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Design and Validation of a New Water Polo Test of Anaerobic Endurance: Preliminary Study of Junior Male Players

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Abstract

Water polo is a team sport in which anaerobic capacity plays a significant role, but there is a lack of ecologically valid tests of water polo-specific anaerobic capacity. Therefore, the purpose of this study was to design and validate a method for evaluating the anaerobic capacity of water polo players. The sample of participants included 10 male junior water polo players (16.70 ± 1.06 years, 186.11 ± 6.06 cm, 81.18 ± 6.88 kg). Measurements included power output in the Wingate anaerobic test (WAnT) and the newly designed eggbeater kick anaerobic test (EKAT). WAnT included peak power (PP), average power (AP), minimal power (MP), and power drop (PD), and EKAT included the same four parameters as well as anaerobic capacity (AC). The results of this study show a significant correlation between test and retest values of power output (Pearson's correlation: 0.63, 0.87, 0.85, and 0.90 for PP, AP, MP, and AC, respectively). T-test calculation showed no significant differences between test and retest values for EKAT. Correlation analysis between EKAT and WAnT showed no significant correlation between corresponding power outputs. In conclusion, our results suggest that EKAT has proper metric characteristics, indicating the practical applicability of this test for male water polo players. Further studies on older players and female players are warranted.

Keywords: *eggbeater kick, EKAT, WanT, test-retest, reliability*

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Introduction

Team sports are characterized as being intermittent activities. The players are required to frequently transition between brief bouts of high-intensity activity and longer periods of low-intensity activity (Milanovic & Vuleta, 2013; Mohr et al., 2003; Reilly, 1976; Varley et al., 2014). Contrary to individual sports such as track and field or swimming, team sports are usually characterized by intense intermittent activity (Meckel et al., 2013). Additionally, team sports players may perform movements such as tackling, blocking, jumping, and directional changes that are integrated with technical skills (Paul et al., 2016; Perazzetti et al., 2023). Thus, due to the constant intensity changes, many team sports can be described as interval sports. Therefore, it has been suggested that success in many sports appears to involve high aerobic and anaerobic capacity (Al'Hazzaa et al., 2001; Hoffman et al., 1996; Smith et al., 1992; Uljevic

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et al., 2014). One of the sports that stands out in terms of the importance of aerobic and anaerobic capacity is water polo.

Water polo is a goal-type ball game played in the water (Kawai, Gonjo, et al., 2023). It is characterized by many complex activities, including swimming and treading water at various intensities, making contact with opponents, passing the ball to teammates, and shooting goals (Botonis et al., 2015; Melchiorri et al., 2010; Platanou, 2004). The difficulty and complexity of water polo can be seen through previously established physiological parameters. Specifically, a high heart rate during the match, with high lactate levels (up to 12 mmol/L-1), suggests that a great deal of energy production originates from anaerobic metabolism (Rodríguez, 1994). Moreover, kinematic analysis of water polo games suggests that there is a great demand on the anaerobic system (Tsekouras et al., 2005). Specifically, sprinting bouts during the game generally do not last longer than 10 s, implying that the major contributor to energy supply during sprinting is the anaerobic system (Bogdanis et al., 1996). To optimise activities while floating in the water, water polo players use a water-treading technique called the eggbeater kick.

The eggbeater kick is primarily used in water polo and artistic (synchronised) swimming (Kawai, Tsunokawa, et al., 2023). The eggbeater kick is used for approximately 45–55% of the total water polo game time (Platanou, 2004; Smith, 1998). During eggbeater kicking, athletes continuously alternate circular movements of their lower limbs to generate an upward propulsive force to elevate the body. The generation of a propulsive force by the eggbeater kick enables players to keep their upper body above the water during passing, shooting, and blocking, and to resist the action of opponents during contact play (McCluskey et al., 2010) (Nakashima et al., 2014; Platanou, 2004; Smith, 1998). Therefore, performing an effective eggbeater kick is important for all water polo players.

Previous brief literature review demonstrates that most of the studies on the eggbeater kick focused mainly on the kinetic and kinematic parameters (Kawai, Gonjo, et al., 2023; Kawai, Tsunokawa, et al., 2023). There are also several studies that developed tests for assessing the eggbeater kick, but in most cases studies implemented test performed in a vertical body position (Melchiorri et al., 2015) or for short intervals of time (Stirn et al., 2014). Therefore, the aim of this study was to construct and validate a new test for determining the anaerobic capacity of water polo players.

Materials and methods

Participants

The sample of participants included 10 male junior water polo players. Their chronological age was 16.70 ± 1.06 years, and they had an average height of 186.11 ± 6.06 cm, body mass of 81.18 ± 6.88, and body fat percentage of 14.14 ± 1.21% (see Table 1). Informed consent was obtained from all subjects involved in the study. The experimental procedures were completed following the Declaration of Helsinki. All athletes participate in water polo training daily; they have a minimum of 5 sessions per week, with matches on weekends during the competitive season. The tested players have extensive experience in sports, with the majority competing in Croatian senior and regional leagues. The water polo technique utilized in this research is commonly practiced during training and matches, thus they had a high level of proficiency. The athletes were aware of the identified minimal risk and voluntarily participated in the study.

Table 1. Descriptive parameters for age, anthropometric parameters, and lactates, in all participants.

Variables	Mean	Minimum	Maximum	SD
Age (years)	16.70	15.00	18.00	1.06
Body height (cm)	186.11	179.00	199.10	6.06
Body mass (kg)	81.18	72.30	92.10	6.88
Body fat percentage (%)	14.14	10.40	19.70	2.78
Lactate pre (mmol/L)	4.15	2.60	4.90	1.21
Lactate post (mmol/L)	9.59	5.80	14.70	2.63

SD, Standard deviation

Variables

The variables in this study included anthropometric indices, lactate levels, and power output from the Wingate anaerobic test (WAnT) and the newly developed eggbeater kick anaerobic test (EKAT).

Anthropometric indices, including body height measured with a measuring tape, body mass, and body height, were assessed by a bioimpedance scale (Tanita BC 418 scale, serial number 15010067, 2015).

To determine blood lactate concentration, blood samples were collected from the fingertip and immediately placed in a portable analyser (Accutrend® Plus, Roche, Lausanne, Switzerland). Blood lactate levels were determined before WAnT and EKAT and immediately after. The assessment was carried out in a sterile environment by an educated professional.

The power outputs of the test were defined using previously established parameters similar to those for the Wingate test (Bar-Or, 1987). The variables included peak power (PP), average power (AP), minimal power (MP), power drop (PD), and anaerobic capacity (AC). PP was calculated as the average for the first 5 seconds of the test. AP was derived as the average during the whole test. MP represents the last 5 seconds of the test. PD was defined as the difference in PP between the first 5 seconds and the last 5 seconds of the test. AC was calculated as the difference between the lowest PP and the highest PP, divided by the highest PP, then multiplied by 100. All power outputs were used as relative values with the body mass of the participants.

PP and MP equation:

$$PP = \frac{Average\ force\ in\ 5\ seconds\ (N)}{Time\ (s)}$$

PD equation:

$$PD = \text{First PP} - \text{Last PP}$$

AC equation:

$$PP = \frac{(High\ PP - Low\ PP)}{High\ PP} x\ 100$$

The variables used for WAnT were peak power (PP), as an indicator of the highest produced power, and average power (AP), as an indicator of anaerobic capacity. They were calculated as relative measurements according to the participant's body mass as W/kg.

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Testing procedure

The testing procedure included 2 anaerobic tests: the Wingate anaerobic test (WAnT), and the newly developed eggbeater kick anaerobic test (EKAT).

Before each EKAT session in the water, all participants executed a 10-to-15-minute warm-up consisting of various styles and intensities of swimming in the pool with appropriate technical elements, such as jumps, turns, water polo scissors, ball handling drills, etc. The warm-up was led and supervised by their coach, who utilized a standard warm-up procedure. Each participant was familiarized in advance with the manner and details of how to perform each test. Between each attempt within the test, participants had a rest period of 3-5 minutes, and there was a 15-minute break between tests. To avoid daily fluctuations in results, all testing sessions were conducted in the morning from 10 to 12 noon, and the testing was carried out in August 2023.

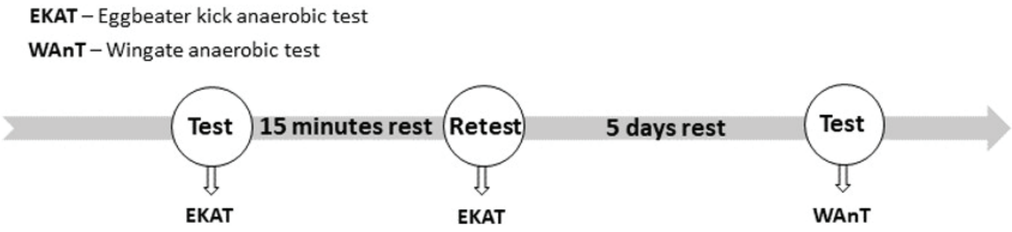

Figure 1. Testing procedure timeline for EKAT test/retest and WAnT.

During the test, participants were connected with a non-elastic rope to a belt tied around their waist. On the other end of the line, the PCE dynamometer (model FB2K, PCE Instruments, Meschede, Germany) was connected and secured so the participants could maintain force throughout the test without the movement of the apparatus. Before the start of the test, all participants were familiarized with the procedure. The participants were instructed to pull the rope as strongly as possible for 30 seconds. In the starting position of the test, the participant elongated the cord as far as possible, then on the mark, "Start!" they started the test. To determine the reliability of the test, the procedure was repeated two times with 15 minute rest between measurements (see Figure 2).

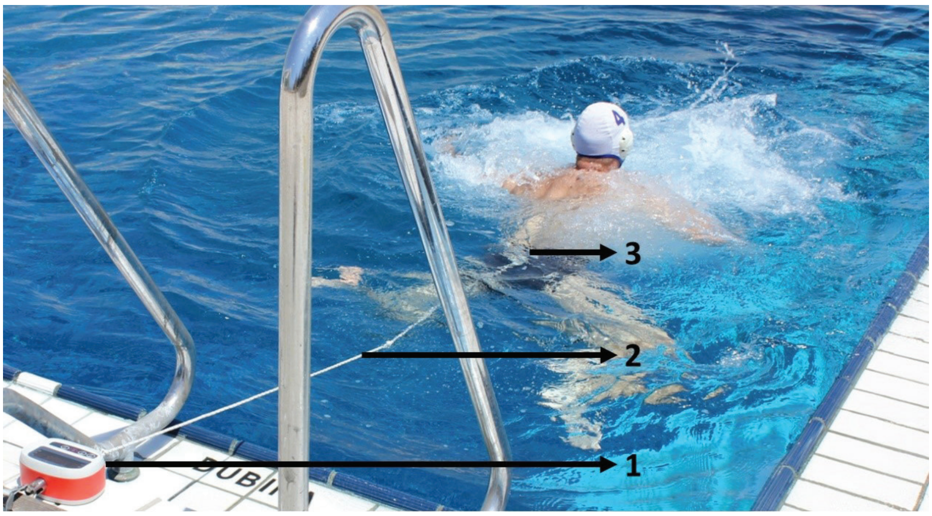

Figure 2. Graphical representation of the EKAT; (1) PCE dynamometer device, (2) cord connecting athlete and device, (3) the waist belt.

The data were derived by using the software for data extraction of the dynamometer during the whole testing procedure. The data are shown as the force value in Newtons (N) during the 30 seconds (see Figure 3). After the test, all data were processed in MATLAB software (MathWorks Inc., Natick, MA, USA).

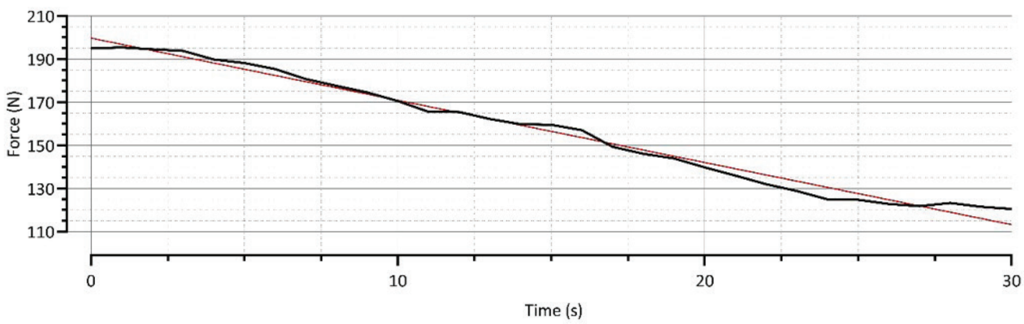

Figure 3. Graphical representation of the force output on the newly designed anaerobic test (EKAT)

WAnT was performed using a Monark 874E cycle ergometer (Monark Exercise AB, Vansbro, Sweden). Before the testing session, all participants executed a 10-to-15-minute warm-up consisting of moderate intensity rowing on an ergometer and self-preparatory exercises. Each athlete performed a 30 s test with the load individually adjusted to their body weight (7.5% of body mass). The task was to produce the highest possible cadence after the "Start!" command and maintain it as high as possible for the duration of the test. The participants were instructed not to raise their hips from the saddle but to always make their best effort to pedal during the Wingate test (Bar-Or, 1987).

Statistical analysis

Statistical analysis included descriptive measurements of all variables, skewness, kurtosis, and Kolmogorov-Smirnov test for determination of sensitivity and homogeneity. To determine the reliability level between variables, Pearson's r correlation coefficient was used. T-test was used to compare the results between test and retest variables, in order to exclude possible bias that may have occurred, due to learning, fatigue, and/or as a consequence of extensive time between measurements. Validity was checked with factor analysis (??? Any rotation???).

All analyses were done in the statistical package Statistica v. 13.5 (Tibco Inc., Palo Alto, CA, USA), with a p-value of 0.05

Results

The obtained results show that the test has good homogeneity and sensitivity according to the K-S test, as the data present normal distribution (K-S p > 0.20) (see Table 2). The reliability values are shown in Figure 4. Pearson's r correlation between test and retest values of power outputs demonstrates a significant relation between PP (0.63), AP (0.87), MP (0.85), and AC (0.90) outputs. On the other hand, there is a small connection between measurements for PD (0.04).

Table 2. Descriptive statistics and test sensitivity parameters for variables of EKAT, in both test and retest measurement.

Variables	Mean	Min	Max	SD	Skewness	Kurtosis	Max D	K-S p
	Test							
Peak Power (N/kg)	2.67	2.22	3.31	0.36	0.68	-0.38	0.16	p > .20
Average Power (N/kg)	2.10	1.72	2.57	0.29	0.21	-1.24	0.13	p > .20
Minimal Power (N/kg)	1.73	1.29	2.14	0.35	-0.07	-1.99	0.23	p > .20
Power Drop (N/kg)	0.93	0.27	1.44	0.36	-0.18	-0.03	0.16	p > .20
Anaerobic Capacity (N/kg)	12.64	10.33	15.41	1.74	0.20	-1.26	0.14	p > .20
	Retest							
Peak Power (N/kg)	2.46	1.76	3.01	0.46	-0.28	-1.67	0.21	p > .20
Average Power (N/kg)	1.96	1.42	2.35	0.34	-0.40	-1.28	0.19	p > .20
Minimal Power (N/kg)	1.69	1.15	2.07	0.32	-0.47	-1.06	0.16	p > .20
Power Drop (N/kg)	0.76	0.31	1.10	0.25	-0.76	-0.20	0.24	p > .20
Anaerobic Capacity (N/kg)	11.83	8.53	14.14	2.07	-0.40	-1.29	0.19	p > .20

Min, minimal result; Max, maximal result; Max D, test value of Kolmogorov-Smirnov test; K-S p, level of significance of Kolmogorov-Smirnov test

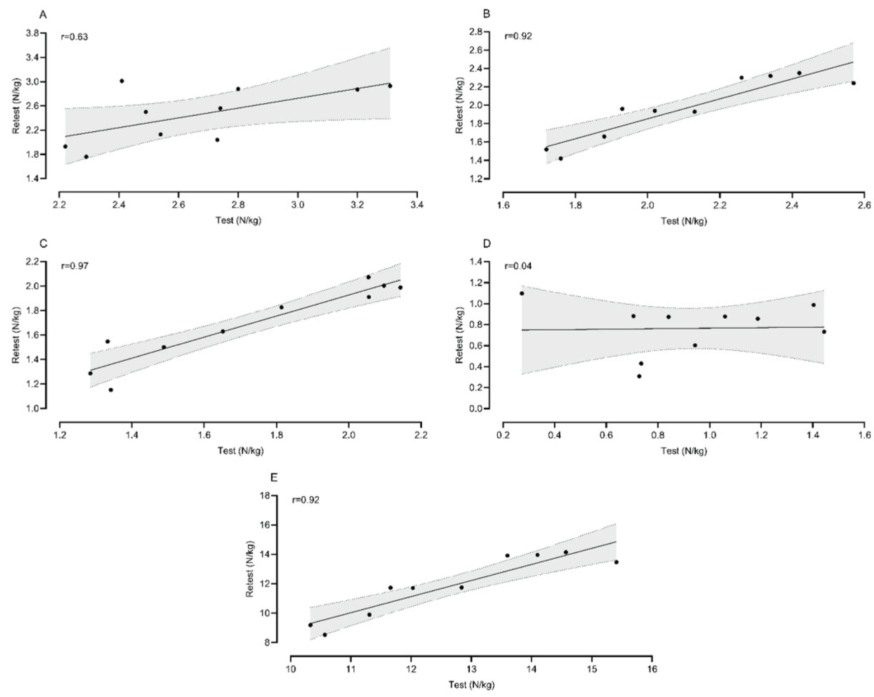

Figure 4. Pearson's r correlation for EKAT power outputs between test and retest measurement: (A) Peak Power; (B) Average Power; (C) Minimal Power; (D) Power Drop; (E) Anaerobic Capacity.

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T-test calculation demonstrates no significant differences between test and retest values of EKAT. Specifically, PP test values (2.67 ± 0.36) do not differ significantly from retest values (2.46 ± 0.46), with p = 0.34. A similar p-value was found for PD (0.93 ± 0.36 and 0.76 ± 0.25, respectively). For AP (test, 2.10 ± 0.29; retest, 1.96 ± 0.34) and AC (test, 12.64 ± 1.74; retest, 11.83 ± 2.07), the significance level is p = 0.11. The highest similarity between test (1.73 ± 0.35) and retest (1.69 ± 0.32) values was found for MP (p = 0.75) (see Table 3). Therefore, all derived power outputs are similar between the two measurements and show that all possible influences between tests were excluded.

Table 3. T-test for dependent samples between test and retest power outputs, of EKAT.

Variables	Test		Retest		t	p
	Mean	SD	Mean	SD		
Peak Power (N/kg)	2.67	0.36	2.46	0.46	1.14	0.27
Average Power (N/kg)	2.10	0.29	1.96	0.34	0.99	0.34
Minimal Power (N/kg)	1.73	0.35	1.69	0.32	0.23	0.82
Power Drop (N/kg)	0.93	0.36	0.76	0.25	1.22	0.24
Anaerobic Capacity (N/kg)	12.64	1.74	11.83	2.07	0.95	0.35

SD, Standard deviation; t, test value of T-test; p, level of significance set at $p<0.05$

Factor analysis extracted two significant factors. Factor one was correlated significantly with the PP (0.70), AP (0.99), MP (0.96), and AC (0.99) of the test measurement, with explained variance of 3.45 and a total proportion of 0.69. PD of the test measurement was included in factor two (-0.96) (see Table 4).

Correlation analysis between EKAT and WAnT showed no significant correlation between any of the measured power outputs. The only significant correlation was found between lactate levels measured before WAnT and after EKAT (r = -0.64) (see Table 5).

Table 4. Factor analysis for test and retest power outputs, of EKAT.

Variables	Factor (1)	Factor (2)
	Test	
Peak Power (N/kg)	0.70	-
Average Power (N/kg)	0.99	-
Minimal Power (N/kg)	0.96	-
Power Drop (N/kg)	-	-0.96
Anaerobic Capacity (N/kg)	0.99	-
EV	3.45	1.47
PT	0.69	0.29

EV, explained variance of factors; PT, Total proportion of factors

Table 5. Correlation between WAnT power outputs and EKAT.

Variables	Peak Power (W/kg)	Average Power (W/kg)	Minimal Power (W/kg)	Power Drop (W/kg)	Lactates WAnT pre (mmol/L)	Lactates WAnT post (mmol/L)
Peak Power (N/kg)	-0.49	-0.52	-0.41	-0.34	-0.25	-0.04
Average Power (N/kg)	-0.05	-0.07	-0.13	0.12	-0.08	0.21
Minimal Power (N/kg)	-0.10	-0.11	-0.19	0.10	-0.11	0.17
Power Drop (N/kg)	-0.35	-0.37	-0.17	-0.45	-0.14	-0.20
Anaerobic Capacity (N/kg)	-0.06	-0.07	-0.14	0.12	-0.08	0.20
Lactates pre (mmol/L)	-0.21	-0.26	-0.29	0.05	0.32	-0.24
Lactates post (mmol/L)	0.10	0.06	0.02	0.18	-0.64*	-0.38

*, significant correlations

Discussion

Water polo is considered to be an aerobic–anaerobic sport. Previous studies defined the aerobic capacity of water polo players using different sport-specific tests (e.g., swimming tests, VO2max analysis) (Galy et al., 2014; Meckel et al., 2013). However, an assessment of the anaerobic characteristics of players is lacking. Therefore, this study aimed to determine the validity and reliability of the newly developed eggbeater anaerobic test (EKAT) for water polo. Based on our results, we can highlight several important findings. First, the newly developed EKAT showed good reliability parameters. Second, retest measurement demonstrated consistency in the results for measured power outputs. Third, EKAT and WAnT showed no significant correlation between corresponding variables.

The results of this study demonstrate a high correlation between test and retest measurements. Specifically, average power, minimal power, and anaerobic capacity had high test–retest correlation coefficients (0.92, 0.97, and 0.92, respectively), whereas peak power showed a moderate effect (0.63). On the other hand, PD showed no significant correlation, with low reliability. Such results can be explained in two ways. First, retesting was done with 15 minutes of rest. Hence, the lack of rest for participants may be an influencing factor on the PD output, since it is a indicator of fatigue during the test (Ozkaya et al., 2018). This can be clearly seen in the PD results, where the test measurement (0.93 ± 0.36) is higher than the retest value (0.76 ± 0.25). Second, factor analysis of the test procedure extracted two significant factors, with the first one collecting all variables except PD in test measurement. Consequently, it can be noted that PD is a variable that indicates different capacity than the other power outputs. This result corroborates with previous findings, in which new variables for fatigue were considered rather than PD (Ozkaya et al., 2018; Pekünlü et al., 2016). Altogether, the results imply that the newly developed test is properly reliable when considering all variables except for PD.

The analysis of differences between test and retest measurements showed no significant difference between the two. This result implies that the measurement procedure is good, and excludes the effects of mastering the technique, becoming fatigued, or having too much time between measurements (influence of training, improved anaerobic capacity). Furthermore, this is a clear indicator of test stability through repeated measurements. Additionally, the power outputs of EKAT follow the traditional pattern of WAnT variables (PP, AP, MP, and PD) (Bar-Or, 1987). Therefore, the lack of differences can be compared to the results of previous studies examining WanT power outputs (Ozkaya et al., 2018; Pekünlü et al., 2016). The authors of these studies reported similar results for all derived parameters/variables in repeated WanT testing. Also, the descriptive parameters of EKAT indicate a slight decrease in force produced during the retest. This result is logical, since two measurements were made with a short rest in between. Nevertheless, the results indicate that the power output of EKAT could be used as an indicator of anaerobic work in sport-specific environments.

Descriptive statistics indicate that lactate levels ranged from 4.15 ± 1.21 mmol/L-1 before the test to 9.59 ± 2.63 mmol/L-1 after the test. Similar results for lactate levels have been seen in water polo players after a match. Specifically, according to Rodríguez (1994), these levels can increase up to 12.00 mmol/L-1. This similarity in lactate accumulation during EKAT and matches shows that the intensity of the test is appropriate for assessing water polo players. This can also be seen at water polo matches, where athletes perform high intensity intervals of anaerobic work during periods of attack and defence (Botonis et al., 2015). Additionally, EKAT is executed during a specific water polo movement, the eggbeater kick, which is a locomotor form used in 45–55% of the total game time (Platanou, 2004; Smith, 1998). Therefore, the similarity of our results to those of previous studies indicates that the newly developed test can measure the sport-specific anaerobic capacity of water polo players.

However, the correlation analysis between the Wingate anaerobic test and both measurements of the newly developed test showed no significant correlation between corresponding variables. Although such results could be interpreted as a certain lack of validity of the newly developed test, the authors believe that the low correlation between the sport-specific EKAT and the generic WAnT can be explained in terms of the differences in locomotor forms and the corresponding influence of anthropometric indices on text execution. Specifically, WAnT is performed on a bicycle ergometer, on which participants have to endure resistance (7.5% of body mass) for 30 seconds. Even though WAnT results are reported relative to body mass, it is an important factor of performance in this test (Galán-Rioja et al., 2020). On the other hand, in EKAT, tested athletes perform the specific water polo eggbeater kick with their legs while executing the rapid circulating manoeuvre with their hands, trying to generate the highest possible force. Contrary to WAnT, during EKAT body mass is not important in test execution because of the medium in which it is performed (i.e., water).

Supporting these results, previous studies reported similar results when comparing the Wingate test with other sport-specific tests (Bampouras & Marrin, 2009; Hoffman et al., 2000). Specifically, Hoffman et al. (2000) compared the Wingate test to a basketball-specific test (anaerobic sprint test, or line drill) and found no correlation between the fatigue indices. Moreover, Bampouras and Marrin (2009) examined the correlation between the Wingate test and sport-specific in-water tests for water polo players. The authors reported a lack of correlation between the Wingate test and water polo-specific tests for anaerobic power. They also suggested that the Wingate test is not a good indicator of decreased anaerobic performance in sports with an intermittent nature. Their results also suggest that the Wingate test cannot be used as an evaluation tool for the sport-specific parameters examined.

Limitations and strengths

One of the main limitations of this study is the relatively small sample size, Therefore, the results of the study should be considered as preliminary. Furthermore, this study is lacking important information on the performance level of study participants. Therefore, we could not correlate test achievement with objective parameters of success in sport. On the other hand, one of the strengths is that the players perform in one of the strongest leagues and most of them compete in senior championships as well. Also, the literature review showed a lack of investigation of sport-specific anaerobic capacity in water polo players. Therefore, this study is the first to develop such a test, which may be helpful for evaluating and assessing players' capacities.

Conclusion

A newly developed anaerobic water polo test, EKAT, has proper metric characteristics. This is demonstrated by the good sensitivity, homogeneity, reliability, and consistency of the measured power outputs. Since the test consists of the eggbeater kick, a technique that is used frequently in water polo, our results indicate that this test is applicable to water polo players. The results suggest that EKAT can measure the sport-specific anaerobic capacity of water polo players. This is supported by the lactate levels that players reached during the test, which were similar to those measured after a water polo match.

The most important advantage of this test is its non-invasiveness. In addition, the test incorporates several parameters applicable to the analysis of anaerobic endurance and strength capacity in water polo. However, a correlation between the generic and specific anaerobic tests was not found since they differ in specificity according to the athletes who perform in a specific medium. Therefore, EKAT should only be used to specifically assess anaerobic capacity in water polo. It is also possible to use the test for the selection of players during the training process.

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