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A complex hybrid heart rate test methodology to analyse elite water polo players' 0-24-hour activities during competition period

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Abstract
Background: *In water polo, performance depends on a variety of physiological functions. This study focuses on the analysis of heart rate, a well-examined physiological indicator, in addition to several other methods for measuring the fitness of elite male water polo players. However, wearing traditional smartwatch systems in a pool is dangerous, thus forbidden by the official rules of the games. One of our methodology innovations is the use of a novel optical sensor approved by competition rules which can measure players' heart rate during matches.*
Materials and Methods*: The study covered 31 days during the regular championship period with an average of 2 pool training sessions per day and in addition 4 games during the intervention period. The heart rate of players was monitored non-stop by a hybrid method using a smartwatch for dryland training and other activities, and an optical sensor for pool workouts and matches. In addition, heart rate variability, energy use, sleep quality and wellness issues, such as mood, stress tolerance and muscle fatigue of elite adult male water polo players were analysed to gain more information about player's physical performance. To collect wellness-related data, a Likert-type scale and an own-developed sports management software were used. This novel methodology is presented in detail, based on data extracted from one players' result.*
Results: *The 0–24-hour heart rate monitoring revealed that most of the active calorie consumption throughout the day resulted from pool workouts and games compared to dryland training or other activities. During the game, the heart rates were similar to the values measured during a more intensive training.*
Conclusions: *As our results suggest, using a complex hybrid heart rate analysis and other associated heart rate based and wellness-related measurements, sports professionals get a better understanding and opportunities on how to further increase the performance of athletes. Additionally, no complex hybrid methodology-based study has been published before, which would build on a 0–24-hour examination of professional water polo players.*
Key Word: *water polo; heart rate; heart rate variability; physical performance; regeneration.*

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I. Introduction

Water polo mainly affects the respiratory and circulatory systems and also the aerobic and anaerobic metabolic pathways. Athletes' overall fitness is based on the following three elements: training load resulting from several hours long pool and dryland training sessions, fatigue and regeneration[1,2,3]. Numerous studies have shown that in endurance sports, more specifically, where strength and speed endurance combined with technique, training plans developed based on heart rate analysis during exercise managed to increase players' performance. Therefore, monitoring heart rate is a commonly used method in sports science[4,5,6]. These simple and easy-to-use heart rate monitors provide objective information to the wearer and trainers with the accuracy of medical instruments. Heart rate control has a role in providing information on (1) sport specific endurance as a result of training sessions; (2) adaptation of the circulatory system in response to different training loads; (3) the efficiency of systems that restore the resting state of the body; (4) the level of training adaptation; (5) the valid measurement of processes that demand and supply energy. The heart rate values of water polo players have already been examined in unofficial match situations using a sensor attached to a chest strap. Based on the results, the average heart rates of players are 80% of the maximum heart rates, from which it can be concluded that the players are under heavy physical exertion[7]. Another study, which examined a total of 20 unofficial matches, found differences in the players' mean heart rate values between the different quarters, showing the fatigue of players in match situations with values steadily decreasing over time[8]. However, to the best of our knowledge, measuring heart rate values in official domestic or international matches has not yet been resolved, even though live matches put an additional psychological burden on players[9]. Thus, there is a need to develop a method that would allow official monitoring of players' heart rate in high stakes situations. In addition, heart rate-based calorie demand and consumption is another important key factor affecting performance. Besides the changes of heart rate values, the measurements of heart rate variability provide accurate information about the internal state of the body. The number of heartbeats and the degree of variability change with emotions, yet the pattern of heartbeats is the primary indicator of emotional state[10,11]. Nowadays, the significance of heart frequency variability for performance is widely studied concerning physical, mental and emotional processes[10]. In general, heart rate variability is higher in athletes and individuals who exercise regularly[12,13]. As the load on the circulatory system approaches its maximum, the R-R intervals between the contraction and relaxation of the heart occur at the same intervals. As training ceased, recovery is signalled by the return of an irregular rhythm characteristic of the resting heart rate. If this cannot be measured, the athlete is not yet ready for another motoric load at peak heart rate. Training plans that consider the analysis of heart rate variability can significantly increase a player's performance[14,15]. Both training and competition load have an effect on athletes' complex personality in all kinds of sports[16]. As a result, the current heart rate is also influenced by factors such as the functioning of the energy supply system, the athlete's physical and mental health, current level of fitness, mental condition and the quality of regeneration and rest[9].

In the present study, we examined heart frequency, heart rate variability, energy use, sleep quality and wellness issues, such as mood, stress tolerance and muscle fatigue of elite adult male water polo players. The presented data can help to gain more information about players' physical performance and provide relevant and new information for water polo coaches and experts to improve training methods and therefore players' performance and also highlight the importance of 0–24-hour heart rate monitoring.

II. Methods

The participants were professional adult male water polo players from the Hungarian Ferencváros Gymnastics Club (FTC), who volunteered to take part in the study covered 31 days. The tests were conducted in the autumn of 2021 during the official competition period at various facilities associated with water polo. Prior to the start of the program, players gave their written consent to participate. The study protocol was approved by the Regional/Institutional Science and Research Ethics Committee (BAZ County Central Hospital and University Teaching Hospital (BORS/18/2021) and conformed to the Declaration of Helsinki. The players took part in an average of one or two pool trainings and one conditioning training daily and participated in four matches within the framework of the Hungarian Championship and the Champions League Tournament.

Study Design: Prospective study

Study Location: Ferencváros Gymnastics Club (FTC), Budapest, Hungary

Study Duration: October/2021.

Procedure methodology

0-24-hour objective measurements: The Hybrid method

Players were asked to wear a smartwatch (Vivoactive 4S, Garmin Ltd, USA) throughout the study period, except for the duration of water polo training and matches. The watch was equipped with an optical pulse sensor (GARMIN ELEVATE ™), an accelerometer and a pulse oximeter. The device measured the following cycles during night sleep: full sleep, deep sleep, light sleep, REM sleep, awake time, pulse oxygen level (during sleep) [SpO2], average heart rate (during sleep) beats/minute and mean respiration rate (during sleep).

A small optical pulse sensor (Polar Verity Sense, Polar Electro Oy, Kempele, Finland) was used to monitor heart rate during pool trainings and games. Optical heart rate measurement is based on photoplethysmography. During training sessions, the sensor was worn by the players placed on the temples of their forehead using a headband by our own design. The advantage of this method was that the changes in training load could be tracked live from the side of the pool via Bluetooth connection using a smart device. During match times however, the sensor was placed 10 cm above the inner ankle and secured with an adhesive bandage and adhesive tape.

The presented heart rate measuring systems, including the smartwatch for dryland training and activities and the optical sensor for pool trainings and games, are also excellent for accurate measurement of heart rate-based calorie demand or consumption of players.

Heart rate variability measurement

Athletes performed an ultrashort (3 min) heart rate variability test at home after each awakening using a strap attached to their chest (HRM-Dual heart rate belt, Garmin Ltd, USA)). The measured HRV data included: min. HR, HRV RMSSD, HRV SDRR, HRV pNN50, HRV pNN20[17].

Subjective measurements (Wellness-related issues)

Performance should always be examined in the context of a players' personality; therefore, it is necessary to measure not only physical but also mental, emotional components. Players answered 6 groups of wellness questions, of which 3 were physical in nature (fatigue, upper body muscle soreness and lower body muscle soreness) and 3 were psychological or lifestyle-related (sleep quality, stress tolerance level and mood). We kept the number of questions relatively low, encouraging players to comply and be willing to complete the questionnaire repeatedly for several weeks. Athletes rated each item daily using a Likert scale from 1 (worst possible feeling) to 5 (best possible feeling). The data were recorded directly using a sports management software (WPDB2020) that we had developed.

III. Results

As this study focuses on the illustration of a novel methodology compiled from different measurement tools, we consider it reasonable to highlight one player's examined parameters from the result list without the statistical analysis of the correlations. From 20 players over 31 days, 620 data list have been collected, not all of them have been complete. Based on the law of large numbers, data loss occurred due to unsupervised home measurements and well-being issues. Special attention needs to be paid to remedy this problem in the future.

The average daily active and passive calorie consumption of the player selected was 35.3 ± 8.3kcal/body weight kg. Most of the active calorie consumption throughout the day was the result of pool workouts and matches (Polar sensor), little derived from dryland conditioning training sessions and other 0-24-hour player activities (Garmin system). There was one exception on day 18 of the study when more calories were burned during the dryland conditioning training than during pool workout. Incidentally, the player's active calorie use dropped drastically over the weekends (Figure no 1). It can be stated that the association between the heart rate and energy values measured during pool workouts and matches should also be considered when compiling training plans.

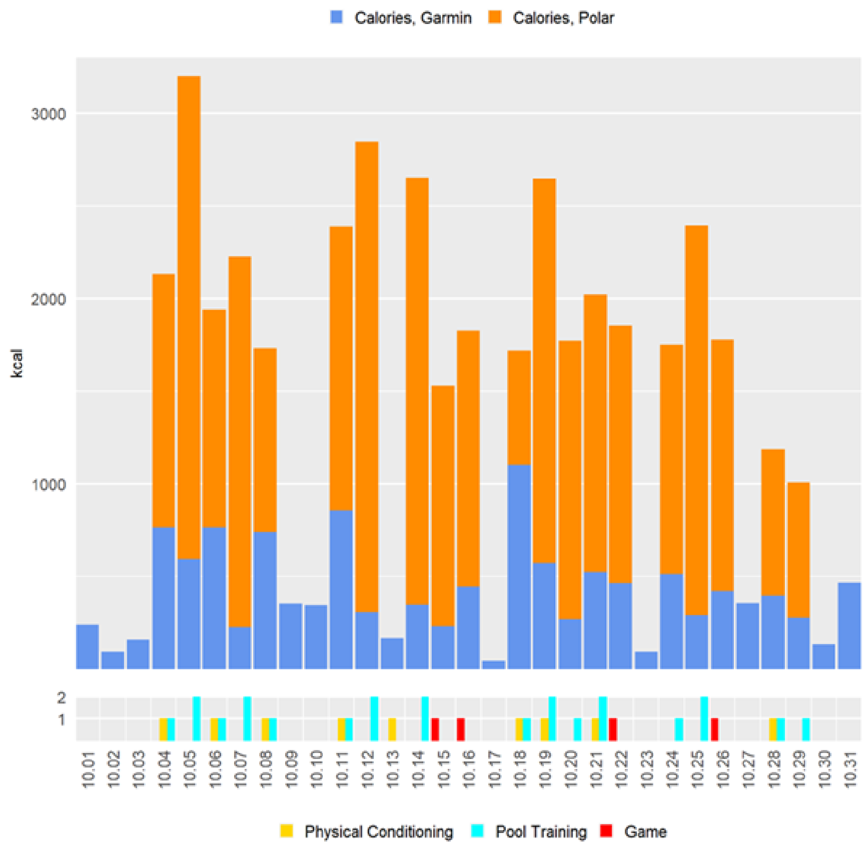

Figure no 1: Daily active calorie consumption during the length of the study. Physical conditioning sessions (Garmin smartwatch) and pool trainings and games (Polar sensor).

Figure no 2 shows the heart rate (HR) values measured by the Garmin and Polar systems based on minute data during the daily activities (physical conditioning, pool training, regeneration and sleep) for 3 selected days (10/13, 10/14, 10/15) and it also displays the time spent in the given heart rate zones during pool trainings and during a game. Three consecutive days during the study period were selected, consideration was given to include 1) a day with dryland conditioning training but no pool workouts (Figure no 2.1), 2) a day with two pool trainings (Figure no 2.2) and 3) a day with a game (Figure no 2.3). The graph reflects well the exceptionally high HR values of pool workouts compared to dryland trainings and routines. On the other hand, the detailed analysis of continuously measured heart rate values during the pool workouts also revealed differences, as on the second day the first pool training was more intensive compared with the second pool workout (Figure no 2.2A and B). During the second pool training the HR values were in zone 1-3, which means that those were under 80% of maximal heart rate, while on the first training the player's heart rate was closer to their maximum heart rate (zone 5). During the game, the HRs were similar to the values measured during the more intensive training (Figure no 2.3A).

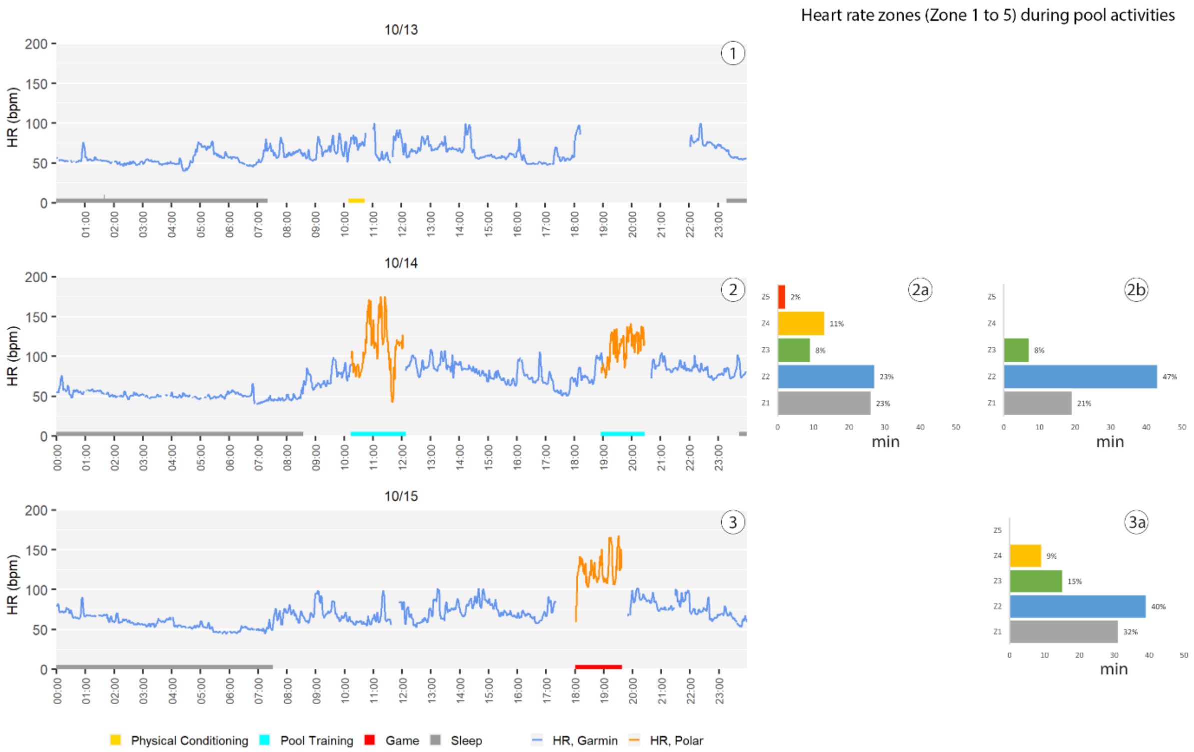

Figure no 2: Heart rate values for three representative days (1, 2 and 3), broken down into minutes and time spent in heart rate zones during pool activities (2A, B and 3A). Heart rate zones: Z1: heart rate is between 50-60% of the maximal heart rate value, Z2: heart rate is between 60-70% of the maximal heart rate value, Z3: heart rate is between 70-80% of the maximal heart rate value, Z4: heart rate is between 80-90% of the maximal heart rate value, Z5: heart rate is over 90% of maximal heart rate value. HR: heart rate.

Indicators of heart rate variability, such as pNN50 and pNN20 (Figure no 3.1), RMSSD and SDRR (Figure no 3.2) and in addition the heart rate value (Figure no 3.3) were examined immediately after awakening. For the selected player, no correlation was found in these parameters and the number of workouts, games, or rest days included in the training programme.

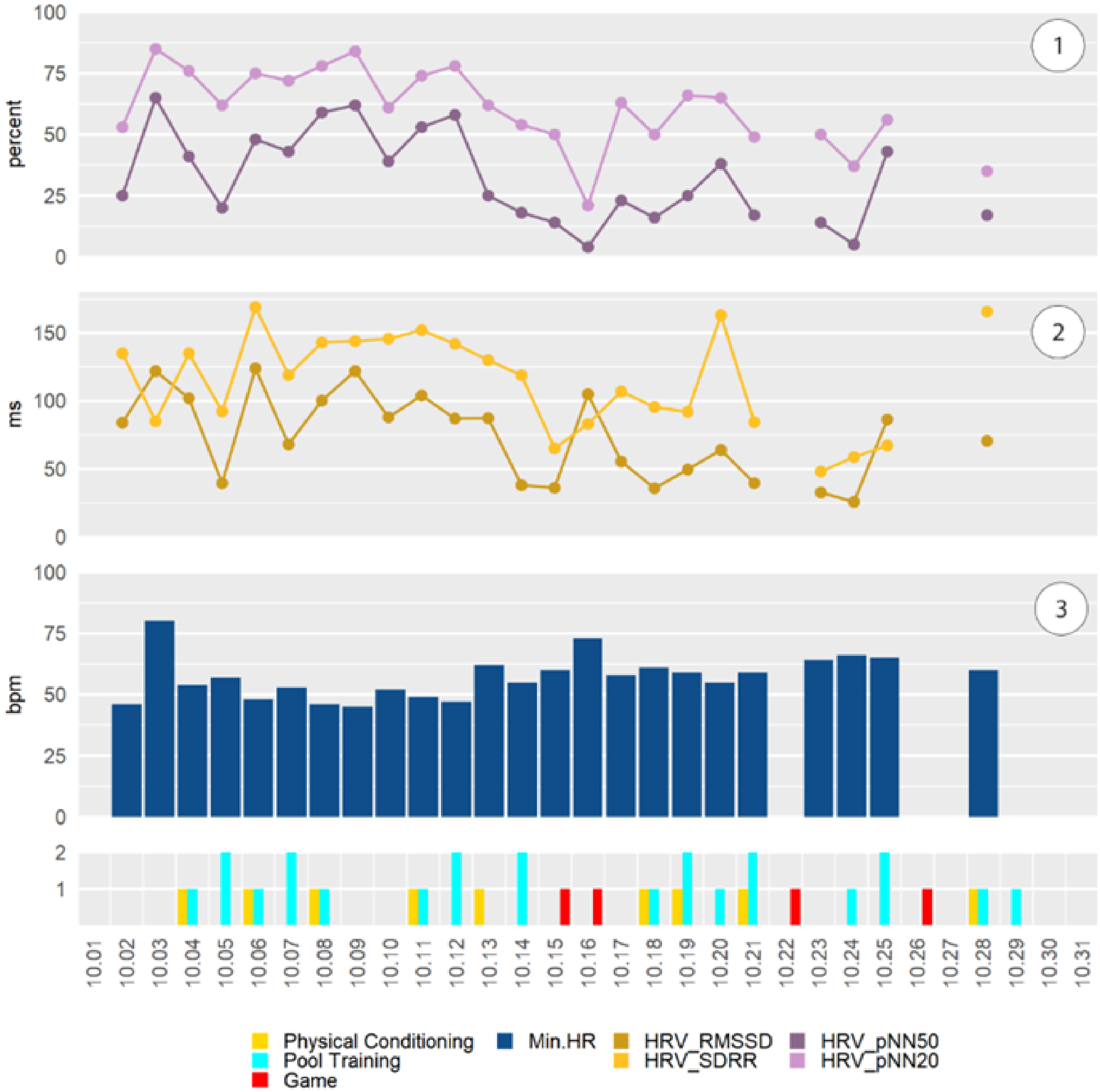

Figure no 3: Indicators of heart rate variability (HRV) (1 and 2) and heart rate (HR) (3) data after awakening, gathered daily

Figure no 4 demonstrates the fluctuating values of the six various wellness parameters measured daily during the intervention period. This draws the attention of professionals to the fact that the performance of players is also significantly affected by a variety of factors related to the current state of the individual.

The average quality of a player's sleep on a scale of 1 to 5 was 2.7, his mood 2.8, and his stress tolerance level 3.4; while upper and lower body muscle soreness was 3.1 and 3.2, while overall fatigue 2.9. The values obtained do not reflect dramatic differences in the averages of each area. The largest difference was 0.7, which occurred between the quality of sleep and muscle soreness in the lower body. At the same time, however, sleep quality affects the quality of daily activities. Nevertheless, it seems that the athlete's higher stress-tolerating ability (higher average score) compensates for this disadvantage, which means that the player processes the workload and competitions well. This is a remarkable aspect because every workout or match is potentially stress-inducing for the individual.

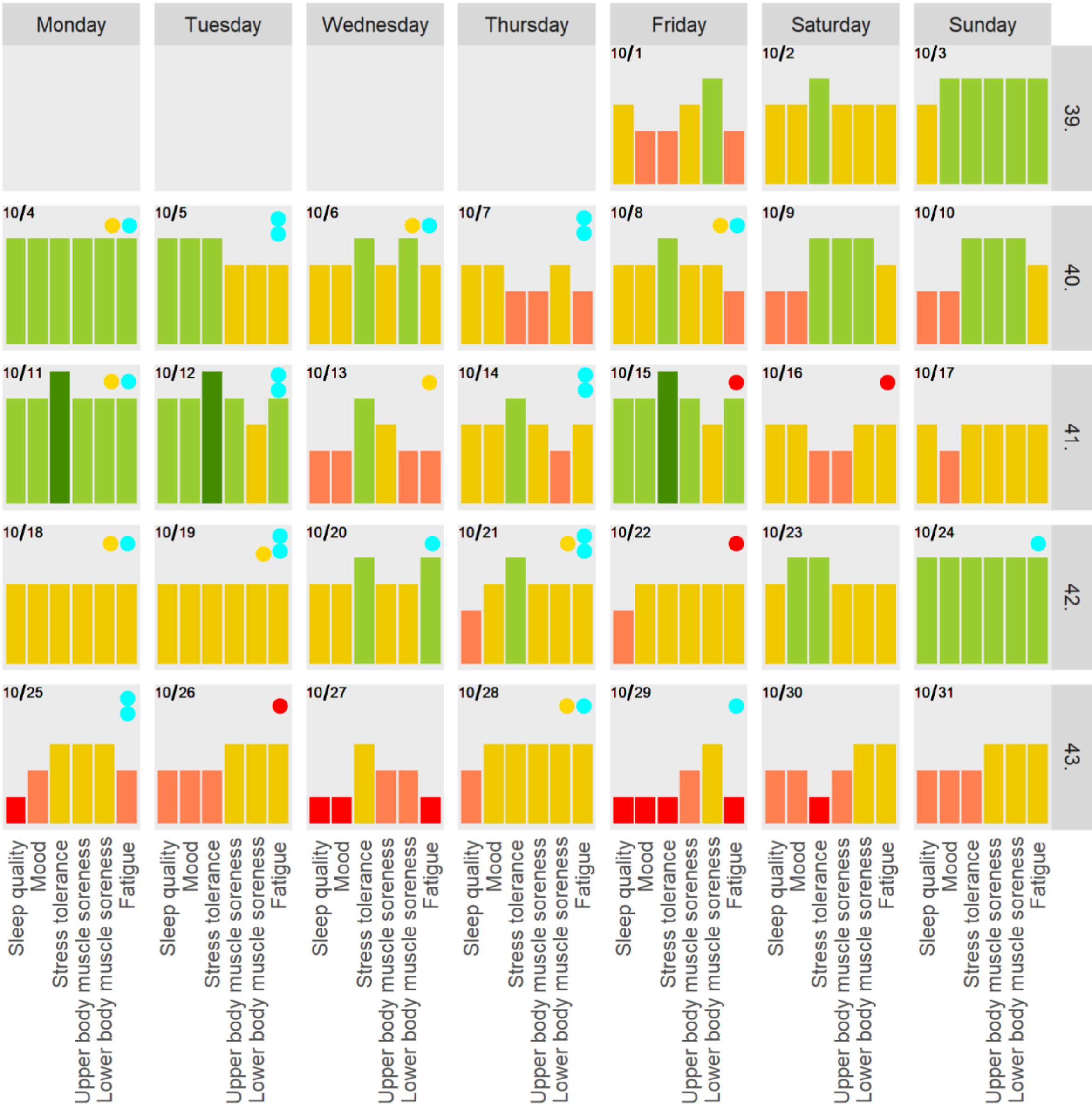

Figure no 4: Wellness-related question group results day by day. Colours and values: dark green (5), green (4), yellow (3), orange (2), red (1). Values of 1 are the worst in all cases, and values of 5 are the best. Dots represent daily activities on different weeks (week 39 – 43): yellow – Physical Conditioning, blue – Pool Training, red – Game.

Wellness parameters measured during the last week of the month are far worse than in the preceding weeks. Rating one occurred nine times, while four or five did not occur even once during the last week. At first glance, it can be said that the fatigue caused by games has a serious knock-on effect on the quality of subjective components for days, as low wellness values reported on the last two days without any workouts or a game). All the above draw attention to the importance of physical and mental rest concerning the quality of the regeneration period. Summa score of daily sleep quality, mood, stress tolerance level, upper- and lower body muscle soreness and fatigue are represented in figure no 5, this score displays an obvious decrease during the last week (10.25 – 10.31). On the other hand, elevated summa wellness scores can be observed after resting days, which highlights the importance of adequate regeneration.

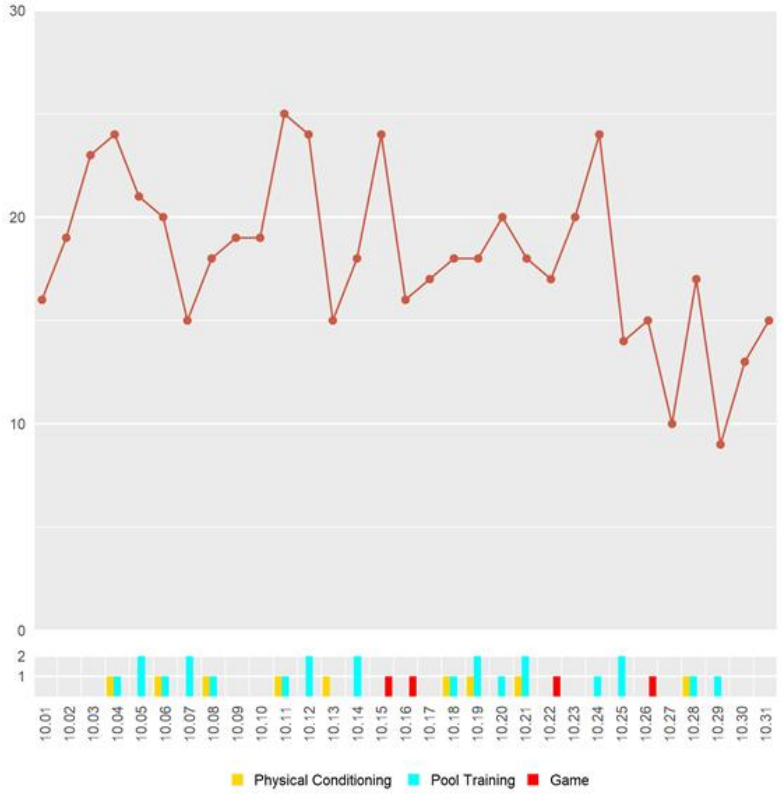

Figure no 5: Aggregated scores of the six measured wellness categories per day

Data related to the amount and quality of sleep allow for a variety of conclusions. The device used made it possible to measure additional components of sleeping time, such as: deep sleep, light sleep, REM sleep and time spent awake. Figure no 6 shows the differences between the individual parameters that affect the quality of sleep, and thus the player's rest and mood. In Figure no 6, sleep data were shifted by one day because the values measured each morning actually applied to the previous night, more specifically, to the previous day's load.

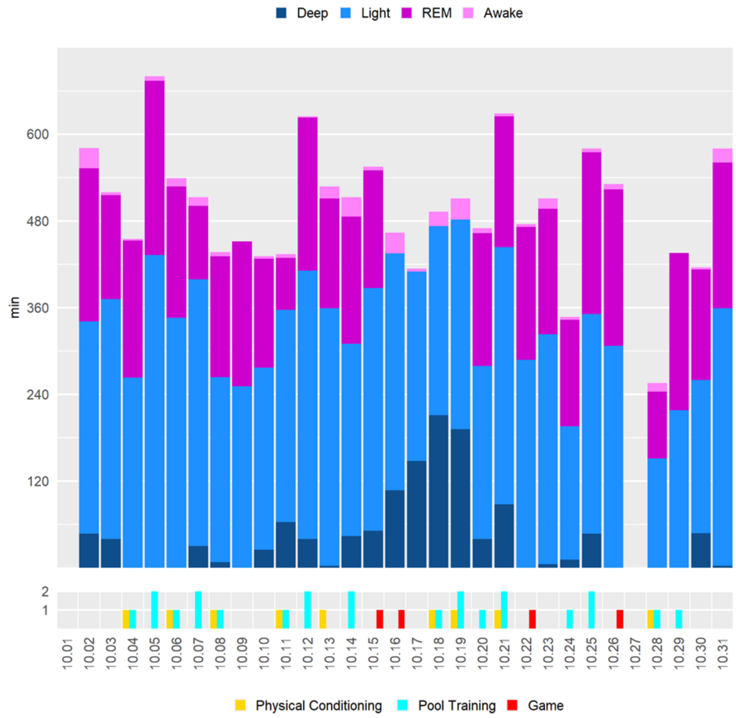

Figure no 6: Time distribution of sleep stages during the 31-day intervention period

IV. Discussion

Our study presents a novel complex hybrid study methodology to analyse the 31-day 0–24-hour activity of professional adult male water polo players (n = 20) of the Ferencváros Gymnastics Club in Hungary. One of the key elements of the methodology was to use an optical sensor for measuring HR data, which was also allowed in the pool environment. Another key element of this study is the 0-24-hour multi-aspect observation of the player. This study is a methodological demonstration, which used data measured in an objective and subjective way by one player, therefore the analysis of the correlations was not considered statistically justified.

Increasing performance by monitoring pulse load is a proven objective measurement method in sports science, especially in endurance sports[18,19,20]. Heart rate measurement is not yet a common method in water polo. Two independent studies have already measured the heart rate of players in game situations using a sensor attached to a chest strap, but to the best of our knowledge, our research is the first to examine the heart rate of male professional water polo players in official matches[7,8]. According to these studies, the players' heart rate during a game was higher than 80% of their maximum heart rate. As the quarters progressed, Platanou et al. (2006) found a decrease in heart rate values that may indicate player fatigue, however, both studies confirmed that at the end of the 4th quarter, the heart rate increased again in the course of the match. In the present study, however, the heart rate of the player is more often in the average range during the games[8]. Consistent with previous independent research, it can be said that high stake games place a heavy burden on players, which calls attention to the importance of regeneration. It is important to note that there is also a small difference in heart rate values depending on the post of the player[21]. The main difference from previous research is that it was the first time that the novel and officially approved Polar optics sensor for heart rate measurement was used. Regarding the measured results, it does not matter at all whether such tests take place in high stakes or friendly matches.

According to the present study, the calorie consumption measured with this optical sensor represents a much higher value than any other 0–24-hour activity. Pool heart rate measurement can bring more performance capital to a team if this method involves 0-24 hours of heart rate measurement (activity, rest and sleep) or a combination of measurement results from the subjective reports of the individual.

One of the important objective indicators of load processing (training and game) is the measurement of complex HRV in addition to the traditional HR measurement. Studies of this nature are being carried out in various sports, but are still less widely used in water polo[22,23,24]. The time of regeneration can be inferred from the time it takes for decreased HRV values to be restored after heavy motoric exertion. This may take up to 24-48 hours[25]. Botonis et al. (2021) in their research examined HRV values at different stages of exertion for a total of 9 weeks, and players were asked every morning how tired/regenerated they felt. Based on their results, the mean LnRMSSD value changed significantly for different load stages. During off-season, when the training load on the players decreased, the LnRMSSD value was higher, which is related to the lower level of fatigue and stress. In line with this, the players also felt more relaxed compared to the end of the pre-season preparation period, based on their self-reports. The data of the selected player were used to present the possibilities provided by the methods and collected data rather than to draw far-reaching conclusions[26].

Subjective measurements (wellness issues) organically linked to the objective measurement of sports loads have already been analysed by many experts[16,27]. In a previous study performed by Botonis et al (2019), the wellness of water polo players was assessed using a 5-point test, which is essentially the same as the wellness questionnaire we used. Players rated their feelings of fatigue, quality of sleep, general muscle soreness and mood on a scale of 1 to 5. Based on their results, the players' wellness scores decreased during intense training load, however, this did not have a negative effect on the results of the swimming tests. In addition to the wellness score during the reduced training load, the players' sports performance of the players also increased[28]. For our player, the number and intensity of training sessions during the 31-day research period was determined by the preparation for the upcoming games. According to the study, our player's quality of sleep, mood, level of fatigue and stress tolerance level, and muscle soreness was positively affected by proper regeneration and the number of rest days included in the intense training and match program. A detailed evaluation of the wellness results requires the extension of the study to the entire team. Of course, this method can only bring performance capital to the team if it is a 0-24-hour heart rate measurement (activity, recovery and sleep) and we plan the preparation and competition period for the players in line with their subjective individual measurement results.

Pulse load and energy consumption are intertwined. Sports science usually focuses on measuring aerobic, anaerobic, VO2max, and lactate data, which is associated with laboratory measurements. With invasive studies, researchers point to correlations related to the energy management of the athletes studied[29], but we also find such studies in water polo[30,31]. Our research fills a gap because it evaluates data obtained directly from the real environment of the sport, thus pointing out the issue of load and regeneration and the resulting questions of energy management.

In an athlete's 0-24-hour activity, the quality and quantity of sleep both affect performance, so it is extremely important to diagnose the elements of sleep. The results of our study highlight that the sleep quality of elite athletes is best predicted by participation in sports, training, and sleep hygiene habits. Another interesting finding of Suppiah et al. (2021) is that team athletes are more sensitive to poorer sleep quality than individual athletes[32]. According to the study, the so-called clustering methods can help solve sleep-related problems. There is only one conclusion that we would like to highlight from our research: an increase in deep sleep time has a negative effect on the period of REM sleep.

V. Conclusions

In summary, it can be stated that a complex hybrid method to analyse the activity of water polo players from 0 to 24 hours is a novel approach in this field of study. We would like to draw the attention of professionals in water polo sports to the results of our study, because it shows ways to increase the performance capital of their players by using an even more efficient method, which measures both subjective and objective tools. Our research plans for the near future include a more accurate way to show coaches the advantages of a complex hybrid test method over traditional methods by involving elite water polo teams.

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Disclosure statement

The authors report there are no competing interests to declare.

Data availability statement

The raw datasets are available from the corresponding author on reasonable request. (Dr. Péter Fritz; efkfritz@uni-miskolc.hu)

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