

RELATIONSHIPS BETWEEN HEART RATE AND PHYSIOLOGICAL PARAMETERS OF PERFORMANCE IN TOP-LEVEL WATER POLO PLAYERS

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AUTHORS: Galy O.^{1,2}, Ben Zoubir S.³, Hambli M.³, Chaouachi A.³, Hue O.¹, Chamari K.⁴

¹ Laboratoire ACTES EA 3596, UFR-STAPS, Antilles-Guyane, Pointe à Pitre, France

² Laboratoire CNEP EA 4242 University of New Caledonia, New Caledonia

³ Research Laboratory "Sport Performance Optimization", National Centre of Medicine and Sciences in Sport (CNMSS), Tunis, Tunisia

⁴ Athlete Health and Performance Research Centre, ASPETAR, Qatar Orthopaedic and Sports Medicine Hospital, Doha, Qatar

Reprint request to:

Galy Olivier

Laboratory ACTES,

UPRES EA 3596

BP 32527

98897 NOUMEA

NEW-CALEDONIA

phone /fax : 00 687 81 56 02

E-mail : olivier.galy@univ-nc.nc

ABSTRACT: The aim of this study was to measure the heart rate (HR) response of eight elite water polo players during the four 7-min quarters of the game and to check for relationships with the physiological parameters of performance ($\dot{V}O_{2\max}$, $Th_{1\text{ventr}}$, $Th_{2\text{ventr}}$). Each athlete performed a $\dot{V}O_{2\max}$ treadmill test and played a water polo game wearing a heart rate monitor. The game fatigue index was calculated as the ratio of the fourth-quarter HR to the first-quarter HR: HR4/HR1. The results showed a slight decrease in fourth-quarter HR compared with the first quarter, with the mean four-quarter HR equal to $79.9 \pm 4.2\%$ of HRmax. Stepwise multiple regression analysis showed $\dot{V}O_{2\max}$ to be the main explanatory factor of game intensity, i.e. game HR expressed in $\%HR_{\text{reserve}}$ ($R=0.88$, $P<0.01$). We observed that higher aerobic capacity resulted in higher game intensity. We also observed a decrease in the playing intensity in the fourth quarter compared with the first, likely due to very high game involvement. We concluded that high aerobic capacity seems necessary to ensure high game intensity in water polo. This suggests that coaches should encourage their athletes to reach a minimum level of $\dot{V}O_{2\max}$ and that HR monitoring could be of great interest in the control of water polo training sessions.

KEY WORDS: water polo, heart rate, aerobic capacity, ventilatory threshold, $VO_{2\max}$

INTRODUCTION

Water polo was the first team sport included in the Olympic Games in Paris, 1900. Unfortunately, despite more than a century of competition, few studies have investigated this Olympic activity and the possible relationships between laboratory testing and the actual game.

In 2008, Platanou et al. [22] performed a thorough physiological analysis of water polo players and characterised the intermittent aspects of this sport, mainly based on the players' aerobic power and lactate threshold. A high percentage of playing time is devoted to sprinting and explosive-type activities, which implies a considerable demand for creatine phosphate [9]. The physiological characteristics of water polo players are similar to those of players of other team sports [6,25] and individual sports [12,15] and are frequently linked to aerobic capacity variables such as maximal oxygen uptake ($\dot{V}O_{2\max}$) and the first and second ventilatory thresholds: $Th_{1\text{vent}}$ and $Th_{2\text{vent}}$. Previous studies have reported $\dot{V}O_{2\max}$ values around $60 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ in internationally ranked water polo players [11, 16,21,22,23,24]. These relatively low $\dot{V}O_{2\max}$ values, when considered alone, could be interpreted as one of the less selective pa-

rameters of water polo performance. Water polo is an intermittent sport, with many intense bursts of activity of <15 seconds duration, thus requiring a high fraction of O_2 consumption. The relationships between the ventilatory thresholds and the game characteristics may therefore be relevant to assess and improve water polo game performance.

Heart rate (HR) has been shown to be a good indicator of exercise intensity [5,6] in both endurance sports and prolonged efforts including intermittent intense exercise [12,15,21,13,14,19]. The measurement of HR during a water polo game could thus provide insight into the game intensity and help to determine the relationships between game heart rate and laboratory parameters of aerobic capacity such as $\dot{V}O_{2\max}$, $Th_{1\text{ventr}}$ and $Th_{2\text{ventr}}$. If relationships indeed exist, this might offer coaches a helpful tool for building better programmes and monitoring water polo training.

To the best of our knowledge, no study has yet attempted to establish the relationships between water polo game HRs and the classic laboratory variables (i.e., $\dot{V}O_{2\max}$, $Th_{1\text{ventr}}$, $Th_{2\text{ventr}}$) relevant to aerobic performance.

The aim of the present study was thus to measure the HR response of water polo players during the four quarters of a game to determine whether these values were correlated with the aerobic capacity variables measured in the laboratory.

MATERIALS AND METHODS

Subjects. Eight male water polo players volunteered to participate in the study and provided written informed consent. The subjects were reminded that withdrawal from the study was possible at any time. They were 26 ± 2.7 years old and had a height of 180.2 ± 8.6 cm and a body mass of 85.5 ± 11.7 kg. All subjects were members of their national water polo team. Their average weekly training programmes included eight water polo sessions and one game. The study was approved by the university ethics committee.

In-pool game heart rate measurements

Heart rate was monitored with a heart rate monitor (Polar Vantage NV, Polar Electro, Kempele, Finland). Five-second recording intervals were selected. In order to reduce the risk of injury, the receivers were taped to the player's wrists.

In order to obtain HRs over the four quarters of the game, the exact time of the start of the heart rate monitor was noted for each subject. Then, the strategic events of the game were accurately noted, i.e. the start and the end of each 7-minute quarter. This allowed further extraction of the relevant HR values.

Testing protocol

Water polo game

All the subjects were training intensively at the time of the study. They were aware that they would soon be participating in a game to help the coach select the players for upcoming competition. The coach had officially informed them that this game was very important for choosing the regular team players. The selective game was played one month before the competition. The present study was therefore designed to assess these highly motivated players during this important period.

The selective game was played at 2.30 pm in an official water polo pool. Fourteen players were divided into two seven-player teams that had been assembled by the coach to be of comparable level. The game was composed of four 7-minute quarters with 2 minutes of recovery in between. The players performed a 20-minute standardised warm-up, according to the coach's instructions. As there had been no change in any of the players, the entire group completed the four 7-minute quarters, and no one was excluded for a 20-second penalty period. The international rules state that the stopwatch has to be stopped each time the referee whistles, and thus the mean duration of the four game periods was $10 \text{ min } 03 \text{ s} \pm 31 \text{ s}$, ranging from 8 min 57 s to 11 min 05 s. Because of technical problems, we could only analyse the game HRs of eight field players. During the 2 weeks preceding the selective game, each subject came to the laboratory to perform a maximal incremental laboratory trial (from 2 to 5 pm at a laboratory temperature of 20 to 22°C).

The subjects were asked (1) to abstain from exercise on the day preceding any assessment, and (2) not to drink caffeine beverages on the days of the laboratory test and the selective game [5,12,15,23].

The water polo HR values were expressed in percentage of (1) HR_{max} ($\% \text{HR}_{\text{max}}$) and (2) $\text{HR}_{\text{reserve}}$, i.e. $\text{HR}_{\text{max}} - \text{HR}_{\text{rest}}$ ($\% \text{HR}_{\text{res}}$). The game fatigue index was calculated as the ratio of the fourth period HR to the first one: HR_4/HR_1 . Due to the specificity of their roles during the game and the differences in their HR responses with respect to field players [24], the goalkeepers were excluded from the statistical analysis.

Laboratory testing

Subjects performed a maximal graded exercise test on a treadmill to measure their maximum oxygen uptake ($\dot{V}\text{O}_2\text{max}$). Prior to the test, they lay quietly on a bed for 15 minutes for the measurement of their resting HR (HR_{rest}), and the test was then performed on a 0 gradient treadmill (Woodway, Ergo XELG 90, Weil, Germany). It began with a 3-minute warm-up at $9 \text{ km} \cdot \text{h}^{-1}$, immediately followed by $1 \text{ km} \cdot \text{h}^{-1}$ increments every minute until exhaustion. Oxygen uptake was considered maximal if the following criteria were met: (1) a levelling off of $\dot{V}\text{O}_2$ despite treadmill speed increase; (2) a respiratory gas exchange ratio higher than 1.1, and (3) attainment of age theoretical $\text{HR}_{\text{max}} \pm 5$ bpm. All the subjects met the physiological criteria for $\dot{V}\text{O}_2\text{max}$. The $\dot{V}\text{O}_2\text{max}$ was expressed relative to (1) body mass ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) according to allometric scaling ($\text{ml} \cdot \text{kg}^{-0.75} \cdot \text{min}^{-1}$) [6] and (2) body surface area ($\text{l} \cdot \text{BSA}^{-1} \cdot \text{min}^{-1}$) according to Izakson's formula [26]: $\text{BSA} = 0.01 (\text{H} + \text{bm}) - 0.60$, where H = body height (cm) and bm = body mass (kg). Indeed, Chatard et al. [7] indicated that swimming resistance is influenced by body surface area. The peak HR attained at exhaustion of maximal graded exercise was considered as HR_{max} [5]. Exhaustion occurred within 10 to 15 minutes of exercise for all subjects.

The measurement of the cardiorespiratory variables was performed with a breath-by-breath cardiorespiratory device (ZAN 680, Oberthulba, Germany), which allowed continuous measurement of HR, the pulmonary gas exchanges, and ventilation during the test. Prior to each test, the gas analysers were calibrated with gases of known concentrations. The ventilatory membrane was calibrated with a 1-l syringe with at least six syringe movements of varying pace. Heart rate was determined from a six-lead ECG with 12 derivations. HR and the respiratory data were provided once every 30 s, with the values averaged over the last ten respiratory cycles on a sliding technique basis [28]. The $\text{Th}_{1\text{-vent}}$ and $\text{Th}_{2\text{-vent}}$, i.e. anaerobic threshold and the respiratory compensation threshold, respectively, were established according to Beaver et al. [2]. These thresholds were determined visually by two investigators using a double-blind procedure. Thresholds were expressed in terms of percentage of $\dot{V}\text{O}_2\text{max}$.

Statistics

Values are expressed as mean \pm standard deviation ($m \pm \text{SD}$). A one-way analysis of variance (ANOVA) was performed on the HRs from

TABLE 1. MEAN HEART RATE (HR) IN BPM DURING THE WARM-UP AND EACH QUARTER OF THE MATCH, INCLUDING RECOVERY QUARTERS. HR VALUES ARE EXPRESSED IN ABSOLUTE VALUES AND IN % OF HR MAX

	Warm up	Quarter 1	Recovery 1	Quarter 2	Recovery 2	Quarter 3	Recovery 3	Quarter 4	Mean HR 4x(Quarter + Recovery)	Mean HR of the four game quarters	Mean HR of the four recovery periods
HR mean values (bpm)	126	157	127	156	124	153	128	153	142	155	127*
(SD)	11	14	16	14	15	14	14	14	15	14	15
% of HR max	67.2	83.8	67.9	83.4	65.8	81.5	67.8	81.5	76.0	82.6	67.5*
(SD)	1.3	1.4	3.1	3.0	2.2	1.3	3.0	2.3	1.4	2.0	2.0
Times lasted during quarters including time-outs		9'15"		9'		11'		11'05"			

the four quarters to determine whether significant evolution in HR had occurred over the game. The same analysis was performed in the last 6 minutes of play between quarters of different durations to overcome the inherently unequal number of data cells due to the referee whistles during the game, as described elsewhere [22]. A bivariate Pearson correlation matrix and a stepwise multiple linear regression analysis were performed between (1) the mean game HRs and the fatigue index measured during the selective game, and (2) the physiological variables measured in the laboratory.

$$\text{Game HR (\%HR}_{\text{res}}) = 0.57 (\text{VO}_{2\text{max}}) + 28.27$$

$$R=0.88, R^2=0.77, P<0.01$$

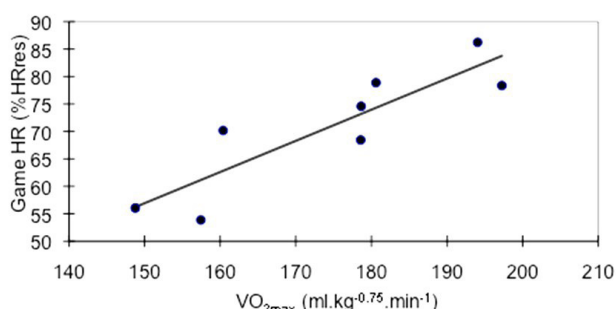


FIG. 1. LINEAR REGRESSION BETWEEN THE PLAYER'S $\dot{V}O_{2\text{MAX}}$ ($\text{ml} \cdot \text{kg}^{-0.75} \cdot \text{min}^{-1}$) AND THE MEAN HEART RATE (HR) FOR THE FOUR QUARTERS OF THE GAME EXPRESSED IN PERCENTAGE OF HRRESERVE ($\%HR_{\text{RES}}$)

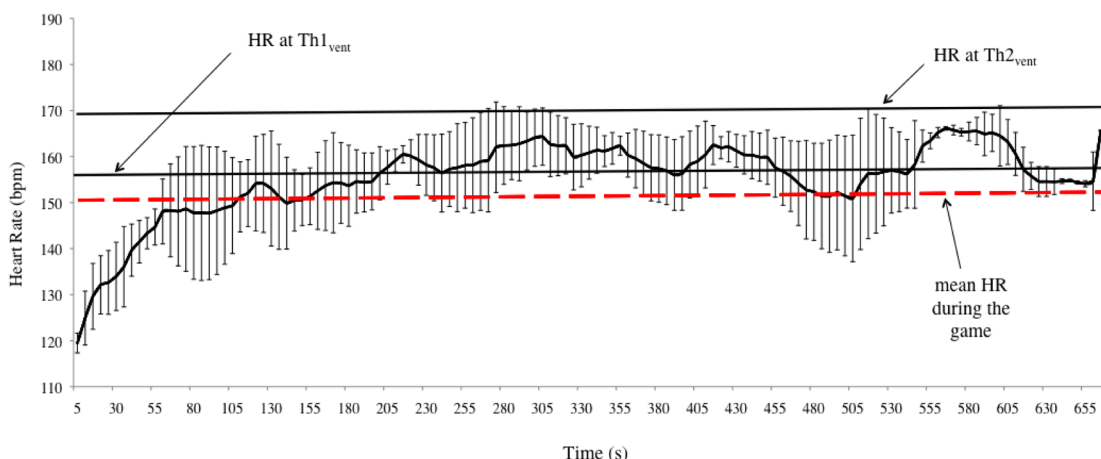


FIG. 2. MEAN HEART RATE (HR) MEASURED CONTINUOUSLY OVER THE FOUR GAME QUARTERS. THE SOLID BLACK LINES REPRESENT THE HR AT $Th_{1\text{VENT}}$ AND $Th_{2\text{VENT}}$. THE DASHED RED LINE REPRESENTS THE MEAN HR OVER THE WHOLE GAME.

The physiological variables introduced into the Pearson correlation matrix were the mean HR values for the four game quarters, the fatigue index (HR_4/HR_1), $\dot{V}O_{2\text{max}}$ (expressed in $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, $\text{ml} \cdot \text{kg}^{-0.75} \cdot \text{min}^{-1}$, and $\text{ml} \cdot \text{BSA}^{-1} \cdot \text{min}^{-1}$), $Th_{1\text{vent}}\% \dot{V}O_{2\text{max}}$ and $Th_{2\text{vent}}\% \dot{V}O_{2\text{max}}$. Statistical significance was fixed at the $P<0.05$ level.

RESULTS

Laboratory testing. The subjects' $\dot{V}O_{2\text{max}}$ was $57.4 \pm 5.6 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ or $174.4 \pm 17.4 \text{ ml} \cdot \text{kg}^{-0.75} \cdot \text{min}^{-1}$. At the end of $\dot{V}O_{2\text{max}}$, HR_{max} reached a mean of $188 \pm 8 \text{ bpm}$. During the test, $Th_{1\text{vent}}\% \dot{V}O_{2\text{max}}$ and $Th_{2\text{vent}}\% \dot{V}O_{2\text{max}}$ corresponded to 81.6 ± 4.5 and $90.4 \pm 6.0 \%$ of $\dot{V}O_{2\text{max}}$, respectively.

In-pool measurements

No difference between the mean HRs for the four quarters was noted. Field data are detailed in Table 1, where absolute and relative values of HR are reported for warm-up and the 1st, 2nd, 3rd, and 4th quarters of the game including recovery quarters. In addition, the cumulated time of the water polo game is reported in this table. Figure 2 shows that the HR value was above the mean HR value after 2 minutes of game play. In addition, Figure 3 shows significantly higher mean HR values in the last 6 minutes compared with the mean HR values of the whole game, although we observed a slight decrease in HR between seconds 150 and 255 of the last 6 minutes.

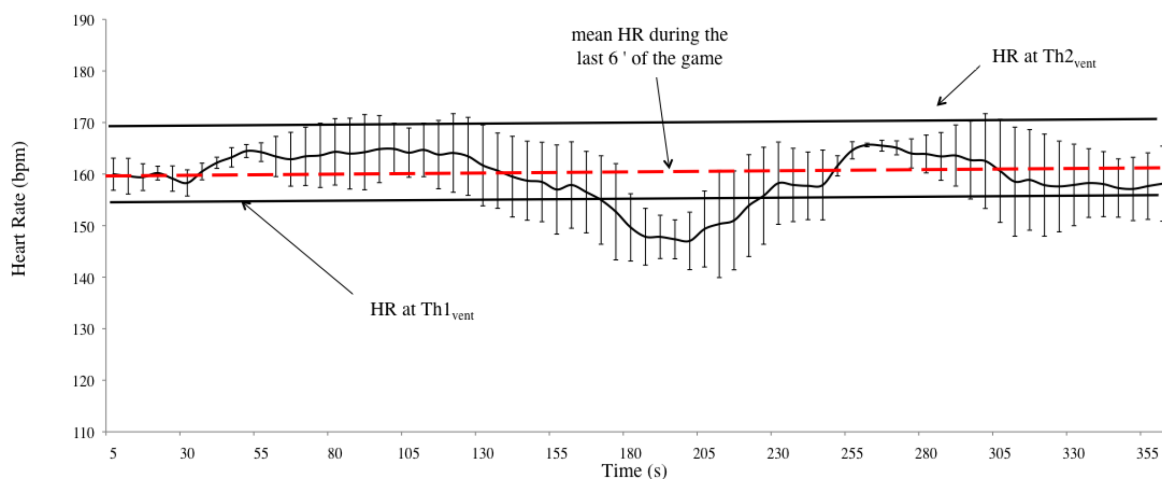


FIG. 3. MEAN HEART RATE (HR) MEASURED CONTINUOUSLY IN THE LAST 6 MINUTES OF EACH QUARTER. THE SOLID BLACK LINES REPRESENT THE HR AT TH1_{VENT} AND TH2_{VENT}. THE DASHED RED LINE REPRESENTS THE MEAN HR IN THE LAST 6 MINUTES OF EACH QUARTER.

Relationship between game HR and laboratory testing

Stepwise multiple regression analysis showed $\dot{V}O_2\max$ ($\text{ml} \cdot \text{kg}^{-0.75} \cdot \text{min}^{-1}$) to be the main explanatory factor of game intensity, i.e. game HR expressed in $\%HR_{\text{res}}$ ($R=0.88$, $P<0.01$; Figure 1).

A negative relation linked the fatigue index to $\dot{V}O_2\max$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$): $y=-0.9(\dot{V}O_2\max)+148.44$; $R=-0.73$; $R^2=0.53$, $P<0.05$, and to the $\text{Th2}_{\text{vent}}\% \dot{V}O_2\max$: $y=-0.41(\text{Th2}_{\text{vent}}\% \dot{V}O_2\max) + 135.07$; $R=0.72$; $R^2=0.52$; $P>0.05$, whereas no significant correlation was found for $\text{Th1}_{\text{vent}}\% \dot{V}O_2\max$.

DISCUSSION

The main finding of the present study is that during a four-quarter water polo game, the mean game HR expressed in percentage of HR reserve was significantly correlated with the player's $\dot{V}O_2\max$. This relationship shows that the water polo game intensity is influenced by the player's aerobic capacity.

The athletes' $\dot{V}O_2\max$ reached almost $60 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, in agreement with current reports [11,16,23,24,21,22]. This indicates that a player's aerobic capacity expressed in O_2 uptake should not be considered as the most important selective variable in elite water polo. Indeed, the Tunisian national team could be considered as presenting an average performance with respect to the international level. As proposed by Smith [24], water polo performance is multi-dimensional, including high stature and body mass, tactical sense, technical abilities facilitated by good muscular power, and the capacity of the player to perform short bursts of exercise with high frequency during the game. This latter point is common to top-level water polo players [9,27]. Therefore, it seems that our subjects presented the characteristics proposed by Veliz et al. [27] as necessary for a good recovery between the short bursts of exercise during a water polo game.

Measuring the maximal oxygen uptake during a swimming test would have given an accurate assessment of aerobic capacity for this water sport, and it is obvious that a pool test is closer to the usual activity of water polo players. Nevertheless, this test requires

equipment not often available in many physiological laboratories [23], and even recent studies still use general fitness tests for water polo players, such as cycling or treadmill running [1,11]. Authors such as Rechichi et al. [23] and Mujika et al. [21] have designed reliable and valid field swimming tests to assess the aerobic performance of water polo players, which may be considered as quite pragmatic. However, as these tests are performed in a pool, they do not give any indication of real O_2 uptake or submaximal variables such as the ventilatory thresholds. A technique to estimate $\dot{V}O_2$ from retroextrapolation calculation has been developed [8], but it requires the swimmers to have sufficient skill to swim at speeds that could generate considerable variations in energy cost. The subjects of the present study were not highly skilled enough, and therefore the risk of error in the $\dot{V}O_2$ estimation was too high using this method. A water polo player swims only about 20% of the time, spending the rest of the game in a vertical position with very specific movements [10].

The $\dot{V}O_2\max$ treadmill test is generally used [3,6,15], and even though this test is not performed in a pool, it gives insight into the subject's general aerobic fitness by way of aerobic capacity assessment [11]. It also gives information on submaximal stages, such as the ventilatory thresholds, which are relevant to endurance performance [3,12,15]. Konstantaki et al. [17] showed that submaximal responses, rather than peak dry land bench test responses, were correlated with game HR in female water polo players. Moreover, despite being in a pool, water polo players are frequently in a vertical position (to defend, wait for the ball, shoot, etc.) for periods ranging from 45 to 63% of the total playing time [4,20,24] and change from vertical to horizontal position about 60 times or more per game [24]. Thus, HR_{\max} was chosen as the running/standing peak HR measured at the end of the treadmill $\dot{V}O_2\max$ test and game HR was expressed as a percentage of this peak HR [5].

During the game, the players' mean HR in the four quarters represented almost 80% of HR_{\max} . However, the HR kinetics re-

vealed that HR was above the mean HR value after 2 minutes of game play in the first quarter and until the end of the game (Figure 2). In addition, Figure 3 shows a significantly higher mean HR value in the last 6 minutes compared with the mean HR value of the whole game. Despite the possible effect of some non-physiological variables on HR, it is widely acknowledged that this variable is a good indicator of continuous exercise intensity [2,3,6,12,15], mainly when expressed as a percentage of HR_{max} rather than the absolute HR value [14,19]. Furthermore, when expressed as a percentage of $HR_{reserve}$, i.e. $HR_{max}-HR_{rest}$, HR is closely related to oxygen uptake in continuous exercise [13]. If the exercise pattern is intermittent, as in prolonged aerobic exercise and other team sports, the HR time course is similar to that of $\dot{V}O_2$ [6], which has been confirmed in other team sports [6,25]. Thus, HR can be used as a game intensity indicator in water polo [9,24,27]

The present results showed a positive and significant correlation between the players' $\dot{V}O_{2max}$ and the game intensity ($\%HR_{res}$; Figure 1). This is in accordance with observations on other team sports such as soccer, as Stohlen et al. [25] reported that the higher the soccer players' $\dot{V}O_{2max}$, the higher his average match HR expressed in $\%HR_{max}$. This indicates that a good aerobic capacity is needed to be able to maintain high game intensity in water polo [16,21,22]. Coaches can thus be advised to encourage their athletes to achieve a certain level of aerobic capacity in order to ensure high game involvement. Indeed, it is generally wrongly thought that intermittent sports do not rely much on aerobic metabolism. The correlation reported in Figure 1 clearly shows that players' aerobic capacity has an impact on their game involvement and thus probably on their game performance. Moreover, a correlation was observed between the index fatigue and Th_{2vent} expressed as a percentage of $\dot{V}O_{2max}$. While a statistical difference was noted ($P<0.05$), the physiological significance should be considered since the points of this correlation are disparate among the eight players. Nevertheless, performance parameters such as Th_{1vent} and Th_{2vent} need to be considered in the aerobic profiles of these players. It is well known that aerobic abilities are position-dependent in team sports, especially in water polo [16,22], which was indicated by the wide dispersion in the observed Th_{2vent} . For this reason, the HR kinetics were analysed during each phase of the game (Figures 2 and 3) to give a picture of the continuous HR responses over the whole game (Figure 2), especially in the last 6 minutes (Figure 3), and then compared with the mean HR at

Th_{1vent} and Th_{2vent} measured during $\dot{V}O_{2max}$. This analysis revealed that in the last 6 minutes of each quarter, the mean HR values were situated between Th_{1vent} and Th_{2vent} , i.e. around 160 bpm, whereas over the whole quarter, the mean HR was around 150 bpm. These values observed during the last 6 minutes of each quarter precisely described the intensity of the water polo game, with HR slightly drifting in the fourth quarter, as previously reported [22]. Indeed, water polo is an intermittent activity, mainly relying on players' aerobic power and lactate threshold [22]. "However, a high percentage of playing time is devoted to sprinting and explosive-type activities, implying also a considerable demand on phosphocreatine. Extending the playing time of each quarter diminishes the exercise intensity during the final 6 min" according to Platanou et al. [22]. We can therefore assume that the HR values at Th_{1vent} and Th_{2vent} are determinants for the training zone, which could help coaches to improve the overall aerobic performance of their players.

CONCLUSIONS

To summarise, it seems that in water polo, the higher the player's aerobic capacity, the higher the game intensity. As a result of the very high game involvement, players slightly reduce their game intensity in the fourth quarter with respect to the first. This decline in HR is significantly linked to $\dot{V}O_{2max}$. As water polo game HR seems to be correlated with the classic physiological variables, this finding emphasises the importance of developing aerobic capacity in training programmes for water polo players.

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Conflict of interest: None.

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