Electromyographic analysis of the upper extremity in water polo players during water polo shots

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The purpose of this study is to understand electromyographic parameters of selected shoulder and arm muscles in water polo shots. The study was carried out with a group of 12 water polo players. Signals were recorded by surface electromyography (EMG) from the pectoralis major (PM), anterior deltoid (AD) and middle deltoid (MD), biceps brachii (BB), triceps brachii (TB), and wrist flexor (WF) muscles. The average and standard deviation of the normalized electrical activity and duration of the muscles were determined during four different water polo shots in water polo players. Post hoc analysis among muscles revealed that PM and AD showed significantly different amplitude values among water polo shots. Because the PM and AD must relax to perform the horizontal abduction necessary in the backhand shot, the amplitude was significantly lower than during overhead, push, or penalty shots. Similarly, the push shot requires elbow extension of a horizontally adducted and internally rotated shoulder; therefore, the AD has greater amplitude during this shot and TB was activated for longer periods of shots required for the elbow extension. There was little difference observed in WF and BB. Thus, this result suggests that these muscles played a similar role during penalty, overhead, and push shots. Therefore, coaches should emphasize the strength, endurance, and flexibility training of the PM and AD that may improve shooting velocity. However, the stabilizing role of the BB and TB is an important factor for overall performance and should also be considered.

Keywords: EMG; upper extremity; water polo; water polo shots

Introduction

Water polo shots are unique techniques in which the players attempt to score a goal from various positions in the pool by throwing the ball. The overhead shot is the most commonly used and researched shot in water polo (Escalante et al. 2013). However, a number of alternative shots (i.e. penalty, back, push shot) have been developed for different offensive strategies, which may be more practical than the overhead shot (Smith 2004; Wende & Keogh 2008). Previous research has reported quantitative biomechanical analysis of various shooting techniques (Wende & Keogh 2008). It was found that 81% of the water polo shots came from the overhead technique compared with 5 and 7% from the back shot and push shot, respectively. The overhead shot provides the greatest ball velocity of water polo shots, while the back shot and push shot generate 23 and 40% less speed, respectively (Whiting et al. 1985; Elliott & Armour 1988; Ball 1996, p. 26–27, 86–87). Likewise, overhead shots have been reported to have higher accuracy (67.3%) when compared to back shots (27.3%) and push shots (50%) (Clarys & Lewillie 1971). The success rate of penalty shots taken during a water polo game was 80.1% and it was reported that the outcome of penalty shots within each game affected the final outcome of 20% of the games (Smith 2004). Although the speed and precision of a water polo shot are highly dependent on the ability to generate muscle force and to synchronize the contractions of various muscles, there has been very little research examining the muscle activity patterns of the upper extremity during these tasks.

The increased velocity and accuracy of the overhead shot could be a result of greater utilization of the kinetic link principle. The kinetic link principle addresses the relationship between proximal and distal muscles during a task (i.e. throwing). The principle states that larger, more proximal muscles contract to increase angular velocity of smaller, more distal segments. Therefore, if more body segments are used in a sequential pattern, the ball will have greater velocity at release (Kreighbaum & Barthels 1990). Research has shown that the movements which contribute to developing ball speed in the overhead shot occur at the trunk rotation, shoulder, elbow, and wrist (Ball 1996, p. 26–27, 86–87; Feltner & Taylor 1997). However, fewer segments are involved in the back shot and push shot, thereby prohibiting the same degree of torque production (Wende & Keogh 2008). Given the discrepancies between shots and the large
number of body segments involved with each shot, it is crucial that more upper extremity musculature is examined across a range of water polo shots. Therefore, the purpose of this study is to understand how upper extremity muscle activity varies between specific water polo shots. Specifically, electromyographic parameters of the pectoralis major (PM), anterior deltoid (AD) and middle deltoid (MD), biceps brachii (BB), triceps brachii (TB), and wrist flexor (WF) muscles were examined because of their previously established role during water polo shots (Escamilla & Andrews 2009; Alexander et al. 2010). Data were collected during the penalty, overhead, push, and backhand shots as they are the main shots performed in water polo.

**Methods**

**Participants**

The study was carried out with a group of 12 experienced male water polo players (181.3 ± 6.0 cm, 75.16 ± 6.52 kg, 22.6 ± 2.3 years) from the Iranian national youth team. All participants had been active in water polo for more than eight years and had attended at least two international water polo events. Participants did not have a history of shoulder injuries, complaints, or surgery, and were cleared by a health professional prior to testing, which ruled out any previous or current upper extremity dysfunction. The current study was administered according to the ethical guidelines and procedures outlined by the Science and Research Ethics Committee of Azad University, Mashhad. All participants were familiarized with the purpose of the study, testing procedures, and instrumentation, and each signed an informed consent statement.

**Procedures and instruments**

Participants performed penalty, overhead, backhand, and push shots with a regulation water polo ball (Mikasa 6000; Irvine, CA); detailed descriptions of each shot can be found in Figure 1. Participants warmed up by swimming a combination of stroke styles specific to water polo (e.g. freestyle, modified butterfly with head out using a butterfly, flutter, or breaststroke kick) for 15 min. Then participants were given another 15 min to warm up without testing equipment, which focused on the upper extremity muscles and joints during shooting and ball handling. The participants were also given an opportunity to familiarize themselves with performing the four specific test shots (a maximum of three shots per shot type) after electrode attachment. Each participant completed three trials of each shot type in a randomized order, with one shot representing each type during data analysis. A single-blinded physiotherapist examined each trial to determine if extraneous noise or movement artifact was present that could diminish the integrity of the signal. Any trial with low signal integrity (or increased noise) was removed from further analysis. The accuracy of the shot was graded according to a rating system, where shots inside the perimeter of the goal were scored higher than those to the center of the goal (Figure 2). The remaining trials with the greatest accuracy (i.e. highest score) were chosen for analysis. Between each type of shot, an interval of five minutes for rest was set to avoid poor performance resulting from fatigue.

EMG data were collected by using surface differential electrodes (G.tec-USBamp; Austria) with a 20 mm inter-electrode distance. Prior to electrode placement, the skin was shaved, exfoliated, and the site cleaned with isopropyl alcohol. The electrodes were applied to the skin in a direction that was parallel with the muscle fibers, using the recommendations of SENIAM (Hermens et al. 2000). EMG activity for the PM, AD, MD, BB, TB, and WF were recorded unilaterally on the dominant arm. Reference electrodes were taped to the acromion and lateral epicondyle of the humerus. The electrodes were protected by waterproofing procedures for each set of electrodes and attached to extended wires (Veneziano et al. 2006; Benfield et al. 2007; Figueiredo et al. 2013). The electrode wires were bundled together along the thoracic spine and routed out of the pool. The electrodes did not occlude total freedom of movement and data were collected continuously over several minutes.

Maximal voluntary isometric contractions (MVIC) were performed for each muscle, in a randomized order, using previously established positions for forearm and shoulder muscles (Ludewig & Cook 2000; Kendall et al. 2005; Konrad et al. 2001). Verbal encouragement was provided to motivate all subjects to achieve their MVIC levels. Five seconds of the MVICs were recorded and a two minute rest interval was given between contractions. All EMG data were reported as a percentage of root mean square (RMS) values obtained in MVICs, allowing data to be compared among exercises, participants, and muscles (Soderberg & Knutson 2000). The muscles were considered active when the EMG value was above the average threshold of three standard deviations (SDs) of a base-line value for a duration of 50 ms (Hodges & Bui 1996). The baseline value for each muscle was identified as the average RMS of a 100 ms time window that preceded the shot. The period of activation was calculated as a percentage of the total activity duration during which the muscles were considered active (Rouffet et al. 2009).

**Statistical analysis**

The Kolmogorov–Smirnov test was utilized to assess the distribution of variables (p-values between 0.001 and 2.00 were observed). Normalized RMS values and activation...
periods were compared across shots for each muscle. Statistical analysis included one-way analyses of variance for normally distributed data and Kruskal–Wallis tests when parametric assumptions were not met. Statistical analysis was carried out using SPSS 20.0 (IBM Corp., New York), with a significance level set at $p < 0.05$.

**Results**

The mean values and SD of the normalized RMS electrical activity (amplitude) and activity duration of each muscle during the four water polo shots are shown in Table 1.

*Post hoc* analyses revealed significant differences for muscle amplitude between water polo shots (Table 1). There was significantly lower amplitude of PM activity during the back shot compared to any other shot ($p$ values between 0.001 and 0.031). The push shot required significantly greater amplitude of AD activity than both the penalty ($p < 0.004$) and back ($p < 0.031$) shots. In contrast, the back shot required significantly greater amplitude of WF activity than the penalty shot.

| Penalty Shot | Overhead Shot | Push Shot | Back Shot |
|--------------|--------------|-----------|-----------|
| **Initial position** | **Cocking Phase** | **Acceleration** | **Penalty Shot** |
| Ready position for the shot, hand on top of ball | Start elevation, ball pick up, top of backswing | Mid forward swing, release | Ready position for the shot, hand on top of ball |
| Top of backswing for the shot, pick up the ball over shoulder and chest out of the water | Start with horizontal abduction of arm as soon as receive the ball, top of backswing | Pushed forward (forward swing), release | Back to the goal, ball positioned in front of the body hand on top of ball |
| In a front crawl position and pick the ball up | Pulls the ball back towards body (backswing) | Start with internal rotation of shoulder. Ball follows a curvilinear path and optimal release | |
| Back to the goal, ball positioned in front of the body hand on top of ball | Start with internal rotation of and lateral bending of trunk. Ball is lifted sideways as the arm abducts | |

Figure 1. Demonstration of water polo shots.
There were no significant differences detected in the amplitudes of MD, BB, and TB between water polo shots.

Post hoc analyses revealed significant differences for activity duration of muscles between water polo shots (Table 1). The duration of PM activity was significantly shorter in the back shot than the overhead shot ($p < 0.01$). The back shot required significantly less duration of AD activity than both the push ($p < 0.004$) and penalty shots ($p < 0.03$). When compared to the overhead shot, the push shot required significantly greater durations of MD and TB activity ($p < 0.012$). Similarly, the back shot also required a longer duration of MD activity than the overhead shot ($p < 0.015$). The penalty shot required a shorter duration of TB activity than both the push and back shots ($p < 0.000$). Conversely, the penalty shot required a longer duration of BB activity than the overhead shot ($p < 0.026$). There

### Table 1. Mean (SD) of duration and average normalized values of the muscles examined in the water polo players in different water polo shots. Significant differences between water polo shots ($p < 0.05$).

| Water polo shots | Pectoralis major Duration (%) | Anterior deltoid Duration (%) | Middle deltoid Duration (%) | Biceps brachii Duration (%) | Triceps brachii Duration (%) | Wrist flexor Duration (%) |
|------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|
| Penalty shot     | 47.97 (18.56)                 | 70.96 (25.52)                 | 65.83 (17.87)                 | 73.65 (24.96)                 | 46.41 (12.24)                 | 62.61 (24.47)                 |
| Amplitude (%)    | 37.16c                        | 22.44b                        | 14.25                         | 49.63a (14.97)                | 52.20d (14.83)                | 66.09 (13.00)                 |
| Overhead shot    | 61.02g                         | 62.73                         | 58.52 (11.10)                 | 49.63a (18.97)                | 52.20d (14.83)                | 66.09 (13.00)                 |
| Amplitude (%)    | 43.60e                         | 26.30                         | 16.31                         | 24.65                         | 35.64                         | 37.08                         |
| Push shot        | 44.76 (7.46)                   | 78.98d (19.86)                | 78.87 (11.65)                 | 66.28                         | 75.38 (6.89)                  | 62.52 (15.59)                 |
| Amplitude (%)    | 42.23f                         | 33.60bf (9.90)                | 17.60                         | 16.09                         | 43.38                         | 38.05                         |
| Back shot        | 35.08c (18.15)                 | 45.00ec (9.90)                | 6.11 (6.11)                   | 16.09                         | 43.38                         | 38.05                         |
| Amplitude (%)    | 20.95ec (25.26)                | 24.78f (23.78)                | 21.93                         | 36.90                         | 54.48c (22.42)                |                               |
|                  |                                |                               |                               |                               |                               |                               |

Significant differences ($p < 0.05$) exist between:

- Penalty shot and overhead shot.
- Penalty shot and push shot.
- Penalty shot and back shot.
- Overhead shot and push shot.
- Overhead shot and back shot.
- Push shot and back shot.

Figure 2. Goal post rating for accuracy.
was no significant difference observed in the duration% of WF between shots.

Discussion

The aim of our study was to examine EMG parameters during different water polo shots. This study is the first to compare the normalized electrical activity and duration of various upper extremity muscles between shots in water polo players. Although kinematic parameters are important in determining the accuracy and velocity of the ball during each shot, the act of synchronized and well-trained muscles facilitates efficient throwing technique (Gowan et al. 1987). Water polo shots are complex tasks that utilize muscles of the upper extremities differently for each shot (Elliott & Armour 1988; Ball 1996, p. 26–27). The current study supports this theory, as amplitude and activity duration of PM, AD, MD, TB, BB, and WF varied between all four tested shots.

Muscle amplitudes differed between shots in accordance with the upper extremity joint kinematics associated with each shot. The back shot required forceful horizontal abduction to position the upper limb posteriorly to the trunk. The PM must relax to allow this motion to occur, thus resulting in significantly lower PM amplitude for the back shot than any other shot. Subsequently, the duration of PM activity was also significantly less during the back shot than the overhead shot, which used the PM to control forward motion. A similar pattern in activity duration was seen for the AD, which also horizontally adducts, and thus, is less active during the back shot than others, specifically the penalty and push shots. Conversely, the push shot requires forceful horizontal adduction at the shoulder; the amplitude of the AD is greater during the push shot than both the penalty or backhand shots. There was no significant difference in AD amplitude between overhead and push shot, as both utilize a forward motion with little posterior positioning of the upper extremity. The push and back shots required greater activity and duration of MD to maintain the abducted shoulder position that is necessary in the back shot (about 90°) and push shot (abducted higher than 90° and pronated). The push and back shots both require the elbow to extend over a large range of motion and against resistance; therefore, the TB is active for longer durations during the push and back shots than the overhead or penalty shots. The penalty shot requires that the elbow maintain a flexed position during initial and cocking phases, which resulted in longer durations of BB activity between penalty and overhead shots, which maintained an extended elbow. At the most distal joint, the amplitude of the WFs was significantly different between the back and penalty shots. Because the ball is cupped between the forearm and hand during the back shot, greater amplitude of the WFs is required.

There were no significant differences observed in the amplitude of TB and BB during shots. This finding is in agreement with previous research in other overhead activities (Werner et al. 1993). The back, overhead, and penalty shots generate substantial rotation of the trunk and horizontal abduction of the shoulder, thus creating a high centrifugal force at the elbow joint. Because the moments at the proximal joint were greater than the moments that could be produced at the elbow (Sisto et al. 1987), both BB and TB had a similar function of transferring energy during all of the shots. Thus, no differences in BB and TB amplitude were found within this study. These findings suggest that PM and AD differed substantially among shots while the action of MD, BB, TB, and WF were more neutralized and synergistic to stabilize the joints and transfer energy to the ball. In addition to an overall shoulder conditioning program, specifically conditioning PM and AD for more strength and endurance may enhance a player’s shooting velocity. Conditioning MD, BB, and TB for more endurance, power, and flexibility training may enhance the ability of proximal muscles to transfer energy to the ball and reduce the chance of injury. There was little difference observed in WF between shots. Thus, this result suggests that this muscle played a similar role in terms of electrical and temporal activity in penalty, overhead, and push shots. The only difference was related to the amplitude of WF that was markedly higher in the back shot, suggesting that more wrist flexion was due to cupping the ball between the forearm and hand rather than wrist flexion during the acceleration and follow through phases in back shot.

Scientific reporting on the collection of EMG with video/kinematics in water polo shots is extremely limited. No studies to date focus specifically in the kinetic, kinematic, and muscle activity of water polo shots simultaneously. Specifically, movement and muscle activity at the trunk and upper extremity during water polo shots can strongly impact the velocity of the throw and the outcome of the water polo shots. Future research will be necessary to use other biomechanical techniques, such as motion analysis and fine-wire EMG, to study muscle activity that occur during different motion phases of shots. Additionally, EMG activity can be associated with shot velocity; however, this assessment was outside the scope of this study. Future research should account for changes in ball velocity. This will benefit many aspects of strength training and develop muscle-specific training and treatment protocols.

Conclusions

This study has focused on the upper extremity muscle characteristics of various water polo shots. The findings support previous research in overhead throwing...
(Hirashima et al. 2008). Specifically, the more proximal muscles (i.e. PM and AD) that are required to generate more force during the shot were also the muscles that differed the most between the type of shot. Likewise, differences were not seen between distal muscles within the same kinetic link. These findings suggest that while the more proximal muscles may require strengthening that would specifically address the motion required to perform certain shots, a more generalized approach would be as appropriate for the distal muscles. However, the stabilizing role of the BB and TB is an important factor for overall performance and should be emphasized as well. Because of the very different joint kinematics associated with each shot, future research is needed to simultaneously analyze joint kinematics and EMG.

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