming at a 0.5 by 0.5 m square target at a height of 1.65 m located in the middle of a handball goal (2 x 3 metres) (according to van den Tillaar, 2003; van den Tillaar and Ettema, 2004; van den Tillaar and Ettema, 2007). Once three successful attempts were captured, the testing was completed. The average of these three attempts was taken for further analysis. The subjects were not informed about the total number of throws they had to make. Each participant had approximately 1 min rest between each attempt to avoid an effect of fatigue on their throwing velocity.

After completing the test, the subjects were matched in terms of their throwing velocity and allocated to the strength training (n=7), variable training (n=7) and control groups (n=6), respectively. The control group threw with a regular weighted ball (0.36 kg). The variable training group threw with over- (0.432 kg) and under-weight balls (0.288 kg), while the strength training group performed a throwing movement with a pulley device. All groups trained an assigned training programme alongside their normal team handball training practices three times per week over eight consecutive weeks. The training workload was calculated by the impulse generated per throwing attempt (Ettema, Gløsen, & van den Tillaar, 2008; van den Tillaar & Marques, 2009; 2010). Impulse ($\int Fdt$) is considered a highly relevant measure for resistance training as it measures the total amount of force produced during the throwing movement (Ettema, Gløsen, & van den Tillaar, 2008). In ball throwing, momentum of the ball at release (mv_{rel}), measured by a 3D motion capture system, was used to indicate impulse as the initial momentum was equal to zero ($\int Fdt = \Delta mv = mv_{rel}$). As the pulley device was equipped with a load cell the impulse could be obtained directly. An evaluation of the pre-test results for the strength exercises on the pulley device at 85% of 1 repetitive maximum (1-RM) and throwing with under-, regular and over-weight balls revealed the following comparison of workload: 28, 5, 6, and 7 Ns, respectively, in throwing with the pulley device at 85% of 1-RM and throwing with, over-, regular and under-weight balls. One training session for the strength-training group consisted of three series of six repetitions at 85% of 1-RM. To match the same workload (504 Ns), the control group performed 84 throws per session with regular balls, while each session the variable training group threw 36 times with overweight balls and 50 times with underweight balls. In all groups these training sessions were carried out in conjunction with their normal team handball practices and competitions. As the aim of this study was to compare the effects of specific throwing training with additional normal training on the kinematics of throwing, we did not include a non-training control group (Kristensen, Ettema, & van den Tillaar, 2006).

Instruments

The ball release velocity, linear and angular velocity of the different segments and joints were measured using a 3D motion capture system (Qualysis, Sävedalen, Sweden, six cameras, 240 Hz) that measured the position of the reflective markers (2.6 cm diameter) on the following anatomical landmarks: a) hip: trochanter major on both sides; b) shoulder: lateral tip of the acromion on the both sides; c) elbow: lateral epicondyle of the throwing arm; d) wrist: radial styloid process and ulnar styloid process of the throwing arm; e) ball: half a hemisphere of the javelin ball was covered with reflective tape to identify the centre of the ball. The moment of ball release was derived from the change in distance between the wrist and the ball. At the moment the ball leaves the hand the distance between the wrist marker and the ball marker increases abruptly and intensely (van den Tillaar & Ettema, 2003; 2004; 2007; 2009a; 2009b).

The computation of the velocity of the different distal endpoints of segments and joints and the ball was done using a five-point differential filter; a filter in which four data points around a point in time are used and differentiated to minimise noise around that data point (van den Tillaar & Ettema, 2003; 2004; 2007; 2009a; 2009b). In addition, the acceleration of the ball and the timing of the initiation and maximal ball acceleration were calculated. The angles and angular movement velocities of the different joints were derived from relative positions between the different markers according to the same methods used by Feltner and Dapena (1989), Fradet et al. (2004), and van den Tillaar and Ettema (2007). The following kinematic variables were analysed: maximal angle and angular velocity of the elbow extension, external/internal rotation of the shoulder, shoulder flexion, shoulder abduction, trunk tilt, trunk tilt sideways, upper torso rotation, and horizontal pelvis rotation with the angles of these joints at ball release (Figure 1).

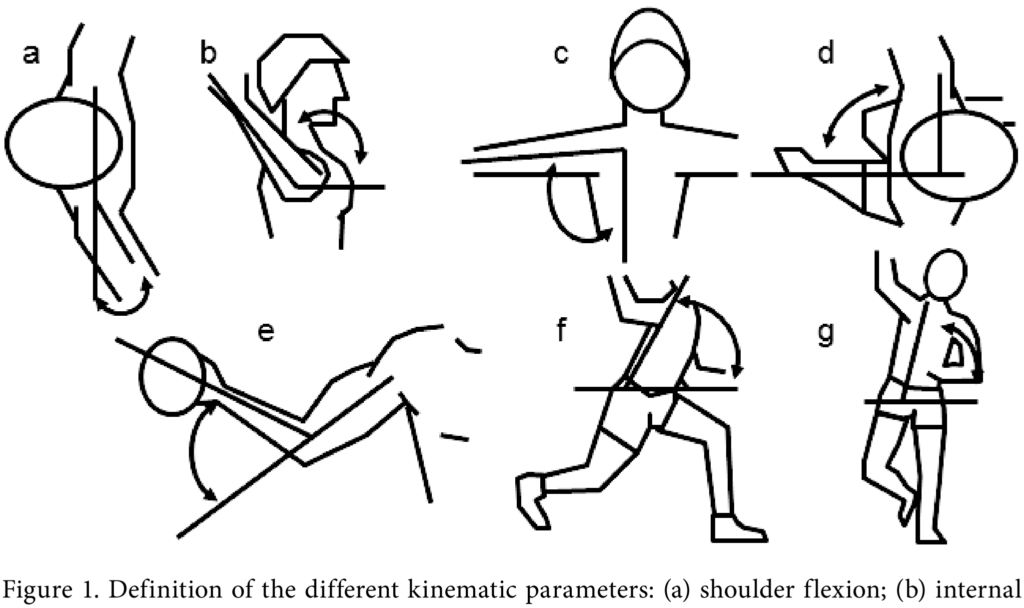


Figure 1. Definition of the different kinematic parameters: (a) shoulder flexion; (b) internal shoulder rotation; (c) shoulder abduction; (d) pelvis and upper torso rotation; (e) elbow flexion; (f) trunk tilt forwards; and (g) trunk tilt sideways.

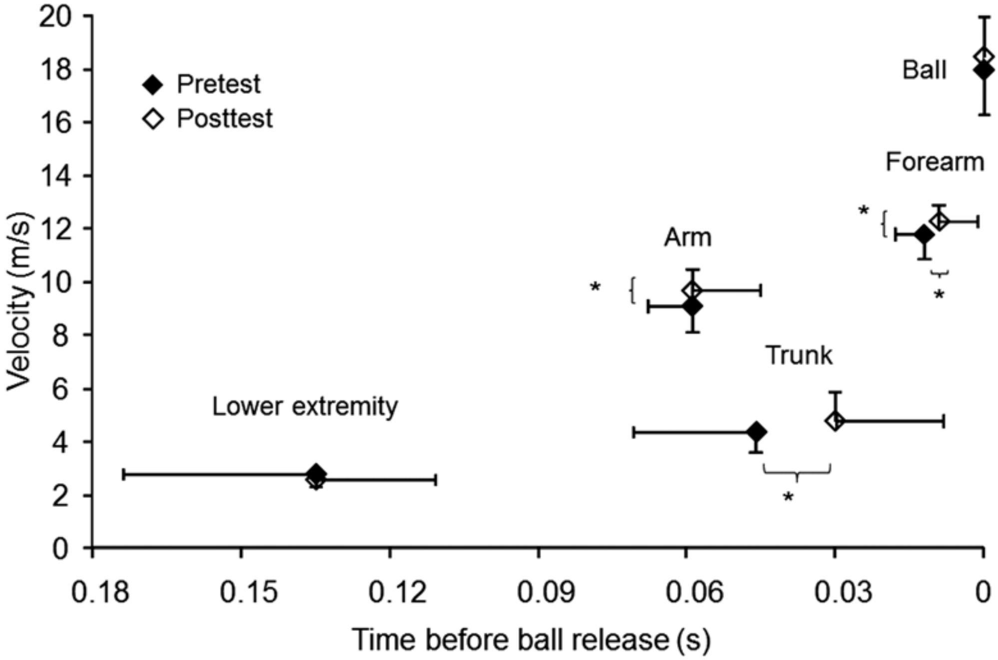
Further, the timing of the maximal angles and velocities of the different segments and joints were calculated. The distal endpoints of the segments we analysed were the forearm (average of the markers on the radial styloid process and ulnar styloid process), arm (elbow marker), trunk (throwing shoulder marker) and lower extremity (throwing hip marker). Timing was measured as the time before ball release. The time at which the ball was released from the hand was defined as zero time (T_0) and the time before the ball release was defined as negative.

Statistical Analysis

To compare the effect of the training on the ball release velocity and kinematics, a one-way ANOVA for repeated measures was used. Pearson's correlation between the change in ball velocity and change in maximal angles, angles at T_0, velocity during the throw and the timing before the ball release was used to locate intra individual relationships. A significance level of 0.05 was used to identify differences.

RESULTS

As the study progressed nine subjects withdrew due to injury, not related to the experiments (five subjects) or since they were unable to attend sufficient additional training sessions (four subjects). Since the study's main aim was to investigate the kinematics and ball release velocity changes after a training period the three groups were taken together.



* indicates a significant difference between throws in the pre and post-tests ($p<0.05$)

Figure 2. Maximal linear velocity of distal endpoints of segments during the throw and their timing before ball release

No significant increase ($p=0.25$) in throwing velocity (from 18.0±1.7 to 18.5±1.5 m/s) was found after the intervention period since four subjects (from all three training groups) did not increase their throwing velocity (Figure 2). However, significant differences ($p<0.05$) were found for the maximal linear velocity of distal endpoints of segments of the arm and the forearm and the timing of the occurrences for the forearm and trunk (Figure 2). In addition, significant differences occurred for the maximal trunk tilt sideways angle ($p<0.001$) after the training period (Table 1). No other significant differences were found for the maximal angular joint velocities, angles and their timing (Tables 1 and 2).

Table 1. Angles at T_0, maximal angles (°), start ball acceleration during the throw and the timing before ball release (sec)

	Angle at T_0		Max angle		Timing max angle	
Variable	**pre test**	**post test**	**pre test**	**post test**	**pre test**	**post test**
Pelvis angle	71±13	72±12	171±4	173±4	-0.398±0.128	-0.389±0.089
Trunk tilt sideways	61±12	63±9	87±8	92±8*	-0.358±0.113	-0.306±0.085
Trunk tilt	62±8	64±11	87±5	86±4	-0.322±0.088	-0.314±0.181
Shoulder flexion	2±8	3±8	-14±9	-13±8	-0.274±0.168	-0.306±0.207
Upper torso angle	53±14	50±14	190±7	196±6	-0.296±0.066	-0.283±0.060
Int. shoulder rotation	93±15	99±13	136±17	136±19	-0.167±0.059	-0.182±0.088
Shoulder abduction	79±13	79±10	85±11	85±9	-0.110±0.105	-0.100±0.086
Elbow angle	60±12	66±14	102±10	105±13	-0.073±0.035	-0.060±0.011
Start acceleration	-	-	-	-	-0.138±0.057	-0.119±0.036

* indicates a significant difference between throws in the pre and post-tests ($p<0.05$)

Table 2. Maximal angular velocity of the different joints and ball acceleration during the throw and their timing before ball release

	Max velocity (rad/sec)		Timing max velocity (s)	
Variable	**pre test**	**post test**	**pre test**	**post test**
Pelvis rotation	10.5±2.5	9.6±1.9	-0.110±0.027	-0.105±0.025
Shoulder flexion	4.2±2.2	4.6±1.6	-0.091±0.038	-0.081±0.040
Shoulder abduction	7.5±2.4	8.8±2.0	-0.072±0.051	-0.081±0.037
Upper torso rotation	17.0±3.4	18.3±3.4	-0.065±0.029	-0.053±0.028
Trunk tilt sideways	5.3±2.0	5.3±1.8	-0.024±0.029	-0.019±0.026
Trunk tilt	6.3±1.8	6.7±1.4	-0.023±0.014	-0.019±0.013
Elbow extension	20.6±4.4	21.8±3.0	-0.007±0.006	-0.004±0.005
Internal Shoulder rotation	25.1±9.1	31.5±22.0	0±0	0±0
Acceleration (m/s^2)	269±46	267±47	-0.049±0.040	-0.036±0.011

Only significant correlations were found between the change of maximal ball release velocity with the change of the maximal angle of the trunk tilt sideways ($r=.84$; $p=0.001$), and the maximal angular velocity of the internal shoulder rotation ($r=.75$; $p=0.02$). Further, the change in ball release velocity correlated negatively with the maximal trunk tilt forwards velocity ($r=-.70$; $p=0.017$). In addition, the present study also observed a significant correlation between the change in maximal ball release velocity with the change in maximal acceleration ($r=.70$; $p=0.016$) and the timing of the start of the ball acceleration ($r=.73$; $p=0.043$), i.e. a more positive change after the training period in maximal acceleration and the timing before ball release results in a higher ball release velocity (Table 3). No other significant correlations were found (Table 3).

Table 3. Correlations between the change in ball velocity and change in maximal angles, angles at T_0, velocity change in ball acceleration during the throw and the timing before ball release

Variable	**Angle at T_0**	**Max angle**	**Max velocity**	**Timing max angle**	**Timing max velocity**
Forearm	-	-	0.58	-	0.04
Arm	-	-	0.32	-	0.46
Trunk	-	-	0.26	-	-0.11
Lower extremity	-	-	0.23	-	0.16
Pelvis rotation	0.01	0.06	0.01	-0.20	-0.14
Upper torso rotation	0.12	0.35	-0.20	-0.05	-0.57
Trunk tilt sideways	-0.18	0.84*	-0.23	-0.14	0.18
Trunk tilt	0.24	0.25	-0.70*	0.42	0.34
Shoulder flexion	0.23	0.52	-0.06	-0.01	-0.10
Shoulder abduction	-0.42	-0.25	0.04	-0.24	-0.09
Int. shoulder rot.	0.27	0.06	0.76*	-0.05	-
Elbow extension	-0.09	-0.18	0.29	0.01	-0.05
Acceleration	-	-	0.70*	0.73*	0.06

* indicates a significant correlation ($p<0.05$)

DISCUSSION

The study's main finding was that no significant increase in ball release velocity was found after the training period. However, the maximal linear velocity of the endpoints of the forearm and arm increased after the training period, indicating that training can increase one's throwing performance. That no significant increase in ball velocity was found while there was a significant increase in the maximal linear velocity of the endpoints of the forearm and arm could be due to the ineffective use of the wrist and finger flexion, which were not considered in this study. In addition, the use of different training regimes could influence the total ball velocity. However, in every group there was at least one subject who saw a decrease in their ball release velocity.

The timing of the maximal linear velocity of distal endpoints of segments of the forearm and the trunk was changed after the training period i.e. after the training period the maximal velocity of the forearm and the trunk were closer to the ball release than before the training period (Figure 2). This is in line with the findings of Jöris, Edwards van Muijen, van Ingen Schenau and Kemper (1985) and van den Tillaar and Ettema (2003, 2006) who found that in overarm throws with a higher ball release velocity the timing of the trunk and the forearm was also was close to the ball release.

Only a significant difference in maximal angles was observed after the training period for the maximal trunk tilt sideways angle (Table 1). This difference was around 5 degrees and occurred at around 0.3 s before ball release, resulting in a more upright position in the trunk of the participants in the arm cocking phase (van den Tillaar & Ettema, 2007). Such a difference would probably not influence the ball release throwing, but perhaps only the height of the ball during the arm cocking phase.

It was hypothesised that the change in performance was caused by the change in maximal velocity of the elbow extension and the internal shoulder rotation. Only a significant positive correlation with the internal shoulder rotation (r=0.75; p=0.02) was found (Table 3), indicating the important contribution of this movement to overarm throwing ability. This is in line with earlier results of van den Tillaar and Ettema (2004, 2007) for male team handball players. The lack of other significant differences in joint kinematics can be explained by the short training period of eight weeks and the experience of the participants (11 years of experience). Due to this experience, they have established a throwing pattern that is difficult to change in just eight weeks' time (Marques, 2010). Perhaps with a longer period of training it would be possible to change the kinematics and the ball release velocity (van den Tillaar, 2004).

The change in ball release velocity was related to the difference in maximal ball acceleration (r=0.70) and the timing of the start of the acceleration (r=0.73; Table 3). The positive association between the ball release velocity and maximal acceleration is not surprising since a higher ball acceleration results in a higher ball velocity. However, the ball acceleration starts later (closer to the ball release) when the ball is thrown faster after the training period. Thus, a tendency exists which suggests that an increase in ball velocity is related to a later start, but also to more intensive acceleration.

A weakness of the study is that only a few participants conducted the whole study. This was the result of the dropouts (around two in each group), which made it impossible to study feasible differences in kinematics due to the different training regimes. Due to the reduced number of participants and use of different training regimes, no clear statement can be made. We suggest that future studies with more participants should focus upon training the internal shoulder rotation to enhance throwing performance and that kinematics are measured to gain more knowledge about the differences in technique that actually change due to the training.

CONCLUSION

The changes in ball velocity after the different types of training were probably caused by the changes in the maximal angular velocity of the internal shoulder rotation, as indicated by the positive correlation. However, studies with more subjects involved in training the internal shoulder rotation should be conducted to allow a general statement to be made about technique changes (kinematics) due to training.

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