Three-Dimensional Cinematographic Analysis of Throwing

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INTRODUCTION

For the past 10 years researchers have been attempting to isolate factors which allow optimal skill development in an individual. Wickstrom (1975) discusses the development of mature motor patterns and later (1983) discusses the importance of achieving the co-ordinated neural control necessary for a mature motor pattern in a skill such as throwing. From the research (Leme & Shambes, 1978; Atwater, 1980) it appears that females generally do not, for whatever reason, achieve a mature throwing pattern. It is of great importance to the teaching of a skill to understand why the majority of female subjects cited in the literature do not achieve a mature throwing pattern. The characteristics of this immature pattern include lack of body rotation, shoulder medial rotation and wrist flexion (Leme & Shambes, 1978; Robertson, 1978; Atwater, 1980; Wickstrom, 1983) and it is these actions which are involved in decreasing the rotational inertia of the body and associated limb segments, to increase ball velocity. Thus it would appear essential to understand why these adaptations are not present in females but are in males. Let's take this step further and examine if this technique difference is present in throwing in water as opposed to throwing on land. Presumably throwing in a sport such as water polo, demands a change in technique due to the inability to plant the front foot on the ground and the use of a large ball. If one considers a youngster, (who has not yet developed a mature throwing technique) entering the sport of waterpolo, they may have to resort (as does his/her land counterpart) to throwing techniques reliant on strength in an attempt to overcome poor velocity. Consequently the young thrower will probably employ excessive shoulder lateral rotation to achieve this and it is this rotation which is related to valgus elbow stretch and excessive wrist flexor in the adult thrower (King, Brelsford & Tullos, 1969; Atwater, 1980). Here an injury component is exposed in the immature performers technique adaptation and the introduction of an error occuring more proximally in the throw which will affect the more distal segments.

Water polo is an interesting sport to study. It is one of the most widely played team sports in the world (De Mestre and Neeshan, 1972). The game has come a long way from its beginnings in Britian where it developed to overcome public boredom with swimming.

How much has water polo really progressed? Certainly the rules have been changed and the style of the game today is vastly different to the first Olympic exhibition match in 1900. What appreciation do players and coaches have of changes in technique involved in the overhand throw, the most adaptable, powerful and accurate of these used in waterpolo (Lambert and Gaughran, 1969; Clarys and Lewillie, 1971; Juba, 1972; Bland, 1978). The overhand throw constitutes 90 percent of all passes thrown (Lambert and Gaughran, 1969) and more goals are scored using this technique than all others (Clarys and Lewillie, 1971). The 1986 Australian male water polo coach, Tom Hoad (personal communication with the author), suggested the female style of game is slower due to an inability to pass the ball quickly.

Previous biomechanical studies involving water polo have been limited to qualitative evaluation and two-dimensionally (Davis and Blanksby, 1977; Whiting et al., 1985). No studies have investigated the overhand throwing techniques used by women water polo players. This study used 3-D cinematography to assist in the analysis of the overhand throw by male and female high performance water polo players. The techniques used by these two groups will be contrasted in an attempt to identify whether this throwing skill is performed differently by these high performance male and female players i.e. to determine the possible existence and extent to which immature patterns appear in elite female water polo performers.

METHODS AND PROCEDURES

Source of the Data

Six male (mean age 25.2 years) and six female (mean age 23.1 years) were filmed. All subjects were selected for their throwing ability by the Australian men's National coach or the Western Australian men's or women's coaches. All subjects were at present, or have previously been National or State (Western Australian) representatives.

Administration and Filming Procedures

Filming was conducted in the Department of Human Movement swimming pool and the Direct Linear Transformation method was used for 3-D space reconstruction from 2-D images. Two Photosonics phase-locked cameras were used to film a reference structure containing markers of known co-ordinates in space encompassing the field of movement of the throw. This structure was then removed and the subject was filmed in the same area with identical camera positions. Subjects were anatomically landmarked after a general warm-up, and prior to the filming were permitted as much time as needed to practice their overhand throw. The two phase-locked cameras operated at 200 fps (exposure time 1/1600s) to film each subject throwing three trials in a prescribed area. To enable film speed calibration, two electric sweep-hand clocks divided into 0.02s intervals were positioned in the field of view of the cameras. Subjects were also filmed throwing a tennis ball at the target.

At the completion of the filming the subjects were measured for height (both standing and sitting), mass, throwing limb shoulder and elbow flexibility, throwing limb (arm and forearm) girth, throwing limb length (including arm, forearm and hand lengths) and finally hand span using procedures outlined by the University of Western Australia, Department of Human Movement, Growth and Development Manual (1983).

Analysis and Treatment of Data

The film images of each throw were then projected by a NAC 16mm motion analysis projector, via an overhead mirror onto the surface of an analysis table. The highest velocity throw that landed in the prescribed area was selected for analysis. The 2.D images of both the reference structure (7 points) and subject were digitized, and the unknown 3-D co-ordinates of each of the subjects' landmarks were determined using the procedures outlined in Marzan and Karara (1975) and Wood and Marshall (1986). After digitizing, the data were then transferred to a DEC System - 10 computer where 3-D joint angles and angular velocities were calculated. An average mean square error of 6mm for the calculation of the X, Y and Z values of the known points in space from the digitized data was calculated for the twelve subjects. A 2-D file was also created in order to use co-ordinates from the sagittal plane for calculating linear land angular kinematics in this plane using procedures outlined by Wood (1977).

A one-way analysis of variance was used to test for the significance of the difference between the means.

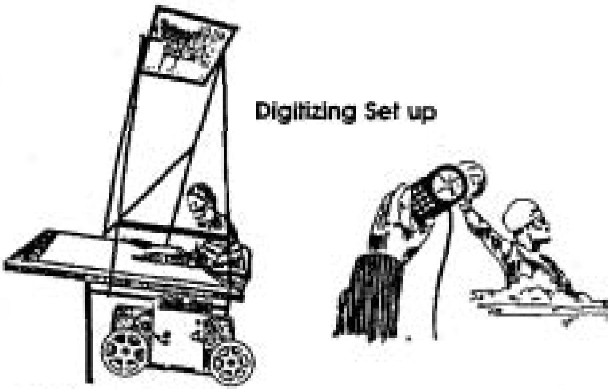

Figure 1: Digitizing Set Up

RESULTS AND DISCUSSION

Anthropometric data of height, mass, stem length, upper limb lever lengths, hand dimensions, throwing limb flexibility and girths were recorded. Male subjects were taller, heavier and had greater throwing limb lever lengths and girths, however age, playing experience and throwing shoulder and elbow flexibility were similar for both groups. Relevant anthropometeric data will be integrated into the throwing technique used by the male and female players. The following discussion of the techniques used by the two groups is divided into two sections which correspond to the phases of the throw; the preparation and backswing and the forward swing to release.

Preparation and Backswing

The two techniques to lift the ball from the water, the rotation lift and the lift from underneath were both employed in this study. The rotation lift which was used by four males and three females produced a ball velocity of 18.4 ms^{-1} compared to 15.3 ms^{-1} for those subjects that used the lift from underneath. This result corroborates the findings of Davis and Blanksby (1977) where male subjects who used the rotation lift achieved a significantly higher velocity (19.4 ms^{-1}) when compared to those subjects who had a preference for other lifts (15.1 ms^{-1}).

Lambert and Gaughran (1969), however, suggested that maximum vertical body displacement and not ball lifting technique was the best indicator of ball velocity. Juba (1972) further suggested that greater vertical displacement from the water resulted from a ball pick-up technique which generally followed the description of a rotation lift. Subjects who used a rotation lift recorded a similar vertical displacement of 0.15 m incomparison tothe 0.18m achieved by subjects using the underneath lift which supports the findings of Davis and Blanksby (1977) where similar vertical displacements were found for different lifting techniques. No significant relationship was also found between ball velocity and maximum vertical displacement for this homogeneous group of high performers.

Hip and shoulder rotation initiated the backswing prior to lateral rotation of the upper arm. The throwing arm is then rotated about the shoulder axis with the elbow flexed as the ball was taken behind the head. The movement pattern in which the upper limb was outwardly rotated about the shoulder joint was different between the two groups, with the males adopting a more horizontal rotation while the females employed a more vertical pathway. The importance of this variation may lie in the conservation of energy from the backswing to the forwardswing phases of the throw. The more continuous motion used by the male subjects may be more conducive to produce higher segment velocities at release compared to the more stop-start pattern used by the female throwers. The reasons for these different movement patterns may in fact be that four of the six women players adopted a relatively square-on position to the target at the rear point due to lack of hip and shoulder rotation thus making a circular movement pattern difficult to achieve, and a smaller hand to ball ratio may have meant that a more vertical pathway was needed for ball control.

Figure 2: Coronal View of Ball Position during the preparation and backswing as seen from the 45° camera

At the rear point in the backswing the ball was above (M:0.19m; F:0.13m) and behind the head (M:0.33m; F:0.21m). A mean elbow angle of 1.86 rad (107°) for male players was significantly higher than the 1.44 rad (83°) recorded for the female subjects. However, all the males and two of the females were within the 90° to 122° range reported by Davis and Blanksby (1977) for elite male players. Similar wrist angles were recorded at the rear point of the throw of 2.83 rad (162°) for the males and 2.76 rad (158°) for the female throwers. These wrist angles were higher than the 135° suggested by De Mestre and Neesham (1972), however, they are smaller than the angles reported in other throwing activities using a smaller ball. The wrist cannot hyperextend as in other throwing skills because of the strain the larger ball places on the hand (Davis, 1976).

The Forward Swing and Release

As the upper limb moved forward at the commencement of the forward swing ten of the subjects flexed at the elbow prior to any elbow extension as reported by Davis (1976) and Whiting et al. (1985). Elbow extension commenced 0.14s prior to release for the female players in comparison to the mean time for the male throwers of 0.08s. The females who then began extending earlier than the males did not develop as high a velocity as the males at release. These values for the male throwers were similar to the 19.8 rad s^{-1} peak velocity and 12 rad s^{-1} release velocity reported by Whiting et al. (1985). At ball release mean elbow angles of 2.19 rad (126°:F) and 2.59 rad (148°:M) were within the 120° to 158° range reported by Davis and Blanksby (1977) and the male players recorded similar angles to the 155° reported by Whiting et al. (1985). All of these angles are lower than the 180° elbow angle suggested in some coaching guidelines (Lambert and Gaughran, 1969; Juba, 1972; Barr and Gordon, 1980). The males also released the ball with the forearm inclined forward (102°), whereas the female players released the ball with the forearm almost vertical (89°).

The movement of the wrist joint must be co-ordinated with elbow extension if a maximum ball velocity is to be achieved. The wrist movement of the female throwers was characterized by wrist flexion throughout the forward swing while the male subjects were able to initially flex, then extend, and finally flex the wrist again just prior to release. This absence of an extension phase and a smaller range of flexion may have resulted from an inability to adequately grip the ball, as the females had a significantly smaller hand span when compared to the male throwers. The smaller hand may cause the female thrower to cradle the ball with the forearm and hand to allow greater ball control and thus reduce the use of this final hand segment. In each subject hand flexion at the wrist joint was present from palmar to finger release of the ball. There was nosignificant difference in the angle of the wrist at release with the female throwers recording 2.59 rad (148°) and the male throwers 2.72 rad (156°), however these values were lower than the 178° reported by Davis (1976). One explanation for these differences in release angles may have been the digitizing of the fifth metacarpo-phalangeal joint rather than the distal phalanx of the third phalange. The male throwers recorded a more rapid increase in wrist angular velocity from palmar release (approximately -0.02) to finger release with males experiencing an increase of 6.1 rad s^{-1} (349 deg s^{-1}) in comparison to the female increase of 1.26 rad s^{-1} (72 deg s^{-1}).

In terms of the summation of body segments it appears that the action of the trunk, arm, and forearm segments are similar to on-land throwing, where the more proximal segments reach maximum levels prior to the smaller more distal segments (Atwater, 1979; Joris et al., 1985). The distal end of the trunk (the shoulder) reached a maximum linear velocity of 3.7 ms^{-1} (M) and 3.3 ms^{-1} (F) 0.06s prior to release. As the trunk began to decelerate the arm horizontally flexed to produce maximum linear velocities of the elbow of 7.0 ms^{-1} for the male throwers 0.04 s prior to release and 5.9ms^{-1} for the female subjects 0.5s prior to release. Elbow extension then produced peak segment end point velocities for the forearm of female subjects during the later part of the forward swing. At release the shoulders and throwing elbow were almost aligned in agreement with the straight, but tilted line reported by Atwater (1979) for overhead throwing tasks. The male players adopted a more tiltedposition than the females, which was a similar result to that of Davis and Blanksby (1977) where elite players adopted a more horizontal position while less experienced players tended to be more vertical.

Ball velocities of 19.9 ms^{-1}(M) and 14.7 ms^{-1}(F) were recorded immediately following release while trajectories of 4° were recorded. The last contact point with the ball in all subjects was the tips of the second and/or third finger. The early follow through phase was characterised by a continuation of elbow extension and wrist flexion while forearm pronation was also evident in all subjects.

It was decided not to analyse the teams ball trials as the technique was very different as illustrated in Figure 3.

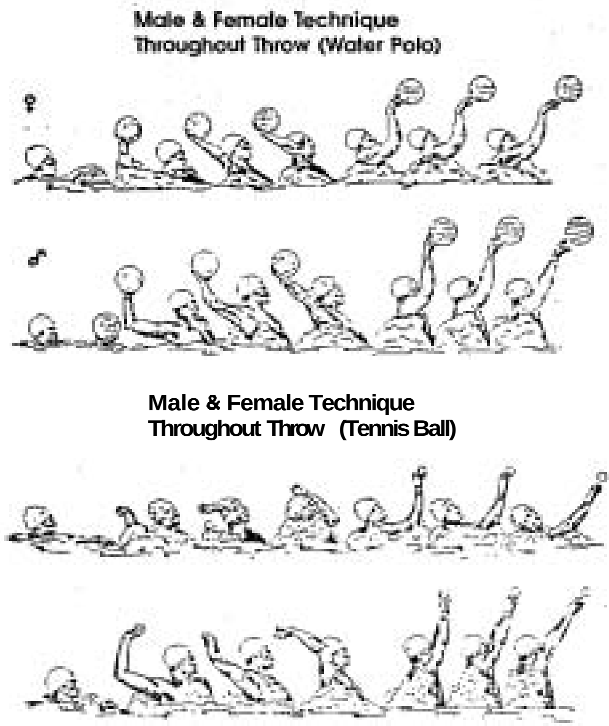

Figure 3: Male and Female throwing techniques

CONCLUSIONS

On the basis of the findings of this study and with due consideration to the literature, the following technique model for water polo overhand penalty shooting has been formulated. Many of these techniques can be generalised such that they are used as the basis for overhand passing or shooting in the game. Individual preference may dictate the lift to be used although the rotation lift tended to produce superior results. The ball should be brought around the body in a circular path with an elbow angle of greater than 90° so that there is a smooth transition from backswing to forwardswing phases of the throw. If this circular backswing path is too difficult for female throwers to perform because of inadequate grip of the ball, then a more vertical backswing may be used which will reduce the displacement of the ball during the backswing. At the rear point of the throw the elbow angle should be approximately 156°. It is difficult to conclude which is the most efficient position for the ball to be, relative to the head at the ear point of the throw, and it may be that this position is determined by individual level lengths. It is essential that the shoulders are in line with the target at the rear point, as this assists throwing elbow extension during the forwardswing. This side-on position is achieved by hip and shoulder rotation and a greater contribution by the lower limbs to the throw.

The sequencing of motion during the forwardswing determines the efficiency of the shot. Throwing shoulder velocity produced by trunk rotation should precede horizontal arm flexion if optimal elbow velocity is to be achieved. The sequencing action of the forearm and hand in water polo appears to be altered by the larger ball when compared to other throwing tasks. The addition of the more proximal segment's velocity to that of the distal is changed with the forearm and hand segments achieving maximum linear end-point velocity simultaneously at release. The femaleplayers throw the ball with similar segment sequencing, however, they are greatly disadvantaged due to the lesser hand to ball ratio, thus the action of the hand as a contributor to final velocity, is reduced.

To gain maximum velocity at release, the elbow joint should continue to flex after the rear point and then extend to release. The wrist action during the forwardswing should include an extension phase prior to final flexion to increase ball displacement and hence release velocity.

Strong leg and trunk actions are essential to increase the contribution from the larger, more proximal segments and assist in forward body motion.

At release, the elbow angle should be approximately 150°. More importantly, the forearm should be ahead of the vertical at release by about 10° to ensure the most powerful release position. After release it is important that the velocity of different body parts are decreased to protect the body from injury, however, 3-D angular velocities of the wrist and elbow may increase immediately after release because of the reduced load on the hand.

Although the female subjects in this study were members of the 1986 Australian team which were the world champions, generally all but one of the female subjects had not achieved a mature throwing pattern. The author acknowledges the fact that there is obviously more to water polo than the overarm throw.

Although physical differences such as throwing limb length and hand span, affected the technique involved in the overhand water polo throw, it would still be possible for females to improve their throwing techniques by training in specific movement patterns involving hip and shoulder rotation, and leg action. Ultimately, the greatest increase in ball velocity at release would come about through a reduction in ball size so as to allow greater ball control. The ability of the hand to act as a final lever is already reduced in water polo throwing, hence this reduction should be relative to the player's hand size. As throwing is a sequential action, any problems which occur early in the throw, such as during the backswing, will influence the remainder of the throw.

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