ORIGINAL ARTICLE

Construction and validation of a water polo specific anaerobic swimming test

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ABSTRACT

Water polo lacks sport-specific anaerobic field tests that adequately reflect the physiological and respiratory demands of competition. The repeated sprint ability (RSA) test is commonly used to assess anaerobic performance; however, it does not account for the dynamic apnoea frequently experienced during match play. This study aimed to evaluate the reliability and validity of a newly developed water polo-specific anaerobic swimming test (TP) that combines repeated sprint swimming with dynamic apnoea. The protocol was designed to provide a more ecologically valid assessment of water polo performance by incorporating respiratory constraints that mimic real-game situations. Ten elite junior male water polo players participated in the study. The TP test consisted of repeated maximal swimming efforts combined with dynamic apnoea. Reliability was assessed using the intraclass correlation coefficient (ICC), coefficient of variation (CV), paired-samples t-test, and minimal detectable change (MDC). Criterion validity was examined through Pearson correlations between TP outcomes and RSA performance. The Kolmogorov-Smirnov test confirmed normal data distribution for all variables ($p > .20$). The TP test demonstrated high relative reliability (ICC = .86), indicating good consistency between testing occasions. The coefficient of variation was 8.6%, suggesting moderate measurement variability, while a significant difference between test and retest scores was observed ($t = 2.50$). The MDC was 1.99. Criterion validity analysis revealed moderate positive correlations with RSA performance (test: $r = .488$; retest: $r = .543$), indicating that both protocols assess related aspects of anaerobic performance while capturing different physiological demands. The TP test showed satisfactory reliability and moderate criterion validity. By integrating dynamic apnoea into repeated sprint assessment, the protocol captures sport-specific respiratory and anaerobic demands not addressed by traditional RSA testing. Although further validation in larger samples is required, the TP test appears to be a practical tool for athlete profiling and performance assessment in water polo.
Keywords: performance analysis; water polo; anaerobic performance; sport-specific test; sprint performance; sports conditioning.

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INTRODUCTION

Water polo is a complex team sport characterized by a large number of alternating activities in which short, intense efforts <15 seconds duration and periods of somewhat lower intensity <20 seconds duration alternate (Smith, 1998). The additional difficulty of the game is represented by the fact that water polo takes place in a water medium, which places additional demands on the players in the form of overcoming water resistance with moments of difficulty or impossibility of breathing. From a physiological point of view, water polo belongs to the combined aerobic-anaerobic sports, although such studies are rare due to the limitation of precise sampling of physiological and metabolic variables during competition. However, anaerobic energy systems play a dominant role in actions where speed, strength, and explosive power come to the fore, such as goal kicks, jumping out of water, water wrestling, sprints, etc. Reviewing the literature, repetitive high-intensity intervals dominate in matches, which rely on the phosphagen and glycolytic systems. Such game intensity results in increased metabolic stress and increased lactate production (Smith, 1998; Tan et al., 2009). This has been confirmed in research with blood lactate concentrations often >10 mmol/L in elite water polo players and supports the fact about the anaerobic demands of the game (Platanou, 2004; Botonis et al., 2018). Anaerobic capacity, including strength, speed, and lactate tolerance, is crucial for success in water polo.

However, in addition to all the listed requirements of playing water polo, water polo players also face another phenomenon, which is difficulty breathing. Namely, during fast sprints, wrestling, fighting for position, etc., players arbitrarily or due to collisions with an opponent reduce or completely (when their head is below the surface of the water) stop breathing, which significantly affects recovery from high-intensity actions. These periods of breath holding, known as apnoea, create progressive hypoxia and hypercapnia due to continued metabolic activity in the absence of ventilation (Ferretti, 2001). Dynamic apnoea presents a unique physiological challenge because, despite a temporary cessation of pulmonary ventilation, oxygen consumption continues, leading to progressive hypoxemia and hypercapnia. Hypoxemia and hypercapnia trigger complex cardiovascular, respiratory, and metabolic responses. These physiological responses lead to a reduction of oxygen delivery to active muscles and increase the work of respiratory muscles, which increases reliance on anaerobic energy production during repeated high-intensity exercise. (Elia & Lemaître, 2025).

Oxygen reduction has been associated with impaired recovery between repeated maximal efforts, accelerated neuromuscular fatigue, and reduced repeated-sprint performance (Faiss et al., 2025). Furthermore, acute hypoxia may negatively affect cognitive performance, including response speed, attention, and executive functioning, particularly when the reduction in oxygen availability is low (McMorris et al., 2017; Virués-Ortega et al., 2004).

Water polo is a sport in which these physiological and cognitive responses are particularly important. Maximal swimming efforts in water polo are often combined with underwater duels and wrestling, rapid tactical decisions, diving, and explosive jumps. Testing protocols that do not take into account respiratory stress imposed by dynamic apnoea may underestimate the true physiological and cognitive demands of competitive water polo.

Avoiding apnoea in water sports, including water polo, is practically impossible. By ignoring such a large element of metabolic and respiratory stressors as apnoea, we are not getting the full picture. In previous research, a number of specific tests in water polo were developed which, according to the author's knowledge, measure almost exclusively functional abilities of an aerobic (I Mujika, G McFadden, M Hubbard, K Royal, and A Hahn, 2006) and anaerobic character (Rodriguez, 1994).

Also, the prolonged and high-intensity nature of the match increases metabolic and cardiovascular disorders and leads to a progressive decrease in game intensity (Galy et al., 2014; Pinnington et al., 1988; Platanou and Geladas, 2006). Therefore, RSA protocols for aquatic sports have been designed and are mainly used to assess sprint reduction, average sprint time, and fatigue development during repeated efforts (Meckel et al., 2013). From these studies, it is clear that this problem is attracting the attention of scientists worldwide. However, to the authors' knowledge, there is no previous research on apnoea in water polo, which represents a major gap in this area of water polo.

These are all valid and important factors for obtaining a complete picture of an athlete's fitness. But do they mimic game situations? The RSA testing protocol that we took as a reference consisted of eight maximal 25 m sprints performed with a 30-second break between sprints (Dalamitros et al., 2021). This type of testing gave us an excellent starting point to include apnoea in the testing.

Namely, you will notice that players in the game have duels, quick changes from attack to defence and have periods in the game in which they perform dynamic apnoea movements. By dynamic apnoea, we mean all underwater wrestling or swimming while holding their breath. This is an element that we believe is missing from the RSA test in order to capture the real demands of water polo.

Therefore, our idea was to include dynamic apnoea in the existing RSA protocol and thus create a new test that provides a better insight into the anaerobic and respiratory capacity of the athlete. Most existing protocols that cover anaerobic capacities neglect apnoea and fail to include the combined metabolic and respiratory demands specific to water polo. As we already know, diagnostic procedures should reflect the real physiological and motor demands of competition as accurately as possible (Young, 2006). Increasing the ecological validity of testing protocols is essential to capture important performance indicators in water polo.

Therefore, the aim of this study was to construct a test, using the gold standard, to assess anaerobic performance in water polo. And to see whether this newly constructed test meets the criteria of validity and reliability in assessing anaerobic performance in water polo. The main hypothesis of the work is that subjects with a lower coefficient on the test will have better anaerobic properties, which will significantly contribute to the quality of performance in water polo.

MATERIALS AND METHODS

Participants

The sample of participants we took was 10 male junior water polo players from the water polo club Jadran Split. Our athletes age was 15.5 ± 1.5 years (range: 14–17 years), with a mean body height of 186.6 ± 5.9 cm (range: 175.3–194.0 cm), a mean body mass of 78.8 ± 11.1 kg (range: 68.7–102.7 kg), and a mean body mass index (BMI) of 22.6 ± 2.8 kg·m^{-2} (range: 20.1–27.2 kg·m^{-2}).

We consider them an elite sample because they were national champions a season before testing. Aside from being champions, part of the junior team we tested is involved in the senior team squad. Jadran Split is currently one of the top water polo teams in Croatia. Last three seasons, they won the Croatian championship title and are playing in the LEN Champions League. Also, some of the participants were chosen for the national junior team squad and are competing in European and World championships.

All of the players have been exposed to multiple years of an organized training system in the club. At the moment of testing, they had a volume of about 12 hours of training a week. To ensure optimal performance, participants completed all tests with a two-day rest period between testing sessions. All participants and their parents provided informed consent prior to participation and received written information about the study procedures. The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the Faculty of Kinesiology, University of Split (approval number: 2181-205-02-05-26-0014).

Procedures

The tests are described in detail as follows:

Repeated sprint ability test (RSA)

The test included 8 repetitions of a single 25-m all-out sprint set (8 × 25 m), executed with the front-crawl technique. Each 25-m effort was separated by a 30-second rest interval. The players started each sprint with a push-start, while they were instructed to start swimming immediately after their feet left the wall. Two experienced researchers timed each 25-m effort individually with a commercial stopwatch, Seiko S141, Japan (Dalamitros et al., 2021).

Newly constructed anaerobic test

The repeated sprint–dynamic apnoea (TP) test consisted of eight consecutive sets, each comprising a 25-m maximal front-crawl sprint followed by a dynamic apnoea swim performed at maximal (sprint) intensity. During the sprint phase, participants were allowed to breathe freely and were instructed to complete the distance in the shortest possible time. Upon completion of the sprint, a 10-s passive recovery period was provided. Immediately thereafter, participants performed a dynamic apnoea swim without breathing and at maximal swimming intensity, during which the total distance covered was recorded. Distance was measured using visual markers placed at 1-m intervals along the poolside to ensure measurement accuracy. After performing the dynamic apnoea swim, participants had 30-s recovery. If participants finish dynamic apnoea in the middle of the pool, we start a 30-s pause, and they swim at a low tempo till they reach the nearest edge of the pool.

Athletes performed this procedure of maximal sprint followed by dynamic apnoea a total of 8 times. To interpret the results, we divide the time of maximal sprint by the number of meters covered in dynamic apnoea. Whichever athlete has the lowest sum of all eight indices has the best result.

The performance index was designed to integrate two key components of water polo-specific performance within a single metric: sprint swimming speed and dynamic apnoea capacity. Dividing sprint time by the distance covered during dynamic apnoea provides an index in which lower values represent athletes capable of completing the sprint in less time while simultaneously maintaining longer apnoea performance. Alternative scoring methods were considered; however, this ratio was selected because it combines both components into a simple and practically interpretable field-based measure without requiring specialized equipment.

As this is the first application of this index, future studies should investigate alternative scoring approaches and determine whether they improve the sensitivity and validity of the protocol.

Statistical analysis

Descriptive data are presented as means (M), minimum and maximum values (MIN and MAX), and standard deviations (SD) to provide an overview of performance distribution. Before further analyses, data normality was assessed using the Kolmogorov–Smirnov test (K–S). The stability of the newly developed TP test between the two measurement occasions was evaluated through the intraclass correlation coefficient (ICC), while absolute reliability was additionally described by the coefficient of variation (CV). Possible systematic changes in performance between trials were investigated using the paired-samples t-test. To assist in practical interpretation, the minimal detectable change (MDC) was calculated, representing the smallest difference that may be considered real and not attributable to measurement error.

To determine the extent to which the new protocol reflects established indicators of repeated sprint performance, criterion validity was analysed by means of Pearson correlation coefficients between TP outcomes and RSA results. Statistical significance was accepted at the level of $p < .05$. All analyses were performed using Statistica 14.0.0.15 (TIBCO Software Inc., USA).

RESULTS

Table 1. Results of descriptive statistics and test for normality.

Variables	M	MIN	MAX	SD	K-S
TP	8.73	6.47	10.86	1.74	$p > .20$
RTP	7.92	5.05	11.42	2.02	$p > .20$
RSA	115.32	109.15	120.09	3.20	$p > .20$

Note. TP = Sum of eight TP TEST indices, RTP = Retest sum of eight TP test indices. RSA = Sum of eight results from the Repeated Sprint Ability test.

Descriptive statistics for the newly developed TP test, its retest (RTP), and the reference RSA test are presented in Table 1. Mean values (M), minimum (MIN) and maximum (MAX) scores, and standard deviations (SD) are reported for each variable. The Kolmogorov–Smirnov test indicated no significant deviations from normality for any variable ($p > .20$).

Table 2. Reliability parameters of the new test.

Variables	M ± SD	ICC	CV	t	MDC
TP	8.73 ± 1.74				
RTP	7.92 ± 2.02	.86	8.6%	2.5*	1.99
RSA	115.32 ± 3.20				

*Note. ICC = intraclass correlation coefficient; CV = coefficient of variation; t = paired-samples t-test statistic; * Statistical significance; MDC = minimal detectable change; TP = new test (first measurement); RTP = new test (second measurement); RSA = Repeated sprint ability test (reference standard test).*

Descriptive statistics (mean ± SD) were calculated for all variables. Test–retest reliability of the RTP test was assessed using the intraclass correlation coefficient (ICC) and coefficient of variation (CV), while systematic differences were examined using a paired-samples t-test. RTP reliability was high (ICC = .86), with a CV of 8.6%. A significant difference between test and retest was observed (t = 2.50), and MDC was 1.99.

Table 3. Validity parameters of the new test.

Variables	RSA	RSA
TP	.488	
RTP		.543

Note. TP = new test (first measurement); RTP = new test (second measurement); RSA = Repeated sprint ability test (reference standard test).

In Table 3, criterion validity was assessed using Pearson correlation coefficients between the newly constructed tests and the RSA test. The TP test showed a moderate positive correlation with RSA (r = .488), while the RTP test showed a slightly stronger moderate positive correlation with RSA (r = .543).

DISCUSSION

This pilot study aimed to evaluate the metric characteristics of a newly constructed repeated sprint–dynamic apnoea (TP) test, with particular emphasis on its reliability and its relationship with a standard measure of anaerobic performance (RSA). Water polo consists mainly of short-distance, high-intensity movements with partial recovery (Tan et al., 2009). This is why the RSA test has been mostly used so far to determine anaerobic performance. Ecological validity is the biggest strength of the TP test. This test incorporates dynamic apnoea, which replicates water polo-specific respiratory constraints. As a result, the test may provide a more sport-specific assessment of athletes' ability to perform repeated high-intensity efforts under conditions that resemble actual match play. Improving ecological validity is an important consideration in sport-specific test design because it recreates the physiological and psychological demands of the match. This gives coaches a tool for assessment where their athletes are under match-condition demands, and we think this is where the importance of the test really lies.

The main findings indicate good relative reliability, acceptable measurement stability, and moderate criterion-related validity in relation to the reference test. The obtained ICC value (.86) indicates high relative reliability, suggesting that participants largely maintained their ranking between repeated measurements. Values above .80 are interpreted as indicative of good consistency (Atkinson & Nevill, 1998; Hopkins, 2000). Because of this, we can say that the TP test is potentially suitable for distinguishing between players of different performance levels, which is particularly relevant in team selection and talent identification contexts. However, to be relevant for talent selection and identification, this test needs to be researched on a bigger and more heterogeneous sample before we can make those claims.

The coefficient of variation (CV = 8.6%) is relatively high but taking into account that this is a high-demanding sport-specific test which includes both maximal effort and breath-hold components, increasing variability in performance. It is expected to have a higher coefficient of variation in complex sport tests (Impellizzeri et al., 2008). It was their first time performing this test, and for researchers as well. Already when performing the test a second time, they knew what they needed to look after, and they adapted to the test. For that reason, a recommendation would be a familiarization session before formal testing to minimize potential learning effects and improve measurement consistency. Future studies should incorporate third testing in order to distinguish true measurement error from performance improvements related to familiarization. Also, some of the athletes might not give the same effort in the test and retest because some of them were sick between testing.

Minimal detectable change (MDC) is the smallest change that can be interpreted as a true performance adaptation beyond measurement error (Weir, 2005). In our case, MDC was 1.99, which is a bit of a higher number, but taking into account the small sample size and adaptation to the second time of performing the test, also known as the familiarization effect (Hopkins, 2000), we can say it is also expected to be higher. For now, this means only relatively large performance changes can be confidently interpreted as true adaptations, which limits the sensitivity of the test for detecting small longitudinal improvements. At this stage, the proposed protocol should primarily be considered a profiling tool for comparing athletes within similar competitive groups rather than an instrument for talent identification or selection decisions. If the test is used for longitudinal monitoring, it requires strict standardization to minimize potential bias. Also, this can be influenced by a small sample of participants. By expanding the sample and trying different age groups, it is reasonable to expect the numbers would be even more stable.

Water polo's intermittent nature relies on anaerobic energy systems during explosive actions and aerobic metabolism for recovery (Smith, 1998). This is why the anaerobic system plays a crucial role in water polo monitoring and conditioning. Validity for the first measurement was r = .488, and the retest score was r = .543. These results don't show a significant correlation, but are meaningful because they share similar variables, primarily anaerobic capacity and repeated sprint performance. This is also expected because the frame of the test is the same; just a newly constructed test captures an additional component of dynamic apnoea, which changes the demands of the test. Not only are we testing anaerobic swim performance, but we are also testing the respiratory organs and muscles under load. This goes well with the thesis that performance assessment depends on the degree to which testing protocols reflect sport-specific demands because general standardized tests often overlook the actual demands of a certain sport (Reilly et al., 2000; Pyne et al., 2004). Two tests are different and measure similar but not the same things. The moderate correlations observed between TP and RSA should not necessarily be interpreted as evidence of weak validity. Rather, they likely reflect that the two protocols assess overlapping but not identical constructs. While RSA primarily evaluates repeated-sprint performance under unrestricted breathing conditions, the TP protocol additionally incorporates respiratory stress induced by dynamic apnoea.

Therefore, criterion validity against RSA should be interpreted within this context. Future studies should include complementary physiological measures, such as blood lactate concentration, oxygen saturation, recovery kinetics, or competitive performance indicators, to provide a more comprehensive evaluation of construct validity. Hypoxia and hypercapnia increase cardiovascular and metabolic stress during exercise (Lindholm & Lundgren, 2009). Knowing that there is breath-holding happening during a match and that the hypoxic state increases metabolic stress, we wanted to make a field test that captures sprint under hypoxic and hypercapnic states. We think that apnoea is a very important factor of performance that has been ignored so far in other field tests.

Both tests should be used in monitoring players' condition levels. The newly constructed test showed potential suitability to differentiate players among groups. Long-term monitoring might have potential problems if the testing procedure is not strictly standardized. Considering that this is a pilot study, the findings should be interpreted with caution. The relatively small sample size may have affected the stability of the ICC estimates, correlation coefficients, and MDC values. Future studies including larger samples from different clubs and competitive levels are required to further evaluate the robustness and generalizability of the proposed protocol.

Overall, we strongly believe that the TP test introduces a more ecologically valid assessment of water polo specific performance by combining anaerobic and respiratory demands, comparing it to other testing protocols. This leaves space for exploring new test and use it on different participants to see where their use is most useful. The idea goes beyond just water polo to other water sports such as swimming, synchronized swimming, and freediving. All of these sports have dynamic apnoea as a component of the sport, so future testing should consider different water sports athletes. Thinking even further, the subject of dynamic apnoea is underestimated as a topic and should be investigated even in non-water sports. That was also one of the goals of this research: to create a new form of testing and generate ideas of breath-hold in sports analysis. We hope researchers and coaches will notice our idea and will investigate this topic even in other sports fields.

Limitations and future directions

The study that we did has several limitations that we need to mention. The first limitation was the small sample size because we only tested 10 athletes. Such a sample may reduce the stability of reliability and validity estimates and limit the generalizability of the findings. So a bigger sample is needed before we can make any general conclusions. This is a pilot study, and in the next research, we plan to test more athletes.

The second limitation was that we tested only one category of players who had a chronological age ranging from 14 to 17. For future research, it would be crucial to test different age groups (older and younger) to see how they react to the newly constructed test.

The third limitation is that most of the athletes tested had a 2-day pause to ensure they were fully recovered. Because of the game schedule and some players playing for the older category, some of them had a bigger pause than 2 days between testing.

The most important limitation of the present study is that normative reference values and meaningful performance thresholds could not be established because the protocol was evaluated in a relatively small and homogeneous sample of junior water polo players. Consequently, the proposed test should currently be interpreted primarily as a profiling tool for comparisons within similar competitive groups rather than as an instrument for absolute performance classification. Future studies involving larger samples across different age categories and competitive levels are needed, as well as physiological measures and performance indicators to establish normative values. To eliminate bias from results, it would be important to strictly follow the testing procedure and try to test everyone on the same day. Also, we tested the elite sample because they won the league last season, so trying it out on lower division players would be a good idea.

Comentado [K1]:

And the last limitation was that during the test and retest, some of the players that we prolonged testing with were sick during that pause. When they were tested, they were fully recovered, but still, this affects the results.

Although the proposed index was designed to provide a simple and practical integration of sprint performance and dynamic apnoea capacity, future studies should compare alternative scoring models to determine the most appropriate representation of the interaction between anaerobic and respiratory performance.

CONCLUSION

In conclusion, the newly constructed anaerobic test shows satisfactory reliability and validity. The test shares a meaningful yet not significant correlation with the RSA test. This indicates it measures similar anaerobic components, yet the new test has a component of dynamic apnoea, which adds additional stress on respiratory organs and muscles. CV shows that the result may vary by 8.6% without a change in capacity. The test is an emerging assessment tool that currently shows promise for profiling athletes but requires further validation before being used in high-stakes decision-making contexts.

Although results showed higher CV and MDC, we think that by expanding the sample, we would confirm these results with even more stable numbers and eliminate potential bias. To date, very little attention has been given to this topic. In aquatic sports, there is a very limited number of anaerobic tests. By conducting this pilot research, we created a new water polo specific anaerobic swimming test that represents a sport-specific and practically applicable assessment tool that incorporates both anaerobic and respiratory demands of water polo performance, providing an additional perspective beyond traditional testing approaches. This gives coaches in water sports another potential test option in assessing players' conditioning. Future research could directly evaluate predictive validity by examining relationships between test scores and objective performance indicators. Because it doesn't require anything but a stopwatch and duct tape (visual markers), we hope it will be used widely.

AUTHOR CONTRIBUTIONS

All authors meet the criteria for authorship in accordance with established ethical guidelines. Contributions are specified according to the CRediT (Contributor Roles Taxonomy) as follows: Conceptualisation: Toni Propadalo, Ognjen Uljević. Methodology: Toni Propadalo, Ognjen Uljević. Formal analysis: Toni Propadalo. Investigation: Toni Propadalo, Jakov Marasović. Data curation: Toni Propadalo, Jakov Marasović. Writing – original draft: Toni Propadalo. Writing – review & editing: Toni Propadalo, Ognjen Uljević, Jakov Marasović. Supervision: Ognjen Uljević.

All authors have critically reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

AI USE DISCLOSURE

In accordance with current publishing ethics and transparency recommendations, artificial intelligence (AI) tools were used solely to assist with translation and language editing, with the aim of improving clarity and readability (ChatGPT). No AI tools were used in the generation of scientific content, including the study design, data collection, analysis, interpretation of results, or the formulation of conclusions. The authors retain full responsibility for the content of the manuscript and confirm its originality, integrity, and accuracy.

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