Water Polo: 
A Biomechanical Analysis of the Shot

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Introduction

The water polo shot is a unique skill in which the player attempts to score a goal by throwing the ball as fast and accurately as possible at the goalie. The throw is an overhand throw, similar to that used by a skilled baseball pitcher. Since the player is in the water, the skill is more difficult as they have no firm surface from which to push off. The skill is also difficult because the rules allow only one hand on the ball, so the ball must be controlled with only one hand throughout the shot. The ball is about twice as large as the average male's hand, so it is difficult to control. It is even more difficult for the average female to control the large ball with one hand and the ball has to be balanced on the hand during the preparation for the throw.

The shot has some similarities to the overhand throw in baseball and softball. The following description applies to the right handed thrower. The ball is brought back behind the head and the trunk is rotated away from the direction of motion so the left shoulder faces the direction of motion of the throw. The throw is initiated by trunk rotation forward in the direction of the throw. In baseball, the hips begin the rotation and this is followed by the mid trunk, then the shoulder girdle, as the trunk acts as a 3 segment model. The throwing arm is abducted 90 degrees to the trunk and the trunk leans laterally away from the throw during delivery. The throwing arm then goes from shoulder lateral rotation and lower arm supination to shoulder medial rotation and lower arm pronation, usually accompanied by elbow extension and wrist flexion. The fingers remain extended during the throw in order to apply spin to the ball at release.

The water polo shot differs from the baseball throw in several important respects, notably that the water polo shot is performed while the athlete is suspended in water and therefore lacks a firm base of support on which to push down and back. The legs and arms must therefore continue to perform sculling movements to help keep the trunk upright during the throw. The trunk often does not perform segmented rotation, but it usually rotates as a single unit. It is more desirable for the trunk to perform segmented rotation in which the hips move forward first and the shoulders follow (Ball, 2005a). The trunk rotation does provide an important source of power to the shot, as the trunk rotation helps to place the throwing arm in the optimal position to produce a powerful shot by maximizing lateral rotation. The trunk rotates forward and leaves the throwing arm and ball behind the body, producing a position of maximal lateral rotation. The angular momentum created by the trunk rotation is then transferred to the shoulder joint and to the throwing arm. The trunk rotation has been estimated to provide 30-35% of the contribution to ball speed (Ball, 2005b). The joint movements of the joints of the arm also contribute to the velocity of the hand, and the ball at release (Newland, 2005).

There are two types of arm action seen in the water polo shot on goal, the more common overhand technique in which the ball is released from a high point above the head using primarily shoulder medial rotation for ball speed; and the sweep technique in which the ball is swept horizontally across the water surface using primarily horizontal adduction (Feltner and Taylor, 1997). The technique described here is the overhand technique as this is more commonly used. It has been suggested that muscular strength is the main determinant for technique chosen in the penalty shot. Subjects who were stronger were found to be able to create the necessary muscle strength to use the overhand technique (Feltner and Taylor, 1997).
Kinematic Description of the Water Polo Shot

Preparation and Backswing

The shot starts with the player facing the goal with the ball in the shooting hand. Prior to the shot, the ball must be lifted upwards from the water. The rotation lift is a lift in which the hand is placed on top of the ball and a downward pressure is applied as the hand is rotated under the ball (Armour and Elliott, 1989). This lift was found to produce a higher ball velocity in a group of elite players compared to the lift from underneath where the hand is placed under the ball and the ball is raised directly from the water. The shooting arm is then raised above the shoulder (shoulder abduction) while the trunk is rotated away from the goal. At the furthest rear point of the backswing the shoulders should be almost in line with the target (Armour and Elliott, 1989). This rotation places the trunk in position to apply the full forces of trunk rotation to the ball during the throw. The non throwing arm is abducted in front of the front shoulder and points in the direction of the throw. The throw is often initiated by the rotation of the front arm in the direction away from the throw to pull the front shoulder around and initiate trunk rotation. The front arm is horizontally abducted and extended to start the trunk rotation (Figure 1).

The height of the trunk out of the water during the throw is a critical factor in shooting technique (Newland, 2005). Players should be able to raise their bodies out of the water a sufficient distance (.2m above start height) to allow the best use of trunk rotation and upper limb action in the throw (Armour and Elliott, 1989). Since the resistance of water to movement is greater than that of air, the more movements that occur out of the water the faster the shot should be. As well, the higher the shot at release the less chance that the shot will be blocked by a defender (Feltner and Taylor, 1997).

At the top of the backswing the throwing shoulder is first medially rotated, then laterally rotated prior to the forward movement of the ball and hand (Figure 2). The amount of medial rotation during the backswing is dependent on the size of the hand and the ability of the player to control the ball in one hand. Few female players are able to hold the ball in one hand with the ball facing the water- usually the hand is under the ball to support it. At the furthest point of the backswing the mean elbow angle was 107° for elite male players while the ball was held on average 19 cm above and 33 cm behind the ear. The top
female athletes in a sample of elite Australian players recorded similar angles and distances to the males (Armour and Elliott, 1989). Wrist hyperextension is a key feature of the arm position during the backswing, and was found to average 70º from the anatomical position (Armour and Elliott, 1989).

Figure 2 The position of the body in mid throw - the trunk is out of the water and throwing arm is abducted and laterally rotated

Forward Swing to Release

The technique of the water polo shot on goal is similar to that seen in a skilled baseball pitcher. The larger muscles of the trunk act first, producing trunk rotation in the direction of the throw as well as trunk flexion forward during the throw. The trunk starts the throw in a position of hyperextension and moves into 20 degrees of flexion during the throw. This trunk motion can also assist in producing ball

Figure 3 Motion analysis of the upper and lower body during the forward swing phase of the shot.
velocity during the throw. The most important muscles in the trunk are the anterior trunk muscles that pull the right side of the trunk around to face the target (Newland, 2005), as well these muscles are active in flexing the trunk forward. Trunk strength is a critical aspect of the water polo shot, as the contribution of the trunk to the speed of the shot is up to 30-35% of ball speed (Ball, 2005b). As the player rotates the trunk (shoulder girdle) forward to face the goal, the ball and the throwing arm are left behind. The shoulder moves into lateral rotation, the elbow is flexed (Armour and Elliott, 1989) and the ball is resting on the palm of the hand. This action of leaving the ball behind the body is critical in producing maximal force on the ball, as the anterior shoulder muscles and the triceps are placed on a stretch prior to forceful contraction during the throw. The throwing shoulder should maintain an angle of 90 degrees of abduction during the throw, to prevent impingement that may occur if the arm is abducted to an angle greater than 90 degrees (Figure 4). It has been reported that the predominant injury seen in water polo athletes is subacromial impingement resulting from combined adduction, horizontal adduction and medial rotation of the throwing arm (Rollins, Puffer et al., 1985).

As forward trunk rotation is nearing completion the arm action begins, so the movements occur in a sequence from larger to smaller joints. The shoulder is medially rotated and horizontally adducted by the anterior shoulder muscles, the elbow is moved toward extension and the lower arm pronates to apply additional force and spin to the ball. The range of motion of medial rotation during the throw has been reported to range from 40 to 80 degrees, with velocities approaching 500 deg/s (Ball, 2005b). These values are quite high, but are not comparable to those attained by skilled baseball pitchers whose peak medial rotation velocities approach 7000 deg/s (Feltner and Dapena, 1986). The horizontal adduction of the upper arm during the throw ranges from 50 to 80 degrees, with angular velocities approaching 80 deg/s. It has been estimated that medial rotation and horizontal adduction contribute 20-30% to developing ball speed (Ball, 2005b).

![Figure 4 Throwing arm position at release.](image)

The elbow is flexed from 80-90 degrees during the forward swing as maximal lateral rotation is reached at the top of the backswing, and then goes through a range of extension prior to release. It has been suggested that elbow extension contributes 22-27% to development of ball speed at release (Ball, 2005b). The elbow does not completely extend at release (Figure 4), but the elbow angle at release is close to 150° for male throwers and 125° for female throwers (Armour and Elliott, 1989). This partial flexion may be to prevent elbow injuries produced from high extension velocities near the end of the range of motion. As well, increased elbow angles at release increase the moment arm for internal rotation during release by increasing the distance from the axis through the upper arm to the ball (Feltner and Taylor, 1997). This will significantly increase ball speed at release from shoulder medial rotation. The wrist also makes a contribution to ball velocity (8-13%) by flexing during the forward swing and at release (Figure 5). Male throwers were seen to experience some increased wrist extension during the forward arm swing, followed by wrist flexion at release. This increased wrist extension increased the
range of motion for wrist flexion and increased the contribution of the wrist to ball velocity (Figure 5). The wrist angle was close to 155° at release, and the forearm is almost vertical (Armour and Elliott, 1989).

![Figure 5 Action of the wrist during the forward swing.](image)

The non throwing arm may assist with support while the trunk is rotating backward by performing sculling motions. These motions may assist with body support while the trunk is raised out of the water for the shot. The front arm may also assist with trunk rotation by horizontally abducting and extending during the throw (Figure 6). This movement may produce more forceful trunk rotation and also assist with lateral flexion.

![Figure 6 The non throwing arm abducts at the shoulder and extends at the elbow during the shot.](image)

Trunk lean is also an important aspect of the shot, as the arm actions are occurring the trunk leans to the left, away from the throwing arm. This position will increase the lever arm for rotation of the arm around the axis through the spine, and increase the velocity of the ball around that axis. Most skilled throwers will lean at least 30 degrees away from the throwing arm at release (Figure 7). This position will maximize the lever arm for trunk rotation as well as increase the height of release of the ball. A higher height of release will allow a flatter angle of release and greater horizontal velocity of the ball towards the goal. Skilled throwers were found to have greater angles of lateral trunk lean than unskilled players, and females were found to have more vertical trunk positions than males (Armour and Elliott, 1989). The speed of lateral trunk movement was found to be related to the velocity of the ball at release. A study (Ball, 2005a) of a faster and a slower throwing group of elite water polo players revealed that the faster throwers had a significantly greater lateral trunk speed at release. The faster throwers had a velocity of .77 m/s at release, while the slower throwers had a lateral trunk velocity of .406 m/s.
Follow Through

The ball will leave the index finger last, allowing the backspin to be applied to the ball (Figure 8). Some throwers have the ball leaving both the 2nd and 3rd fingers last (Armour and Elliott, 1989). The throwing arm will decelerate over a long follow through to prevent injuries to the throwing arm by decreasing the speed over the greatest time and distance possible.

Figure 7 Thirty degrees of lateral lean in the trunk is recommended at release for optimal throwing arm mechanics.

Figure 8 At release the ball will leave either the 2nd or the 2nd and 3rd fingers last.

Following ball release the elbow continues to extend, the wrist flexes and the forearm continues to pronate to ensure that peak ball velocity was achieved at release (Figure 9). The body segments should slow down gradually over the greatest time and distance possible to prevent overuse injuries to the throwing arm. These could include rotator cuff strains, impingement syndromes and elbow strains.
Other Factors in Shooting

Water polo players usually have a defender between themselves and the goal, so they have to shoot around or through the arms of a defender. This action will alter the mechanics of the shot, and may not allow the player to use all of the joints through an optimal range of motion for every shot.

The player must also attempt to deceive both the goalie and the defender when taking the shot. This often forces the player to use head fakes or ball fakes to get the defenders moving in the wrong direction prior to the actual shot on goal. The player shooting on goal will often try to be deceptive by looking at one side of the goal and then shooting at the other side. The player may also point the shoulders in one direction, and then shoot to the other corner of the goal in order to be deceptive. Another deceptive move used in water polo is the delay shot, in which the shot is delayed in mid swing to deceive opponents. Ball, (1996) has reported that the delay shot is slower at release than the regular shot on goal, but the final arm movements prior to release are faster.

Speed of the Shot

The speed of a fast shot in water polo for highly skilled players can reach up to 22 m/s, which is close to 80 km/h or 50 mph (Ball, 2005a). The forward swing time for the ball from first forward movement to release was found to be .17 sec for the faster throwers and .16 for the slower throwers (Ball, 2005a). The angle of release for most shots was found to be close to 4º for both males and females.

The speed of the ball at release is dependent on the strength and technique of the thrower, as well as on the length of his arms and amount of lateral trunk lean. A faster shot has a greater likelihood of scoring because the goalie has less time to react to the ball.
Figure 10 Average angle of release is 4 degrees with elite shots reaching speeds of close to 80 km/hr.

**Contribution of the Legs**

The challenging aspect of the water polo shot as compared to overhand throwing tasks in other sports is the lack of firm support on which the legs can push on during force production. Suspension in water prevents the athlete from transferring ground reaction forces through the body and into the shot. The action of the legs during a water polo shot has a much different purpose than in any dry land sport overhand throwing task. The lower core and legs in the water polo shot assume a supportive role, maintaining balance and height out of the water as well as contributing to force production. Dr. Jim Solum, author of *Science of Shooting – Water Polo Fundamentals*, stresses the importance of the legs in the shot stating “The legs are the shot. The legs are aim, accuracy, angularity, verticality and velocity” (Solum, 2010). Scientific reporting on the contribution of the legs to the water polo shot is extremely limited. No studies to date focus specifically on the legs, with most studies of shooting technique carrying just a few sentences on observed lower limb behaviours.

In preparation for the shot it has been reported that the frequency of the eggbeater kick increases to help raise the body up out of the water (Ball, K. 1996), though some controversy exists as some studies do not show increased speed of the kick (Davis, T. 1977). A 2005 study of Canadian national team senior men athletes showed a variation between athletes, with some increasing frequency of the kick and some not. These athletes were filmed during a shooting practice session where they where balls were repeatedly passed to them at a stationary position in front of the net and may best represent a penalty shot scenario. The technique for preparation for the shot may be dependent on game specific situation, where time to release the shot may be limited. Solum (2010) recommends athletes are coached to kick hard and fast in preparation for the purpose of raising the body from the water as this is the most immediate correction that can have positive effects on the shot. During the initial boost the body must be at a vertical position in the water, this will present the least amount of surface area as the athlete opposes the downward force of the water limiting water resistance. Raising the body to a certain height out of the water assists the athlete by reducing the amount of resistance to forward movement as drag forces are reduced in the air. Attaining a certain height out of the water also allows the athlete to flex the trunk both anteriorly and laterally creating optimal mechanics in the throwing arm. Ideally the highest point of the boost will occur at the point of release. Increased height of release results in more accurate shooting and fewer blocked shots, it is recommended the height of release be approximately 76cm above water which places ball release at the midpoint of the height of the goal (Solum, J. 2010).
Figure 11 Abduction of the right hip and neutral positioning of the left hip at the beginning of the backswing phase for a right handed shooter.

When the athlete begins the backswing phase of the throw the eggbeater kick is stopped and the legs are positioned in preparation for the shot (Figure 1). For a right handed shooter the legs are spread with the right hip laterally rotated and extended (Solum, J. 2010) and the left hip in a neutral position underneath the athlete (Davis, T. 1977). This position helps to maintain balance and control of the upper body during the shot. The left toe should point directly at the target; the ball will travel in the direction the foot is pointing. This is a major fault that can be easily corrected in unsuccessful shooting. The left toe also provides a stationary point over which the body will rotate over and pivot around during the shot (Solum, J. 2010). Correct positioning of the right hip ensures a counterbalance as the athlete catches the ball and provides a long lever to use during force production. The left knee is flexed in preparation for a forceful extension during the force producing phase.

At onset of the forward swing of the throwing arm the legs are positioned as in Figure 11. Force production must be initiated by what Solum (2010) terms the “snap-in” of the right foot. This initiates subsequent medial rotation of the right hip, followed by the hips, trunk, shoulders and finally throwing arm. Missing the critical action of the ‘snap-in’ is often the cause of weak, slow and inaccurate shooting as it is required for the successful optimization of the kinetic chain.

The forceful extension of the left knee occurs simultaneously with the forward swing of the throwing arm (Elliott, B.C. 1988), and is imperative to maximizing force production. Due to the lack of a firm base of support with which to push down on, the downward rotation created by the forward swing of the upper body must be opposed by an equal and opposite reaction or force transfer to the ball will be drastically reduced, “Correct motion has all of the shooter’s body moving forward” (Solum, J. 2010). In national team athletes the action of the forward swing of the upper body is taken up by the forceful extension of the left knees and flexion of the hips. The full extension of the right hip at the beginning of the shot is now used as a lever on the forward swing creating both lift and opposing forces to the upper body. As both hips are flexed the right knee can sometimes be seen passively flexing (Figure 2). The passive flexion in the right knee prepares for the final push from the legs resulting in the highest point in the boost at release. At the end of the force production phase the right knee extends forcefully creating an additional downward force in the water which affords the athlete the final bit of lift required just prior to the point of release (Figure 12).
At the beginning of force production the left knee extends and the hips flex counteracting the forward swing of the throwing arm. Later in force production the right knee and hips extend producing the final boost required for optimal mechanics.

Just as in dry land overhand throwing patterns a distinct shift in body weight should be noted during the water polo shot. The athlete should begin with most of the body weight overtop of the right leg with a forward shift occurring to the left leg through the shot. This will ensure balance, accuracy, and maximum force transfer through complete forward motion (Solum, J. 2010).

Following release of the shot the main action of the legs should be directed at the maintenance of balance and regaining control of the body, ensuring the ability to move quickly and efficiently if required in the case of a missed shot or rebound. In some athletes it has been noted that the legs continue in a forward motion throughout the shot resulting in a coiled up position in the follow through (Figure 13). This position may result in a greater ability for the athlete to move in any direction immediately after the shot in reaction to any specific game situation.

Figure 12 At the beginning of force production the left knee extends and the hips flex counteracting the forward swing of the throwing arm. Later in force production the right knee and hips extend producing the final boost required for optimal mechanics.

Figure 13 Follow through position with the hips and knees flexed, resulting in great balance, control and the ability to move quickly and react to any game situation.
Variables of Interest when Coaching the Shot

- Range of trunk rotation at the end of the backswing - greater range of trunk rotation will produce a faster shot

- Height of the trunk out of the water during shot

- Height of the hand and ball above the head during the shot

- Amount of shoulder lateral rotation during the trunk rotation forward

- Position of shoulder abduction during delivery - should be close to 90 degrees during shot; increased shoulder abduction angle can lead to shoulder impingement problems

- Amount of elbow flexion at release - should be close to 150º, or 40º short of full extension

- Lateral trunk lean during release of the ball - greater trunk lean will produce higher heights of release and lesser angles of shoulder abduction

- Angle of release of the ball should be close to the horizontal to maximize speed of ball

- Maintaining control of the ball during the forward swing

- Hips, knees and trunk are flexed maximally prior to the shot, then are forcefully extended to raise the upper body out of the water for the shot - the boost

- Not looking at the target point in the goal while shooting
REFERENCES


