

# PoloTrac: A Water Polo Tracking and Advanced Statistics Application

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**Abstract:** PoloTrac is an iOS mobile application designed to allow coaches, players, and spectators to record water polo game events as they happen in real-time. PoloTrac contains features of a standard score-keeping application (such as a functioning scoreboard, clock, and foul counter), however, PoloTrac also calculates and produces post-game reports that provide advanced statistical output. This is accomplished by allowing the user to input the location, type, tactic, and outcome of every shot attempted during a match. These reports are intended to aid in determining player performance, team performance and the effectiveness of certain strategic methods on scoring goals. While PoloTrac contains features recommended by top collegiate water polo coaches, these features are designed to be accessible to users from all areas of water polo (from amateur to professional).

## 1 INTRODUCTION

Water polo is a competitive, aquatic sport that has been played around the world for over a century. Being the first team sport in the Olympic Games, water polo has been a staple in high-level competitive sports at the amateur, collegiate, and professional levels (Escalante et al., 2011). The landscape of sports statistics has changed considerably over the past twenty years. Real-time sports performance analysis is a crucial aspect of matches in major sports around the world (Legg et al., 2012). Professional sports have seen massive improvements in the way player performance, individual play tactics, and overall game strategies are evaluated. This progress known as the “sabermetric revolution” has resulted in a trickle-down effect into amateur leagues (Baumer and Zimbalist, 2014). The progress of professional organizations and the availability of coinciding statistical software has led to an increase in the use of advanced statistical tracking and analysis in many sports at the amateur level as well. However, while the physiological and biomechanical aspects of water polo have been studied extensively, advanced performance tracking and statistical analysis have received less attention.

Many software programs available to collegiate and amateur water polo teams produce only basic

player and team statistics. These statistics include goals scored, shots attempted, steals, blocks, and fouls along with the tracking of game events as they occur. The limited progress and availability of new statistics have created a need in the collegiate and amateur water polo community for a system that is able to record and provide advanced analytics based on the latest statistical research and the recommendations of top collegiate coaches.

PoloTrac is a mobile, iOS application designed to allow coaches, players, and spectators to record play-by-play water polo game events as they happen in the pool. PoloTrac has the features that one might expect from a score-keeping app such as a functioning scoreboard and clock that can keep track of team fouls and timeouts remaining. However, PoloTrac also produces post-game reports that are designed to be useful in determining player performance, team performance and the effectiveness of certain tactics. PoloTrac makes use of the touch interface of iOS devices (iPhones and iPads) to allow users, with a simple tap of the finger, to input specific locations in the pool from which players shoot as well as locations on the net at which they aim. Compiling and charting this data may provide useful insights to water polo players and coaches as to what positions and tactics are producing success in competitions. By utilizing the latest research and statistical models, PoloTrac is

also the first application of its kind to bring advanced data analytics to the average water polo player, coach, and spectator.

## 2 RELATED WORKS

There is a growing body of literature describing the use of computing and advanced algorithms to analyze data related to athletics and sports competitions (Wang and Hsieh, 2016; Gruic and Gruic, 2018; Beernaerts et al., 2018). Our application, PoloTrac, is a mobile application that allows users to record and analyze data from water polo matches using advanced data analytics techniques. In section 2.1 we present several uses of mobile applications in sports. In section 2.2 we discuss recent advancements in the collection and analysis of water polo statistics.

### 2.1 Mobile Applications in Sports

The use of mobile applications to record statistics and to deliver content related to athletic events is becoming increasingly common (Ault et al., 2008; Savva et al., 2015; Berentowicz et al., 2017). Suomela and Soinio (2005) were among the first to discuss the use of smart phones to keep the score and time of outdoor sporting competitions. Specifically, they describe a novel system, StatKeeper, used in the 2004 World Ultimate Frisbee Championship. Like PoloTrac, StatKeeper was designed to be simple and user-friendly. Since it had to be usable by untrained volunteers on a regular basis, the application had to have a clear and intuitive flow of events to maximize scorekeeping efficiency.

Park et al., (2014) propose an integrated management system designed as a mobile application to monitor participation in various sports activities. The system was developed as a mobile application and aims to systematically manage user activity level. Similar to PoloTrac, this application uses two main user interfaces, one for the tracking and logging of data and the other for the presentation of statistics and charts designed to provide the user with useful information.

Can and Donmez (2015) describe an Android application designed to utilize sensors that measure GPS location, speed, and acceleration. These measurements are tracked by the application and are presented to users before, during, and after cardio exercise sessions. The main user interface of the application relies on a GPS enabled map that presents the user's location along with activity statistics. The

statistics are interactive and users are able to explore data in a variety of fashions.

Hlupic et al., (2015) discuss a system to record and process actions that occur at handball competitions and provide statistical analysis during and after each match. Like PoloTrac, this system can provide coaches with data about player and team efficiency during competitions. A mobile application was developed to allow users to record player actions (such as a shot to the goal) as a handball match progresses. A separate web application is used to generate reports.

### 2.2 Water Polo Statistics

Enomoto et al. (2003) were among the first to report findings from an analysis of water polo statistics that sought to identify characteristics of high performing teams. Their findings suggest that, among other things, highly ranked teams take more shots and make fewer offensive mistakes than lower ranked teams. Other authors followed with similar discriminatory analyses of water polo contests based on common box-score statistics (Argudo et al., 2009; Lupo et al., 2010, 2011; Escalante et al., 2011, 2013).

More relevant to this paper is the work of Harris and Graham (n.d.) who examined factors that affect individual shot probabilities. This work explored the "hot hand" effect, suggesting that as a player makes more shots, the odds of a goal increase. This paper also found several significant elements in predicting the success of a shot, such as if the shot was a penalty shot, where the shot was taken, and the sequence of passes leading up to the shot. The shot-based approach described by Harris and Graham is a simplified approach of the shot-tracking methods employed by PoloTrac.

Also paramount to the development of PoloTrac is the work of Graham and Mayberry (2014) who present a notational analysis of offensive tactics commonly employed in elite men's water polo competitions. Following earlier analyses of basketball game data (eg. Kubatko et al., 2007), this work took a possession-based approach to studying water polo and introduced the idea of measuring tactical efficiency as the expected proportion of tactical uses which lead to a goal being scored. This work also provided a list of tactical definitions and additional performance metrics adapted for use by PoloTrac. Graham and Mayberry (2016) additionally applied a possession-based approach to address the question of referee bias in water polo. The authors used a logistic model to predict foul calling probabilities based on various game-state statistics.

PoloTrac utilizes a similar logistic-based approach to estimate shot probabilities based on shot location, shot type, shooter hand, and defender position.

### 3 POLOTRAC OVERVIEW

The idea behind PoloTrac was to use the extended tablet model of the Apple iPad to create a touch screen interface that allows for rapid input and recording of plays in real time as they take place during a water polo match. The application can then generate statistics and charts as well as export spreadsheet enabled reports to leverage the model of tactical efficiency described by Mayberry and Graham (2014). PoloTrac is designed to be a standalone application capable of tracking events during a water polo match. While other score-keeping applications also attempt to simplify the recording of in-game events, PoloTrac uses an intuitive and sequence-based event flow that allows for the recording and advanced analysis of various tactics, outcomes, and locations within the pool.

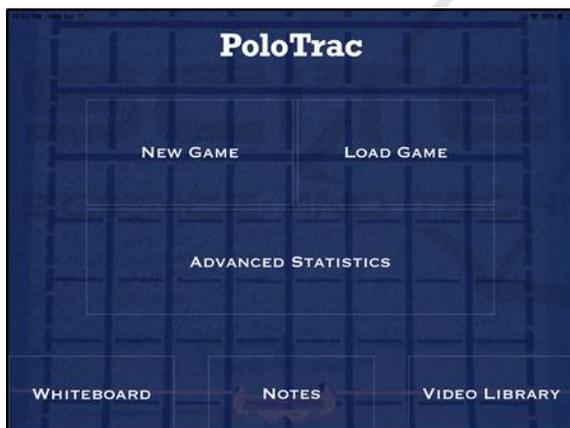


Figure 1: The Main Menu of PoloTrac.

#### 3.1 Main Menu

The PoloTrac main menu has three core functions (New Game, Load Game, and Advanced Statistics) accompanied by three subfunctions (Whiteboard, Notebook, and Video Library) as seen in Figure 1. The core functions serve as a method for opening new games, loading previous games, and viewing and exporting outputs based on the events recorded during games. The subfunctions are independent coaching tools that have been recommended to increase the usefulness of PoloTrac in a game or practice setting. These features are separate from the tracking and analysis that represent the core functionality of

PoloTrac and serve as simple tools for completing actions such as drawing up plays to instruct player positioning, saving notes about specific players and strategies, and uploading video to be organized and viewed for instruction or strategic scouting.

#### 3.1.1 Team Management

In order to track players and their corresponding statistics appropriately, values for name and cap number must be attached and saved. PoloTrac accomplishes this through a feature called team building. Team building allows for the creation, editing, and saving of teams made up of unique, individual players. These teams are saved within the application, therefore, once a user inputs the players and numbers of a specific team this information persists in the application until manually deleted. In the New Game creation screen, users have the option to select two teams from their current list of saved teams or to create a new team. This functionality was designed specifically with water polo leagues in mind as teams who are in the same league frequently play one another more than once.

Teams also serve as an attribute to a specific player. This allows for the sorting of players by teams which is particularly useful in many use cases involving statistical output. For example, a coach may want to see a compilation of a specific team's statistics. They may also want to see what players have the highest statistics from a specific team for scouting and preparation purposes. Or they may want to see which players have recorded the best statistics overall to provide some insight as to which team's players are producing the best statistics. From a coaching perspective, this information is critical in creating a competitive advantage through scouting. Therefore, PoloTrac's ability to input, store and track players from different teams is one of the critical underlying features of the application from a coaching and evaluation perspective.

#### 3.2 Secondary Functions

In addition to its primary features, PoloTrac includes three secondary functions designed specifically with the coach and spectator in mind. These features include a virtual whiteboard in which coaches can draw plays and strategies and erase them with the tap of a button, a notebook designed to keep typed notes, and a video library designed for the user to upload and organize videos.

### 3.2.1 Whiteboard

The whiteboard feature was designed and implemented as a way to “draw up” specific plays, tactics, and positioning over the image of a pool (see Figure 2). This gives both the players and coaches a better perspective of certain locations in the pool relative to the goal. Traditionally, coaches use dry erase boards to communicate this information. By using a tablet interface such as the iPad with programmable software, functionality can be implemented that extends far beyond the reach of a traditional dry erase board.

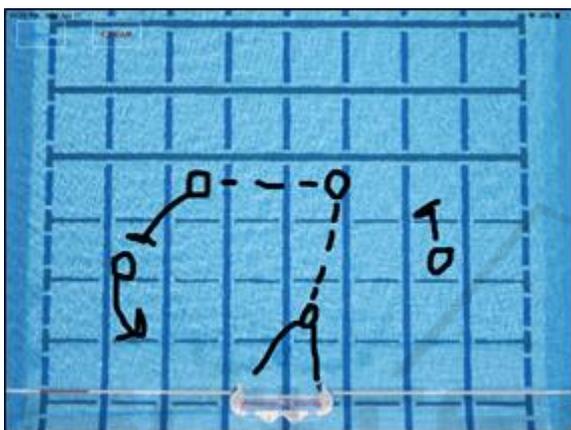


Figure 2: Example of a play drawn on the virtual whiteboard.

Users are able to draw on the whiteboard in a variety of colors, place markers for both offenders and defenders, and erase the entire board at the press of a button. While these features are relatively simple, in the context of a game the ability to accurately draw and erase legible diagrams over the course of a thirty-second to one-minute timeout is critical. A match outcome could be determined by the ability or inability of a coach to effectively communicate with players to execute an important play or possession.

### 3.2.2 Notebook and Video Library

The early stages of PoloTrac’s development included observations of the coaching process during water polo games. Through attending matches and viewing past televised matches, it was observed that coaches frequently jot down notes containing information to refer back to during timeouts and at the conclusion of games. Due to the rapid pace of play in water polo, these game-time notes were often on various pieces of scratch paper and written in formats that were illegible. Therefore, the need to have a section dedicated to simple notes arose. PoloTrac’s Notebook

feature is designed to provide a centralized location for notes. Notes can be attached to specific teams for organizational purposes. For example, a coach might collect notes on his team in order to recall key points of improvement during practice and training sessions, while also collecting notes on opposing teams based on the style and tactics of their play. This allows for a much clearer and organized method of note taking that can be stored and referenced when needed.

A similar ideology lies behind the video library. Often times during water polo tournaments, multiple matches will take place in one day giving coaches and players the ability to watch their upcoming competition before playing them. In order to better understand and outline what an opponent's strengths and weaknesses are, video of previous matches is studied. The video library in PoloTrac serves as a centralized location for images and videos of matches, plays, or practices. Similar to the notebook, videos can be linked with specific teams for organizational purposes. A personal collection of videos and tactics can be accumulated over time and used as a coaching tool to demonstrate strategies to increase the competence of one’s own team while studying the tactics of a competitor.



Figure 3: PoloTrac’s primary tracking screen. The draggable ball user interface is also depicted in the center of the screen.

### 3.3 Primary Tracking Screen

The primary tracking screen (shown in Figure 3) is the key component of PoloTrac. This screen is designed for entering and recording inputs of various aspects of water polo matches. The primary tracking screen has two main purposes. The first is to keep score for the game as a traditional scoreboard would. This includes information that is common in sports competitions, but also critical to the success of the

application’s tracking and analysis features. The second purpose is to provide an intuitive and fast-paced system to track shot information during a match and record it accurately. This is accomplished by leveraging the landscape orientation of the iPad in order to create a “two-thumbbed” interface that can be used in a similar manner as a game-pad controller.

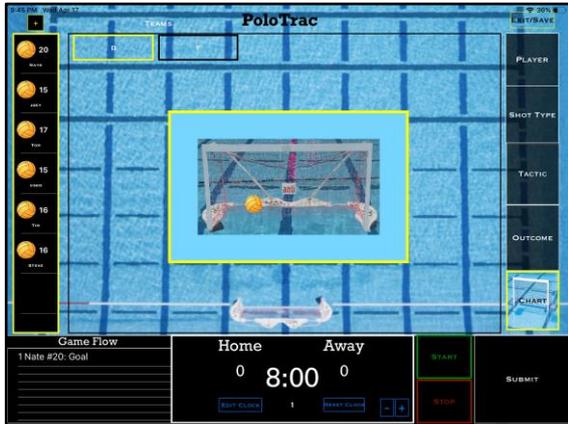


Figure 4: The shot chart displayed in the center of the screen used to track the location of an attempted shot.

### 3.3.1 Scoreboard and Clock

The scoreboard and clock features seen at the bottom of Figures 3 and 4 serve as the basic information display that mirrors the standard water polo scoreboard. This includes data such as home and away score, the current quarter of play, the current time remaining in that quarter, the total exclusions for each team and the total number of timeouts remaining for each team. The score itself is dynamic and will update if a shot with the outcome of “goal” is tracked for a certain player. The team in which that player is on is awarded a point and their score is automatically incremented. The clock feature is controlled by the start and stop buttons directly next to the scoreboard. The clock appears green when it is running and red when it is stopped. This feature is designed to highlight the clock in the user’s mind to ensure it is not running when it should be stopped or stopped when it should be running. The clock, quarter, and timeout values can all be manually configured in the case of a discrepancy between the match and what is reflected on the PoloTrac scoreboard. In some scenarios, it is not uncommon to see the clock be reset to a certain value by the officials of the game in order to ensure accuracy and fairness. Since the clock plays a role in the recording and tracking of shots and shot data, its accuracy is of utmost importance.

### 3.3.2 Draggable Ball and Player Location

PoloTrac utilizes a unique user interface to keep track of shooting locations in the pool. The touch and pan gesture-recognizing capabilities of the iPad allows for the user to “tap” or “drag” the water polo ball to the approximate place in the pool from where the player attempted the shot (as shown in the middle of Figure 3). The pool image embedded as the background on the PoloTrac screen (shown as the background image of Figures 1 to 4) has squares that represent 2 meters by 2 meters. While these squares may not be on every pool the user encounters, knowing their length will aid the user in approximating the player’s location in the pool at the time of a shot. Based on this action, coordinates are created and attached to the specific shot and later used for building charts that can show the location of a player or team’s shot attempts.

### 3.3.3 Shot Chart

In addition to tracking shot locations in the pool, PoloTrac also captures the location on the goal in which the ball was shot. Figure 4 shows the goal image that the user is shown before the shot is submitted. This image, like the main pool, contains a water polo ball icon that can be tapped or dragged to the location in the goal at which the player shot. The coordinates of this approximate location are saved along with the details of the shot and used for statistical analysis and outputs.

### 3.3.4 Shot Tracking Flow

Water polo is a fast-paced game and one offensive possession could contain multiple shot attempts. In order to provide the most accurate results possible, PoloTrac’s user interface is designed in a sequence-specific order that allows for the user to input details and location of a shot in a timely manner. The actions of selecting events in sequence are carried out on the two sides of the screen. The right side of the screen is intended to be selected with the user’s right thumb and indicates the content to appear on the left side of the screen that is selectable by the user’s left thumb.

When users select the Player button on the primary screen (shown in the upper right of Figures 3 and 4) the left side of the screen displays the list of players on the current team so that users can quickly select the player that took the shot (depicted on the left side of Figures 3 and 4). Users can then indicate the shot type and tactic that the player used to attack the goal using the appropriate buttons on the right of the screen, which generates a list of corresponding options on the left side of the screen. Similarly, the

Outcome button presents a table of outcomes (such as “goal” and “miss”) that are possible throughout the course of a game. Lastly, the “Chart” button should be selected and the user can indicate the location of the successful or unsuccessful shot (shown in the center of Figure 4). Once all shot details are entered, users record the shot using the Submit button (shown in the bottom right of Figures 3 and 4) and the outcome is used to update the scoreboard and statistics automatically. For example if a player from the home team scores a goal, the home score will automatically increment by one.

### 3.4 Advanced Outputs

An advanced statistics screen was designed to provide useful feedback to coaches and players through statistics and charts. Users are able to organize these statistics and charts by both individual, team, and game. For example, users could see a shot chart for a specific player from today’s game or they could see a chart for all of that player’s games. The output of the entire team can be viewed as well. This allows coaches and players to easily access statistics for both informational and instructional purposes. The advanced output screen may also be used as a scouting tool. By looking through previous matches of an opponent and their players, trends in the shot diagram could indicate specific strategies used by a team thus giving the user a competitive advantage.

#### 3.4.1 Basic Statistics

Like other water polo scorekeeping programs, PoloTrac allows users to track statistics for each player such as shots attempted, goals scored, assists, total points, exclusions, and steals (as shown in Figure 5). PoloTrac also provides these statistics for both teams and players over the course of an individual game or an entire season. This information is accessible through the advanced statistics menu option and allows users to filter through the data by specifying a team, player, and game on the left side of the screen.

#### 3.4.2 Shot Diagram and Tactical Efficiency

In addition to the basic statistics presented by PoloTrac, users are also able to view the locations in the pool from which players and teams are taking shots. As can be seen in the upper right of Figure 5, the application displays an image of a pool with color coded icons corresponding to the coordinates of each recorded shot. Made shots appear with a green hue and missed shots appear with a red hue. This view can

allow coaches to identify trends in shot locations based on their own expertise to provide feedback to their players. Each shot displayed in the chart is selectable, meaning that it can be “tapped” to see more information. This information contains all of the recorded and calculated details of the shot following the tactical definitions of Graham and Mayberry (2014).



Figure 5: The Advanced Statistics screen.

PoloTrac calculates a predicted goal probability for each shot (displayed as “Tactical Efficiency” and shown under “Individual Shot Statistics” in Figure 5). This value is obtained from a logistic model that uses shot location, shot type, hand, defender position, and offensive tactic as predictors and the binary variable goal or no goal as the response. To obtain coefficients, the model uses a sample of 5177 shots from 86 collegiate water polo games during the 2016-2018 seasons. The model was trained on a randomly selected subsample of shots using a 60-40 split and the remaining 40% of shots were used as a testing set for model validation. The model achieved 70% prediction accuracy on the testing set.

Incorporation of predicted goal probabilities allows users to quantify the quality of their shot selections, a feature that sets PoloTrac apart from other scorekeeping applications. Players and coaches can use this information both during games and in post-game evaluation to identify weaknesses and areas for improvement. For example, by looking at a team’s average tactical efficiency throughout a game, a team can distinguish between scenarios in which they were taking poor shots and scenarios where they were just shooting poorly. A team can evaluate their defensive performance by comparing the actual number of goals allowed with the expected number based on predicted shot probabilities and number of shots allowed. These advanced statistical features

allow players and coaches to make better use of their data and gain a competitive edge in the sport.

## 4 EVALUATION

To perform an initial evaluation of PoloTrac we conducted usability testing (Rogers et al., 2011) with five members of the local water polo community who each had experience coaching or playing the sport. The goal of our usability testing was to determine ways that the interface of PoloTrac could be improved to create a more usable and useful application. Three of our participants used PoloTrac to record statistics at live water polo games and two participants recorded statistics of previously recorded games that they watched on television. All participants were asked to track the statistics of the game they watched and told that they could use the Advanced Statistics button on the home screen to see reports for their inputs. Participants were observed while they used the application, and then asked to comment on the usability and usefulness of PoloTrac at the conclusion of the game that they tracked.

Participants found the overall experience of using PoloTrac to be “positive” and “successful.” Participants also used words such as “easy” and “intuitive” to describe the interface. They were generally pleased with the “two-thumbed” layout of the application. In addition, they found dragging or tapping the ball to a specific location in the pool to be convenient. Participants also felt that buttons such as Submit, Start, and Stop were “in the correct place”. However, participants found inputting shot information to be somewhat challenging at times. In PoloTrac, users are able to select menu buttons (such as Player, Shot Type, and Tactic) in any order they choose. However, during our evaluation users occasionally forgot what information had already been entered as they recorded some of the shots. This led to incorrect data entries, which decreased the accuracy of the statistical output. Participants also commented on the order of many of the selection tabs. For example, a “skip shot” is used often in water polo. However, users had to scroll to the bottom of the shot type list to select skip shot, which slowed them down.

Participants were generally pleased with the functionality provided by the Advanced Statistics screen to filter information based on criteria such as team, player, and game. Participants commented that that the layout and appearance of this screen looked “professional” and “sleek.” However, participants requested that a cumulative statistics screen also be provided to display statistics for all the players on

both the home and away teams for a specific game. Participants suggested it would be useful to see the comparison between two teams for a specific game for information and strategic purposes.

## 5 CONCLUSION

In this paper we describe PoloTrac, an application that allows users to record statistics of live water polo competitions, and that utilizes advanced statistical models to provide reports and analysis not found in other similar applications. Our initial usability testing suggests that while users found many aspects of the application to be intuitive, they sometimes struggled to accurately record shot data in real time as games progressed. PoloTrac has already been modified to place the most recently selected shot types at the top of the shot type list to improve the speed of the shot entry process. To improve the accuracy of shot entry, we plan to modify PoloTrac to require that users input information on each option (such as Shot Type and Outcome) before the Submit button is enabled to record a shot. This should help remind users of all the information required before a shot can be correctly recorded. In response to user feedback, we also plan to implement an additional statistics screen that allows users to compare game statistics for two teams.

In the future, to further improve the application, we would like to collect feedback from coaches who use PoloTrac’s other features before, during, and after matches. Future work could also include modifying PoloTrac to allow users to record additional match information. The tactical efficiency statistic calculated by PoloTrac takes into account features such as a player’s shot location, type of shot taken, and specific tactic used (such as perimeter attack or direct attack). However, PoloTrac does not currently record other player responsibilities in the pool and how those responsibilities are carried out. Tracking information such as the length of passes between players, whether or not plays are executed correctly, and goalkeeper efficiency is not currently supported.

Our hope is that PoloTrac can provide users with a powerful tool for real time tracking and analysis of water polo games. PoloTrac's ability to isolate teams allows coaches to perform in-depth analyses of opponents' shot taking tendencies and evaluate their own team's performance. The ability to isolate individuals can also be used for player development and training. We believe PoloTrac can provide the water polo community with advanced knowledge of their sport, revealing new insights about how shots are made and ultimately, how games are won.

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