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CARDIOVASCULAR AND METABOLIC REQUIREMENTS OF WATER POLO

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Abstract This study is a review of literature related to the energy mechanisms that are used during a water polo game, and it also provides the structure of technical and tactical game activities of water polo players so that useful training conclusions can be drawn. Based on the evidence derived from this review, the mechanisms responsible for the availability of water polo energy and the percent contribution of the aerobic and anaerobic mechanisms rely on the methodological approach and the defensive system of the game. However, as it appears in all of the studies reviewed, the aerobic as well as the anaerobic alactic mechanisms predominate over the anaerobic lactate mechanism. In addition, this review demonstrates that the intensity of the game is reduced, resulting in the increase of the contribution of the aerobic and, in parallel, the decrease of the anaerobic mechanism, in the following situations: 1) in the last minutes of the 4 x 9 minutes' periods in comparison to the 4 x 7 minutes' periods; 2) in the last period of the game compared to the first periods in contrast to the goalkeeper's performance intensity which does not differ from period to period; 3) in games with lower levels of competitiveness compared to the games of higher level; while 4) there are no differences in the intensity of the game (energy requirements) between players of different positions and different levels even though players of a higher level swim considerably faster.

For the water polo training plan, the primary informative sources need to be taken into consideration, i.e. the physiological demands of the game based on the differences in game durations, the period of the game, the level of competitiveness of the players, the level of competitiveness of the teams, and the different player positions.
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Key words: Water polo energy demands, time motion analysis, game duration, period of the game, level of competitiveness, level of athletes, position of players

INTRODUCTION

Water polo (WP) has been played for over a century and it is the oldest activity in the modern Olympic Games, as it was included in the second Olympiad in Paris in the 1900's. Besides, water polo is also played by women. Female water polo has been included in the Olympic Games program since the Sydney 2000 Olympiad. Despite its history and evolution, water polo has not been studied enough probably because of the limited publicity and the difficulties that arise during the collection of data under water. The information referring to the real physiological demands of water polo is limited, even though reference to other sports that demonstrate periodic loads similar to water polo, such as soccer, basketball, rugby, ice-hockey, volleyball, has been cited by other authors who describe the basic moves and physiological reactions of these activities [3, 16, 39].

Previous reviews have examined the physical and physiological characteristics of water polo players as well as the energy demands of water polo [34]. However, in recent years there have been studies investigating the energy demands of water polo game and taking into account the specific characteristics of the game, in particular the physiological characteristics of water polo players. Accordingly, new evidence regarding the physiological demands of water polo players has recently emerged including the position and the role of the players during the game, the competitive level of the players, the different periods of the game, etc [21, 23, 24].

This study is a review of literature relative to the energy mechanisms that are used during a water polo game and it also provides the structure of technical and tactical game activities of water polo players, so that useful training conclusions can be drawn.

THE STRUCTURE OF TECHNICAL AND TACTICAL GAME ACTIVITIES OF FIELD WATER POLO PLAYERS

Time-motion analysis has been proposed as a reliable method for collecting information regarding the demands placed on an athlete as well as for identifying the basic activities in various team sports [9, 16, 29]. The scientific literature regarding game analysis in water polo is very rare and it is limited to the level of local championships or friendly games using the old rules (before 1995). Since that time there have been significant changes in water polo (WP) rules which significantly changed the game demands. Moreover, because of different coding and classification of activities in these studies, comparisons cannot be made.

In measurements of the total linear distance covered by WP players throughout the game, it was found out that the mean was from 500 to 1000 meters [17, 32], with the peak reached from 1500 to 1800 meters [12, 17]. In these studies, only linear movements were recorded while other distances with shorter and non-linear movements which were included in other actions were not calculated. The calculations based on time and motion analysis indicated that field players spend only 45% to 55% of game time in the horizontal body position. The remainder of the time is spent performing activities in predominantly vertical body positions, with and/or without contact with an opponent, and a moderate to high intensity as indicated by heart rate recordings in some studies.

Pinnington and his colleagues [19], as well as Platanou & Geladas [23], however, tried to analyze WP games with different rules and classified actions by recording the heart rate (HR) simultaneously. The analysis of these data allowed the estimation of the effort intensity that the player needs in order to succeed in different skills of the game and be able to play at different positions in the team according to the heart rate percentage presented (Table 1). According to Pinnington, both the HR responses of the subjects while performing game skills and the phases of play revealed that the greatest demands are placed on water polo players when performing skills associated with centre forward play. During this phase of the game, the forward water polo players are under continuous pressure from the defense players while they are trying to position themselves favorably in relation to the defense and the ball. In the Platanou study, greater HR responses of the subjects appeared during the phase of the fast break and to a lesser extent when they were performing skills associated with centre forward play. However, this study took into account both the intensity of the actions of the centre forward player as well as the intensity of the actions of the players who came into contact in the periphery. Also, the divergence between the two studies could be attributed to the changes of the rules and also to the changes of the tactics of the game. Between 1988 and 2004 the game became more mobile, and swimming from on side to the other more frequent and more significant. In any event, it is obvious from both studies that those two actions, i.e. the centre forward play and the fast break play, are the most intense. Consequently, those who intend to play predominantly in the centre forward position or to have a fast break play may be required to have specific, high intensity training regimes in order to maximize their playing potential.

Further information comes from national level players of Canada [33]. Smith accomplished a time analysis of the game activities by videotaping eight games of the 1990 finals of Canadian championship and nine games from those in 1991. The game components were identified and classified, and the frequencies and durations of those activities were measured during each game for further analysis. According to this study, swimming from and to each side comprises 20% of the total game time (11 to 13 minutes) and about 33% of the real game time. About one half of this time is spent in sprinting, i.e. near maximal velocity. Over the course of a game, a player swims an average 60 times for transport, each time lasting 10 to 12 seconds (13 to 15 meters).

All previously mentioned studies were done with national level athletes. In a more extensive study, the game analysis with high level players participating in World class games was recorded [22]. The activities of 48 WP players (16 forwards, 14 center defenders and 18 attackers) were videotaped and analyzed in eight games of the 1997 FINA CUP in Athens. The activities with the higher frequency and overall duration which characterize this sport were: (a) treading water (11:08±01:47 min·sec^{-1}) where the body was in a vertical position and the percentage of the entire game time was 26.8±6.0%, (b) treading water with the "extra man'' or the "man down'' with the duration of 03:00±00:55 min·sec^{-1} and the percentage of 7.2±2.2% (c) swimming from the defense area to the offence area during the fast break or during the fast return to the defense (09:27±01:18 min·sec^{-1} and 22.7±3.1%), and (d) the contact with the opponent (05:22±01:54 min·sec^{-1} and 12.9±6.0%). Additionally, there was a long duration when the game was paused (08:56±00:57 min·sec^{-1} and 21.4±2.1%). All these activities sum to the 91% of medium to long mean duration (8–25 sec) and the interchange with the activities in offence and defense of shorter mean duration (1.8–5.5 sec), which represents only 9% of the total duration of the game. A summary of frequency and duration of the multiple activities accomplished during the game is presented in Table 2.

The WP players were in vertical position almost half the time of the game (46.9%), which is at the same level with the percentage of time that was found in the national games, while "treading water", "treading water with an extra man or a man down" and during the "contact with the opponent". Due to different coding and classification of activities between the national and international games more comparisons cannot be made. Furthermore, the frequency and duration of the activities depend on the players' position. Certain activities are performed more frequently and with an increased overall duration by center forwards compared to attackers and defenders.

Moreover, another study reveals that a player performs an average of 38.7±14.5 passes, 32.1±9.6 receivings, and 7.9±3.1 shots in a game; pass and catch effectiveness does not vary between periods, while shot effectiveness does not vary considerably [9].

It should be pointed out that all the previous data included in these studies were taken before the change of the rules concerning the period duration which was extended from 7 to 8 minutes. The latter had no influence on the percentage with which each activity participates in the total game time.

In 2005, the World Swimming Federation (FINA) changed the water polo rules to make the game more offensive. The most important changes concerned: a) the game duration, which extended from 7 to 8 min for each period, b) the period for keeping the ball which was shortened from 35 to 30 sec, and c) the 2, 4, 7m lines game was limited to 2 and 5m only. Due to the above mentioned, the game duration increased by 14.3% and the ball keeping period was reduced by 14.3%.

Comparing the offence activities in the games with the old and the new rules, it was noticed that the total number of shot attempts was greater (27±4 vs. 22±3.6) as well as the goals scored (10±2.7 vs. 7±2.9) by each team under the new rules ($p<0.001$). However, there was no statistically significant difference in the percentage of goals per shots [25]. Furthermore, there was no difference in the number of exclusions and penalties with the new rules in comparison to the old rules. Regarding the position from which the shots were executed and the goals were scored, the analysis showed that the number of shots from the periphery was greater with the new rules (10.4±2.8 vs. 6.7±2.4, $p<0.001$) but not so of the goals. This may be due to the fact that the foul line came closer to the goal, which might have resulted in an increase of shot frequency, but not in an increase of goals. Also, for the "extra man'', a greater number of shots (8.9±2.7 vs. 5.6±3.0, $p<0.001$) and goals (4.2±1.5 vs. 2.3±1.2, $p<0.001$) were executed with the new rules. However, neither in this or any other case was it found that the percentage (the rate) of goal success in relation with attempted shots was considerably greater with the new rules [25]. In conclusion, it seems that although the number of offensive actions has increased with the new rules (the extended game duration, the shortened time of "keeping the ball" and the foul line coming closer to the goal), there has been no change in the percentage (the rhythm) of the successful attempts achieved by the team. The obvious objective to make the game more spectacular through the latest changes in the rules by increasing the goal frequency in relation to the shots has apparently not been achieved.

The results of time analysis for women were also recorded at the 13th FINA Women' s Water Polo World Cup in Perth in 2002, and they were found to be different from the respective men's activities. Women's games are performed with a smaller ball and in a smaller competitive area than the men's games (25 against 30 meters). According to this study [7], the average exercise bout lasted 7.4±2.5sec, and the game components were: ''swimming'' 64±15.3%, "contested swimming" 13.1±9.2%, "struggling with the opponent" 14.1±11.6%, and "holding the position" 8.9±7.1%. A significant difference concerning the percentage of swimming time and struggling time was found among the field and the central players.

In another study, which investigated the relation between the performance and the technical activities of players at the 9th FINA World Swimming Championship of Water Polo in 2001, it was found that the ''counter-attack'' and the effectiveness of having ''a man down'' were two more significant activities which determine the game result [36].

Table 1. Summary of the intensity of various game activities (mean ± standard error of the mean) [19, 23]

Activities ***Pinnington* [19]**	**Mean HR (beats·min^{-1})**	**% HR peak**	**% $VO2_{max}$**	**Activities** ***Platanou* [23]**	**Mean HR (beats·min^{-1})**	**%HR peak**
Centre offence	175±1	95	>87			
Sprinting crawl	173±2	94	>87	Sprinting crawl	169±1	92.3%
Centre defense	170±2	92	>80	Contacts	166±2	90.7%
Active offence	168-172	92-94	>80	Active offence	164±2	89.6%
Active defense	161-172	88-94	>80	Active defense	160±2	87.4%
Medium crawl	170±1	92	>80	Treading	159±3	86.9%
Ready offence	161-165	88-90	>74	Out of game	153±2	83.6%
Ready defense	161-165	88	>74			
Easy crawl	162±1		>74	Easy crawl	149±2	81.4%
Between	130±4	71				

Table 2. Mean ± SD for the frequency, mean and total duration and percentage of activities during 8 water polo games (4 x 7 min) at the 10th FINA World Cup [22]

Activities	**Frequency (number)**	**Mean Duration (sec)**	**Total Duration (min:sec)**	**% of total time (%)**
1. Swimming crawl	50±6	11.4±1.2	09:27±01:18	22.7±3.1
2. Contact with opponent	32±9	9.8±3.4	05:22±01:54	12.9±6.0
3. Treading Water	82±16	8.1±1.0	11:08±01:47	26.8±6.0
4. Treading Water vigorous	14±5	13.0±3.2	03:00±00:55	7.2±2.2
5. ACTIVE OFFENCE				
A. Attacking without the ball	11±7	4.4±1.5	00:52±00:38	2.1±1.5
• Driving	6±6	3.5±1.8	00:27±00:30	1.0±1.2
• Shift	5±4	4.9±2.7	00:25±00:19	1.1±0.9
B. Attacking with the ball	38±18	2.6±0.7	01:46±01:02	4.2±2.5
6. ACTIVE DEFENSE				
A. Defense to the ball	12±10	3.0±0.9	00:36±00:28	1.4±1.1
• Block	5±6	1.8±1.3	00:12±00:15	0.5±0.5
• Swimming to the ball	7±5	3.4±0.9	00:24±00:17	0.9±0.6
B. Shift	6±5	5.5±2.8	00:36±00:22	1.3±0.7
7. Out of the game	22±3	25.1±2.8	08:56±00:57	21.4±2.1
Total	**279±35**		**41:38±01:28**	

COMPETITIVE INTENSITY – FIELD PLAYERS' CARDIOVASCULAR AND METABOLIC REQUIREMENTS

Four recent studies referring to the energy demands of water polo players have been reported since 1986 up to the present. Prior to that date, one study was conducted in 1966, which involved physically unconditioned players at a limited game space [11]. Also, one more study refers to women's play [13]. In these studies, energy demands were evaluated using a variety of methods, game rules and defense strategies. The evaluation was based on: a) the measured relationship between oxygen consumption and heart rate (HR) during a tethered swimming laboratory test, and the extrapolation of HR values to oxygen consumption (VO_2) values during the game [19]; b) the measured relationship between swimming speed and lactic acid production on a 2 x 400 meters freestyle swimming test and the extrapolation of the recorded speed during the game to lactic acid [12]; c) the measured relationship between HR and the anaerobic lactic threshold which was defined by a specific test of 4 x 200 meters freestyle swimming; the evaluation of the participation of the anaerobic lactic mechanism during the game (Lactate Anaerobic Threshold) by the measurement of HR during the game and lactic acid at the end of the periods [13, 23]; d) the measured oxygen consumption assessed by the Douglas bag method and further by a breath-by-breath gas analysis, at the end of the periods [31]. All the results are presented in Table 3.

Table 3. Physiological adaptations of water polo players in 4 x 7 minutes' games (mean ± SD)

Studies	N	H.R. (Beat·min^{-1})	La (mmol·L^{-1})	VO_2 (L·min^{-1})	En. cost (KJ/min)	Percentage of time played above HR zone (%)		
						HR≥85%	*HR≥90%*	*HR≥95%*
Pinnington	8					85.3±3.5	68.5±6.7	43.3±7.9
Platanou	30	157±18	3.9±1.9			58.5±3.8	39.3±5.4	18.3±4.2
Rodriguez	7			2.96±0.3	57.3±9.0			
Hohman	24		<2					
Hollander	19		5.4			80.1% H.R≥80%		

En. Cost: Energy cost

HEART RATE

Table 3 shows HR data from thirty Greek water polo players, who participated in 10 water polo games of 4 x 7 minutes' duration each, with a zone defense system [35]. The average HR was 157±18 beat·min^{-1} and corresponded to the HR recorded in the anaerobic threshold (155±12 beat·min^{-1}) [23]. In the same study [23], data analysis of time percentage of the game, with predefined limits of the maximum HR (HR max) (Table 3), shows that 58.5% of the game was played in intensities higher than 85% of HR max, 39.3% in intensities higher than 90% of HR max and 18.3% in intensities higher than 95%. Greater percentages of time were played with HRs over these intensity limits, according to Pinnigton et al [19]: 85.3% of the real game time was played with intensities higher than 85% of HR max, 68.5% of real time with intensities higher than 90% and 43.8% of the time with intensities higher than 95% of HR max. Moreover, greater percentages in high intensities were displayed by women as compared with the Greek water polo players [13]. Heart rate measurements of 19 women during the warm up and the 4 x 7 minutes play periods including the recess in between showed that they played with a mean HR percentage 80.1% higher than 80% of HR max. However, the two preview studies did not define the defensive system which the teams employed. They probably played in a pressing defense system, where the intensity of the effort and HR are expected to be higher.

LACTATE RESPONSES

The concentration of lactic acid in the elite Greek male players' blood which was measured during play and in between game quarters, ranged from 2 mmol·L^{-1} to 12mmol·L^{-1} with a mean value of 3.9±1.9 mmol/L^{-1} [23] (Table 3). According to Rodriguez et al [30], lactic acid ranged at similar levels in 9 Spanish athletes but with a greater mean value (7 to 9 mmol·L^{-1}). The low mean value of blood lactic acid accumulation (3.9±1.9 mmol·L^{-1}) which was recorded in the study concerning Greek players might be ascribed to the fact that the games were not official, or even to the zone defense system. Moreover, it might be associated with the relatively low anaerobic capacity (9.90±2.51 mmol·L^{-1}) and probably even more to the sufficient aerobic capacity level which was found (63.69±10.44 ml·kg^{-1}·min^{-1}) in Greek players. The latter fact led to an improved capacity to remove the lactic acid from the blood.

The high lactate values recorded during the game or in between game quarters cannot be commented, since aerobic conditioning of the subjects was not evaluated in the study by Rodriguez et al [30]. However, the relatively low values of lactic acid accumulation which approached the values recorded in the Greek water polo players were also present in women, with a lactic acid range from 1.52 to 9.79, and a mean of 5.34 mmol·L^{-1} [13].

According to the observations of the notational analysis of the players during international water polo games, most activities in water polo are intense and explosive, they last 7-14 seconds and are interspaced temporarily with lower intensity moves that last less than 20 seconds [19, 22, 33]. According to Hohmann and Frase [12], each performance of an activity of such intensity and duration is very likely to be highly dependent on the anaerobic alactic metabolism and muscular power.

However, based on Smith's observations, it could be noticed that these water polo activities are performed continually and end up in accumulation, i.e. in activities of higher duration and medium and high intensity effort [34]. Observations on players during international games have shown that for approximately 85% of the time, the velocity of the activities in the horizontal level was below the velocity of continuous swimming at stable speed that produced blood lactic acid of 2 mmol·L^{-1} [1, 12]. This information is attributed to the high demand from the anaerobic alactic and aerobic mechanism for the reformation of the creatin phosphate and less often from the anaerobic lactic metabolism for providing energy [12]. Despite the above, the glycolytic metabolism accelerates intensely at the beginning of the maximum activity [35] and lactic acid may accumulate in the muscles and in the blood after a brief period of 6-10 seconds of maximum intensity exercise [2, 5]. In addition, the blood samples which were taken during the game and after the quarters of the game showed that the individual levels of lactic acid ranged from 2-12 mmol·L^{-1} [23, 30]. In combination with the high HR which was recorded during the game, a moderate demand of the anaerobic lactic mechanism was shown [19, 23]. It is therefore possible that the speed of the horizontal movements that Hohmann and Frase [12] found does not fully reflect the intensity of the intermittent nature of the activities performed in water polo, especially acceleration and deceleration and activities on the vertical level or in contact with the opponent.

Concerning the maximum concentration of blood lactic acid in water polo players, literature cites medium to relatively high values, ranging from 9.9-16.0 mmol·L^{-1}, which reflects a mediocre training effect upon the anaerobic glycolitic mechanism, in comparison to sports whose energy demands are based on an anaerobic skill (Table 8). On the contrary, the women's values that were recorded were quite lower compared to the men's (6.8- 8.9 mmol·L^{-1}).

Oxygen Consumption

The average maximum aerobic power (VO_{2max}) measured from the collection of gases in Douglas bags at the end of the periods during a game was 70.5±13.6% of the maximum aerobic power measured in a laboratory [31]. In another study where the oxygen demands were calculated with HR recordings during the game, the respective oxygen values rose to over 80% of the VO_{2max} [19], at 2/3 of the game time duration. In addition, according to the estimation of the expended energy rate of the game, it was measured to be from 35 to 80 KJ·min^{-1} (8-19 Kcal·min^{-1}), with a mean value of 57.3±9.0 KJ·min^{-1} [31]. These results show average to high aerobic requirements and energy cost (Table 3).

Fatigue may occur in case of premature intramuscular lactate accumulation or phosphocreatine (PC) depletion that will impair exercise performance. A well-developed cardiorespiratory system is essential to facilitate recovery from the high intensity swims during the periods of rest or low intensity swimming. Endurance-trained athletes with an increased aerobic capacity tend to have a high rate of recovery, with enhanced rates of lactate clearance from the blood and a rapid PC resynthesis in the muscle [10].

Maximal oxygen consumption (VO_{2max}) in men water polo players has been investigated in many studies, as it is seen in Table 8. It varies and usually ranges from 4.7 to 5.2 L·min^{-1} or 58-63 ml·kg^{-1}·min^{-1}, depending on the study and the measurement test (Table 8). As far as it is known, physical and physiological attributes of elite water polo players reflect the adaptations that result from training and competition. Therefore, the evidence that the aerobic mechanism greatly contributes to the overall supply of energy is supported.

Thus, it is concluded that contemporary water polo demands both high cardio respiratory and metabolic aerobic and anaerobic (mostly alactic) loads in elite players. The anaerobic lactate energy mechanism can also be important during training and must be taken into consideration for the training program.

THE EFFECTS OF SPECIFIC GAME CHARACTERISTICS ON CARDIOVASCULAR AND METABOLIC REQUIREMENTS

In water polo – like in all team sports – the physical and physiological demands of the game depend not only on the rules but also on the special characteristics of each game. Such characteristics include the duration of the real game time (four 7-minute periods, or four 9-minute periods, or four 8-minute periods according to the recent changes of the rules), grade importance, the difference in the competitive level between the teams, possible extra time, frequency of interruptions due to fouls, and the position of the players in the game. There has been research into some cases of the physiological demands relative to the special features of the game. More specifically, the following points have been explored and observations can be drawn upon:

a) The absence of significant differences between games of 4 x 7 and 4 x 9 minutes' duration, at the total time of the game (Table 4).

Table 4. Physiological demands of 30 water polo players in 10 games lasting 4 x 7 minutes and 10 games lasting 4 x 9 minutes (mean ± SD) [23].

	N	H.R. (Beat·min^{-1})	La (mmol·L^{-1})	Percentage of time played above HR zone (%)		
				HR≥85%	*HR≥90%*	*HR≥95%*
4 x 7 min	30	155.66±18.24	3.81±1.92	58.5±3.8	39.3±5.4	18.3±4.2
4 x 9 min	30	156.68±17.85	3.91±1.89	59.3±4.4	38.8±5.2	17.7±4.3

The average HR during the game ($p<0.001$) was significantly lower during the last quarter, when the game lasted 36 minutes (4 x 9) in comparison with the 28 (4 x 7) minutes' game. The last 6 minutes of the game during the 9-minute periods were played with players' average HR of 152±7.49 beat·min^{-1} in comparison to 156±2.85 beat·min^{-1} during the 7-minute periods [23]. According to the most recent regulations the game is played in 4 periods lasting 8 min each. It is likely that there is not a significant difference in the intensity and rhythm of the game in comparison to the game consisting of 4 periods of 8 min.

b) The significant and gradual drop ($p<0.001$) in the game intensity throughout the quarters [19, 23].

This significant drop (Table 5) was caused by fatigue from the preceding effort of the players and their reduced ability to maintain a high intensity level. It could also have been caused by the general sense of fatigue of other players in the game which consequently led to the drop of the intensity of the game. The recorded variations in intensity during the game may mean that the coach and the players attempted to gain an advantage over the opponent team at the beginning of the game.

c) A physiological advantage of elite players versus other players.

In a previous study conducted in order to examine the effects of the level of competitiveness on the intensity of the players' game, no important differences were found between players of different levels concerning the time of the game that was played over and under the anaerobic threshold. This occurred even though the values of the average HR and lactic acid in the highest league in the Greek National Championship, A1 category players (162.9±9.9 beat·min^{-1}, 4.67±2.17 mmol·L^{-1}) were higher than those measured in players of the national team (149.8±9.9 beat·min^{-1}, 3.04±1.09 mmol·L^{-1}) [24]. Despite the above, the finding that the members of the national team showed a higher swimming velocity at the lactic threshold than the players of the A1 category (1.31± 0.06 vs 1.25± 0.07 m·sec^{-1}, respectively) suggests a physiological advantage of the national team members versus the A1 category players during the game (Table 6).

d) The physiological demands of the game depend on the level of competitiveness of the teams.

More specifically, it was observed that the anaerobic metabolism was involved more during games with a difference of two goals than at games with more than a two goal difference [21] (Table 7).

Table 5. Physiological demands of water polo players of the 4 periods in games lasting 4 x 7 min (mean ± SD) [19, 23]

	H.R. (Beat·min^{-1})	La (mmol·L^{-1})	Percentage of time played above HR zone (%)		
			HR≥85%	*HR≥90%*	*HR≥95%*
Pinnington (N=8)					
1st Period			87.8±2.9	69.6±7.4	44.2±8.9
2nd Period			86.2±3.8	71.7±7.7	49.4±9.1
3rd Period			83.7±4.5	68.9±6.9	40.0±7.9**
4th Period			83.2±3.7**	63.8±6.7**	39.7±7.2 **
Platanou (N=30)					
1st Period	157.71±11.56	4.02±1.9	61.84±2.8	36.78±4.8	18.26±4.6
2nd Period	158.53±11.64	4.22±1.8	63.12±3.7	41.31±6.2	19.37±4.4
3rd Period	154.99±11.64**	3.71±1.9	56.65±4.4	36.38±5.2	19.77±3.9
4th Period	152.74±11.43*,**	3.47±1.9**	52.46±4.2**	35.15±5.4**	20.74±3.9

Statistically significant differences between periods, * Statistically significant differences from the 1st period. ** Statistically significant differences from the 2nd period, $p<0.05$

Table 6. Physiological demands of a game of water polo players at different levels of competitiveness (mean ± SD) [24]

	N	H.R. (Beat·min^{-1})	La (mmol·L^{-1})	HR ≤ HR_{LT} (%)	V_{LT} (m·sec^{-1})
National	15	162.89±10.37	4.67±2.2	47.5±3.6	1.25±0.07
International	15	149.77±08.41	3.04±1.1	43.6±3.1	1.31±0.06
p value		0.001	0.002	n.s	0.02

V_{LT}: Velocity at lactate threshold, HR_{LT}: Heart rate at lactate threshold

Table 7. Heart rate and lactic acid requirements at different competitiveness (mean ± SD) [21]

Zone HR	Games with 2 goals difference (%)	Games with more than 2 goals difference (%)	P
HR<85% HRmax	33.09±16.54	47.79±24.67	0.01
85%<HR<90% HRmax	21.02±08.05	19.36±06.38	n.s.
90%<HR<95% HRmax	24.52±09.41	18.21±10.46	0.01
95%<HR<100% HRmax	21.37±10.59	14.64±05.48	0.01
HR Beat·min^{-1}.	158±18	154±17	0.001
La mmol·L^{-1}	4.4±2.2	3.4±1.5	0.001

e) No significant difference was observed concerning the energy demands of the central offensive players (center forward), the central defensive players and the peripheral players at training games, between teams which played during the game, with the zone defense system [23].

This is a contradiction with regard to training strategies which often use different physical conditioning training on players with different game positions. Based on data of other athletic activities (team sports), the energy demands of players vary at different positions. These results agree with those results of the studies by Hohmann et al [12] and Smith [33], where the players played a defense system different from the zone. These two studies, which were done under actual game conditions, revealed that there really are differences in skills and activities due to the position of players, however, without the existence of differences concerning swimming velocity or the distance covered during the game. In water polo, it seems that there is a balance between duration and intensity of the different activities characteristic of each position.

PHYSIOLOGICAL DEMANDS OF THE GOALKEEPER

We have less information concerning the demands of the goalkeeper's game. The data come from four studies, with the results drawn from a) two studies dealing with the kinematic analysis of the players' actions [20, 33], b) a study where lactic acid measurements at the end of the periods were determined [30], and c) a recent study where HR, lactic acid and a kinematic analysis of 8 goalkeepers were determined during the game to establish the game intensity [26].

Table 8. Physiological characteristics of water polo players

Athletes studied	Number of athletes	VO_{2max} ($L\cdot min^{-1}$)	VO_{2max} (ml/kg/min)	HR_{max} ($Beat\cdot min^{-1}$)	La ($mmol\cdot L^{-1}$)	Reference
			Males			
Australian state or national	8	4.9	61	184		*19*
Greek national team	20	4.2	49			*1*
UC Berkeley varsity team	20		52.3			*4*
French national team	8	4.5	60.8			*6*
Israeli 'top level'	23	3.9	53.3			*8*
Canadian national team	16	4.7				*37*
Canadian club teams	14	4.1	53.3			*11*
Canadian national team						*34*
• goalkeepers	4	4.6	56			
• field players	24	4.6	58.1			
Greek 'top level'	30	5.2	63.7	183	10	*23*
Spanish national team	16				12	*30*
Canadian national team	16				13	*37*
Hungarian elite					16	*14*
Greek national team	19	5.2	57.9	174	13.6	*38*
			Females			
Serbian national team	12					*27*
• On arm ergometer			46.5			
• On leg ergometer			61.8			
Scottish national team	14	3.4	51.4		6.8	*15*
Australian high level	13	3.2	46.4		8.9	*28*
Greek national team	26	3.1	47.8		7.4	*40*

THE STRUCTURE OF TECHNICAL AND TACTICAL ACTIVITIES OF WP GOALKEEPERS' GAME

The analysis of video tapes and the study of the duration and frequency of the activities of men goalkeepers showed continuity on the demands of 8 athletes at 10 different games during the Canadian championship and of 16 goalkeepers at 8 games during the Greek championship [20, 33]. According to the results after ranking the intensity of the activities, the goalkeepers' game was characterized by short duration activities (<15 seconds), of medium and high intensity (Table 9). The intense activities (hands out, jump) were not so frequent. They were of very short duration (<2 seconds) and followed by activities of almost intense effort (ready to jump). These activities were continuous and lasted 30 seconds in total, followed by a 45-second period of treading water for as long as the game was played at the opponent's side.

In a recent study, a classification in agreement with the analysis of the goalkeeper's game strategy was performed in order to make the analysis more feasible. According to the classification of playing activities, six distinct activities were observed [26]. Three of them (“treading water”, “treading water goal”, “‘time out”) refer to well controlled situations, whereas the other three ("ready to jump", "ready to jump and jump", "man down") are associated with the situations where the goalkeeper was considered to be under threat. The duration of each of the goalkeeper’s activities, when under control, varied between 28 and 77 seconds, representing 66.7% of the whole duration of the game. The activities under pressure corresponded to the remaining 33.3% of the game duration. Their mean duration ranged from 17 to 24 seconds per activity.

Table 9. Summary of goalkeeper activities in a water polo game [20, 34].

Activities	Intensity rating	Frequency (events per game)	Mean duration (sec)	Total duration (min)	% Water time	% Total game time
Smith 4 x 7 min						
Jumps	5 (high)	21	<1	0.2	<1	<1
Hands up	5 (high)	21	1	0.4	<1	<1
Ready sculling	4-5 (medium-high)	55	14	12.6	27	23
Steal/foul	4 (medium)	4	2	0.1	<1	<1
Swimming-passing	4 (medium)	22	7	2.7	6	5
Easy sculling	2 (rest)	40	47	31.4	66	57
Between quarters	1 (rest)	3	154	7.7		14
Platanou 4 x 9 min						
Jumps	5 (high)	35	<1	0.4	<1	<1
Hands up	5 (high)	11	1.5	0.3	<1	<1
Ready sculling	4-5 (medium-high)	55	14	12.2	24	19
Steal/foul	4 (medium)	7	3	0.4	<1	<1
Swimming-passing	3 (medium)	24	6	2.3	5	4
Easy sculling	2 (rest)	46	47	36.3	70	63
Between quarters	1 (rest)	3	154	7.4	<1	12

COMPETITIVE INTENSITY–GOALKEEPERS' CARDIOVASCULAR AND METABOLIC REQUIREMENTS

The mean HR of total mixed playing time, excluding breaks between quarters, was 134.3±20.3 beat·min^{-1} for 36 (4 x 9) min of game duration as it was recorded in 8 goalkeepers during the official games of the high level Greek championship [26]. A large proportion of the game (85.6%) was performed with an HR lower than 151.4±2.7 beat·min^{-1} (82.1±1.4% of HR peak) and an intensity corresponding to the players’ anaerobic threshold (3.49±0.60 mmol·L^{-1}). However, an important part of the game (14.4%) contained activities with sudden HR increases above the anaerobic threshold. Mean blood lactate (BLa) accumulation at the end of each game period was 3.93±1.64 mmol·L^{-1}. Individual lactate values varied from 2.0 to 8.3 mmol·L^{-1}.

Fifty-four percent (54%) of the whole number of measurements provided values above the anaerobic threshold value. Moreover, lactic acid that was measured at the end of the periods, in selected goalkeepers of the national games of Spain was found to be at the levels of 6 and 8 mmol·L^{-1} [30]. In combination with the high HR recorded during a corresponding time portion of the game, a moderate involvement of anaerobic glycolitic (lactic system) can be assumed.

The goalkeeper's exercise intensity reached the highest value (152.5±10.1 beats·min^{-1}), when his team was competing with a player down due to exclusion. In 58% of the time spent in this activity, the HR fluctuated above the anaerobic threshold point. High HR values were also found in other activities that the players performed, such as jumping, saving or blocking the ball.

As far as the physiological requirements of goalkeeping during the 4 periods of the game are concerned, it appears that they remain the same and are not influenced by the progression of time, as is the case with field players [19, 23]. This difference is possibly explained by the fact that during the game, high intensity–short duration effort is frequently interrupted by low intensity–long duration activities. This pattern gives the opportunity for a complete recovery which probably permits the goalkeeper to perform without reducing the intensity throughout periods.

In addition, the total time of work, rest and the ratio of *work:rest* between the goalkeepers of winner or loser teams did not vary significantly. In a comparison study that was done between 8 goalkeepers of winner teams and 8 goalkeepers of loser teams, no significant differences were found [20]. According to this finding, the effectiveness of a good goalkeeper depends on the quality of the execution of specific activities (e.g. timing, speed, angle, height, body position) and on the score skills which the shooting players have.

CONCLUSIONS

According to the data of this review, we conclude that the high cardio respiratory and metabolic aerobic and anaerobic (mostly non lactate) abilities are required simultaneously in high class WP players. Even though some differences exist among the researchers concerning the participation percentage of each mechanism during the WP game, it is generally accepted that the participation of the aerobic mechanism during the game is great while the participation of the anaerobic lactate mechanism is probably limited. This is further confirmed by the physiological characteristics of water polo players. The aerobic capacity of water polo players ranges, at very high performance levels, from 57.5 to 63.7 $ml \cdot kg^{-1} \cdot min^{-1}$. Physical and physiological characteristics of elite water polo players may offer some insight into the minimum requirements for participation, and the adaptations that result from training and competition. Moreover, from this review it is also apparent that the intensity of the game is reduced resulting in the increase of the contribution of the aerobic and, in parallel, the decrease of the anaerobic mechanism, in the following situations:

- During the last minutes of the games of 4 x 9 minutes' duration in comparison with the 4 x 7 minutes' games;
- During the last period of the game in comparison with the first periods;
- At the games with a lower competition in comparison with the games with a higher competition;
- There are no differences concerning the game intensity (energetic requirements) among players of different position and of different performance level even though the high class players swim significantly faster.

Concerning the goalkeeper's game, it can be described as an interrupted game with a great variance in intensity. Most of the game is related to a low aerobic requirement, while a small percentage of the game includes activities with a sudden increase of the heart rate over the anaerobic threshold, indicating also a significant requirement of the anaerobic lactate and non lactate mechanism. During the game, the goalkeeper plays with the greatest possible intensity when the "man down" situation occurs. The goalkeeper's performance intensity does not vary from period to period and is composed of movements which seem to be relatively stable. The goalkeeper's effectiveness is independent of the pressing time but is dependent on other reasons.

PRACTICAL APPLICATION

As we have seen, today's water polo is a highly demanding sport, which may differ from game to game depending on the special circumstances of each game. There are occasions where the game conditions are more intensive and for which the players should be well prepared. That is why coaches should train their teams by increasing the intensity and quantity of the training in comparison with a regular game.

In a review of the literature related to WP, it seems that coaches should examine in advance if their teams need to participate in a championship with an over-the-regular game time (i.e. 4 x 9 min against 4 x 8 min). In this case, they should increase the overall training quantity and intensity in order to obtain better physical fitness which the additional minutes require.

The training purpose should also concern the players' game intensity, which should not be reduced in the course of the game periods. The game rate and intensity should be stable during all the different phases of the game and, more specifically, during the third and fourth periods. Coaches should train all the players of the team with the same intensity regardless of their position during the game, but with a different exercise variety. As for the different energetic systems of the players with different abilities, the overloading should have absolutely the same intensity percentage but with the speed adjusted to their abilities. However, the swimming speed of lower ability players should be improved by means of the repetitive method at short distances.

The goalkeeper's training should focus on exercises which increase explosive power in order to improve the ability to do different kind of jumps. Their training should also include a small quantity of high intensity and middle duration exercises which will result in lactate concentration in order to improve their performance in situations of “man down” or “ready for jump and jump”. The aerobic metabolism of low intensity, which is mostly used in the goalkeeper's game, is not necessarily emphasized in extended training for high level aerobic capacity.

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