

Relationship between VO_{2max} , under Water Swim Testing and Artistic Swim Solo Performance



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ABSTRACT

The purpose of this study was to evaluate the relationship between: 1) laboratory-determined cycling peak oxygen consumption (VO_{2max}) and AS performance in a new underwater swim test (UWST), and 2) cycling VO_{2max} and ventilatory threshold (VT) in cycling and performance score during a simulated AS solo routine. Trained artistic swimmers ($n = 15$, 15.8 ± 0.8 yrs., height: 169.1 ± 5.4 cm, body mass: 57.1 ± 6.3 kg) completed (1) a maximal incremental cycle test to exhaustion to determine VO_{2max} , (2) the UWST which comprised 275 m of freestyle and underwater breaststroke, and (3) a simulated solo competition where artistic swimming elements were evaluated by five FINA judges. There was a significant correlation between mean element score and (i) VO_{2max} (48 ± 4 mL \cdot kg $^{-1}$ \cdot min $^{-1}$, $r = 0.44$, $p = 0.05$), and (ii) UWST ($r = -0.64$, $p = 0.005$). However, there was an insignificant relationship between cycling ventilatory threshold and mean element score ($r = -0.36$, $p = 0.10$). In addition, the results demonstrate a significant relationship between HR at the ventilatory threshold and peak HR of the UWST ($r = -0.64$, $p = 0.014$). The results of this study demonstrate that VO_{2max} is an important determinant of AS performance. In addition, the UWST appears to be a useful indicator of AS performance.

Introduction

Artistic swimming (AS), formerly known as synchronized swimming, is a unique aesthetic sport based on both technical merit and artistry [1]. The positioning and movements of athletes in an AS competition are choreographed to music and costume themes to form a full AS routine, which ranges in the number of athletes (1–8: solo, duet, team combo, and highlight routine) [1–3]. An AS routine is composed of ‘elements’ that are sport-specific body positions and movement patterns, each of which requires different physical demands with the combination of movements, along with choreography, and influences the physiological demands of a routine [4, 5]. Additionally, routines may have mandatory elements seen in all technical routines or no mandatory elements in free rou-

tines [6]. Despite these differences in routine requirements and number of athletes competing at any one time, all disciplines of AS share a common demand: repeated apneic exposures, which in combination with vigorous movements imposed by the specific elements, represent a considerable respiratory and metabolic challenge for athletes [4, 5]. Previous authors have reported the time spent underwater (UW) in international competitions was highest in solo (62%), duets (56%), and teams (51%) with UW bouts lasting ~40 s in length [3, 7–9]. Therefore, the physiological assessment of artistic swimmers should consider the specific demands of the sport including repeated breathhold combined with vigorous exercise [5].

The significance of maximal oxygen uptake (VO_{2max}) in endurance-based sports has been widely reported [10]. However, the importance of VO_{2max} in AS is controversial, with the majority of studies conducted in AS having examined VO_{2max} in mixed cohorts and having used a variety of exercise challenge tests to induce a maximal response [11–15]. In one study a non significant correlation was shown between whole-body VO_{2max} and solo AS performance [14]. Aside from this study, there are minimal investigations examining the aerobic performance variables related to solo AS performance. The relationship between whole-body VO_{2max} and AS performance has not been directly determined in high-level athletes. Furthermore, a valid and sport-specific field test has yet to be developed where underwater exposures are combined with exertion to determine how this test correlates with competitive AS performances.

Therefore, in light of the scarcity of studies examining the relationship between VO_{2max} and performance in AS [3], the purpose of this study was to evaluate the relationship between: 1) laboratory-determined cycling peak oxygen consumption (VO_{2max}) and AS performance in a new underwater swim test (UWST), and 2) VO_{2max} and ventilatory threshold (VT) in cycling and performance score during a simulated AS solo routine. We hypothesised that whole-body VO_{2max} during cycling exercise would be correlated to performance during the UWST and the simulated solo routine.

Materials and Methods

Subjects

Fifteen ($n = 15$) trained provincial- and national-level Canadian artistic swimmers voluntarily participated in the study after written and informed consent was obtained. All athletes were members of the same training group and all testing was conducted at their daily training environment. The athletes were included in the trial be-

cause they were all members of the same elite provision AS program. Athletes were excluded if they were injured at the time of experimental testing. All athletes were informed of the experimental protocol, both verbally and in an information document. The study was approved by the institutional Research Ethics Board. The research was conducted adhering to international ethical standards of research [16].

Maximal incremental exercise testing

A maximal incremental exercise test to exhaustion was performed on a cycle ergometer (Velotron; RaceMate Inc., Seattle, Washington, USA) to determine VO_{2max} . A cycle ergometer test was chosen because it places demands on the lower limbs which are used in the 'egg beater' kick, which can occupy up to 40% of an AS routine [7]. Additionally, this dryland mode of exercise was the most familiar for all athletes. Each participant performed a 5 min warm-up at 0.5 watts per kilogram (kg) of total body mass (w/kg). Participants then performed three, 3-minute submaximal stages at 50, 100 and 150 watts (W) followed by an increase of 15 W every 30 s until volitional fatigue. During the test the resistance was electronically controlled and modified by the researcher with the athlete asked to maintain a consistent cadence of 70–75 rpm. Expired gases were continuously collected breath by breath by a calorimetry system calibrated prior to every test (Moxus; AEI Technologies Inc., Pittsburgh, PA, USA). The standard criterion used to determine a maximal test was the attainment of respiratory ventilation greater than 150 litres/minute, an athlete-reported rating of perceived exertion of 20 (Borg, 1970), and a respiratory exchange ratio of > 1.15 . The highest consecutive 15 sec average value for oxygen uptake (VO_2) was considered to be maximal oxygen VO_{2max} , which occurred at the onset of volitional fatigue. Ventilatory threshold was determined using the V-slope method as described previously [17, 18].

► **Table 1** Individual mean element score for the thrust one, vertical twist spin, cyclone, manta ray, and rocket split ($n = 15$). Mean element score of the five elements.

Athlete	Thrust one	Vertical twist spin	Cyclone	Manta ray	Rocket split	Mean element score
1	6.88	6.58	6.88	6.80	6.82	6.79
2	6.76	6.92	6.82	6.88	7.12	6.90
3	7.14	7.0	7.04	6.84	7.26	7.06
4	6.9	7.24	7.10	6.98	7.30	7.10
5	7.46	7.62	7.70	7.48	7.66	7.58
6	7.18	7.42	7.28	7.34	7.30	7.30
7	7.46	7.3	7.48	7.16	7.34	7.35
8	7.66	7.58	7.76	7.38	7.88	7.65
9	7.94	7.72	7.40	7.66	7.96	7.74
10	7.56	7.38	6.9	7.46	7.58	7.38
11	8.16	8.16	7.44	7.90	8.48	8.03
12	7.42	7.54	7.00	7.38	7.46	7.36
13	7.06	7.12	7.10	7.22	7.18	7.14
14	7.24	7.4	7.46	7.38	7.46	7.39
15	7.36	7.4	7.70	7.28	7.36	7.42
Mean	7.35	7.36	7.27	7.28	7.48	7.35
SD	0.39	0.37	0.32	0.31	0.40	0.32

Underwater swim test (UWST)

The pool-based performance testing was performed on another day with 24 h separating the maximal exercise testing. The pool-based testing consisted of an AS-specific, 275 meter (m) UWST held in a 25 m pool. After a standardized warm-up consisting of 600 m (about 10 min) of easy swimming, sculling, and elements, the participants performed the UWST, with the goal being to complete the 275 m distance in the least amount of time possible. Participants began the UWST from a push-off start, and then completed 50 m of freestyle stroke followed by 25 m of underwater breaststroke (BS) where the participants were discouraged from breathing during the 25 m. This format of 50 m freestyle and 25 m underwater BS was completed until 275 m was achieved. The test-retest reliability of the UWST in this group of athletes was determined to be $r = 0.93$.

Three minutes after the UWST was concluded, a capillary blood sample (3 μL) was obtained on the index finger using a small incision under aseptic conditions. The blood sample was analysed for blood lactate concentration (mM) using a portable analyser (EDGE Lactate Analyser, Transatlantic Science, Houston, TX, USA). Beat-by-beat heart rate (HR) ($\text{b} \cdot \text{min}^{-1}$) was sampled for 30 sec immediately upon completion of the UWST using a Polar monitor (Equine Healthcheck; Polar Electro, Kempele, Finland). The chest strap was placed against the athlete's chest after completing the UWST and the highest HR value recorded as the post-exercise HR (HR_{post}).

Simulated 'solo routine' performance

On a separate day, all athletes completed a standardised solo routine with all elements in the solo scored by five FINA-accredited judges with the mean score calculated. All element scores are based on a 10-point scale and displayed as mean \pm SD (range). The following five individual elements were scored: thrust one, vertical twist spin, cyclone, manta ray, and rocket split. Blood lactate concentration was measured after the solo performance as previously described.

Statistical analysis

Descriptive data in this study are presented as mean, standard deviation (\pm SD) and range. Pearson's r correlation coefficients were used to determine the relationship between laboratory testing, the UWST, and performance scores during a simulated solo routine. Pearson's r correlations were performed at the 95% confidence intervals (CI_{95}) with an α value of 0.05. All statistics were calculated using IBM SPSS version 24 (IBM Corp., Armonk, NY, USA). Effect sizes (ES) were calculated to supplement important findings as the ratio of the mean difference to the pooled SD of the difference. The magnitude of the ES was classed as trivial (< 0.2), small (0.2–0.6), moderate (0.6–1.2), large (1.2–2.0), and very large (≥ 2.0) based on previous published guidelines [19].

Results

The $\text{VO}_{2\text{max}}$ on the cycle ergometer was found to be $47.1 \pm 4.3 \text{ mL} \cdot \text{kg} \cdot \text{min}^{-1}$ (range: 41.4–52.7 $\text{mL} \cdot \text{kg} \cdot \text{min}^{-1}$). Mean max heart rate was 194.8 ± 7.2 (182–206). Mean ventilatory threshold occurred at $64.4 \pm 3.9\%$ of $\text{VO}_{2\text{max}}$ (57.7–71.0) and at $87.4 \pm 2.7\%$ of max heart rate (81.1–91.6).

The mean time to complete the UWST was 177 ± 16 (138–210) seconds (s) and mean peak HR at the end of the UWST was 171 ± 11 (151–187) bpm. Based on the UWST peak heart rate data, athletes performed the UWST at 100 ± 5 (93–108) % of ventilatory threshold (65 ± 5 (58–71) % of $\text{VO}_{2\text{max}}$), and 88 ± 6 (75–93) % of their max heart rate during the cycling $\text{VO}_{2\text{max}}$ test. There was a significant correlation between UWST time and cycling determined $\text{VO}_{2\text{max}}$ ($r = -0.44$, $p = 0.05$; ► **Fig. 1**) Mean blood lactate response at the end of the UWST was 6.8 ± 1.9 (4.2–11.7) $\text{mmol} \cdot \text{L}^{-1}$.

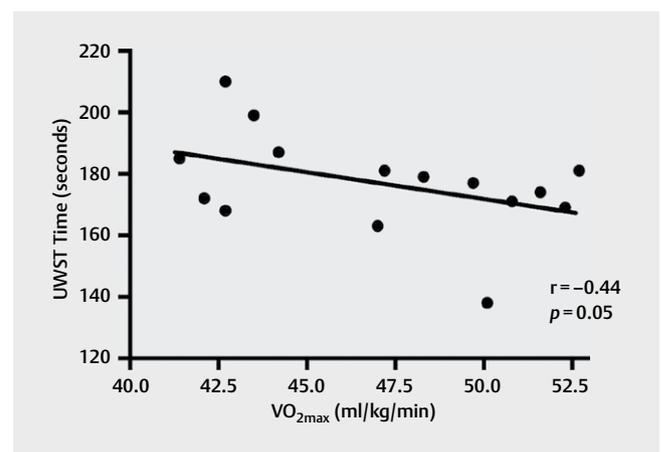
Athletes were evaluated by five FINA judges on the performance of the following solo elements during a simulated solo routine: thrust one, vertical twist spin, cyclone, manta ray, and rocket split. Individual element scores are provided in ► **Table 1**. The mean blood lactate concentration after the solo swim performance was $8.7 \pm 2.1 \text{ mmol} \cdot \text{L}^{-1}$.

There was a significant correlation between mean element score and (i) $\text{VO}_{2\text{max}}$ ($r = 0.44$, $p = 0.05$; ► **Fig. 2**), and (ii) UWST ($r = -0.64$, $p = 0.005$). However, there was an insignificant relationship between cycling ventilatory threshold and mean element score ($r = -0.36$, $p = 0.10$). The results also demonstrate a significant relationship between HR at the ventilatory threshold and peak HR of the UWST ($r = -0.64$, $p = 0.014$; ► **Fig. 3**).

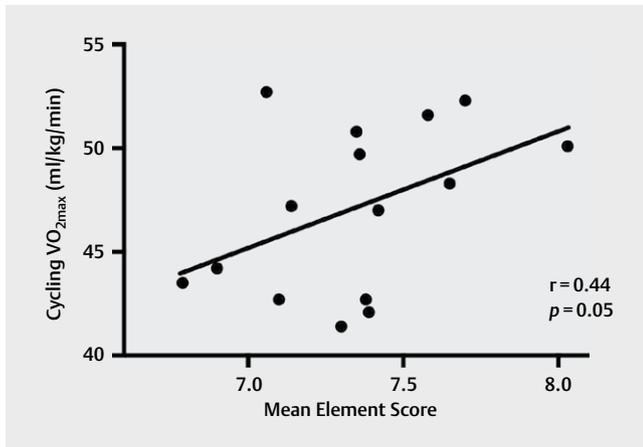
Discussion

This is the first study to examine the relationship between $\text{VO}_{2\text{max}}$, an AS-specific UWST, and technical scores of individual AS elements in highly trained female artistic swimmers. The results of this study demonstrate a significantly positive correlation between mean element score and cycling $\text{VO}_{2\text{max}}$, and a significantly negative correlation between mean element score and UWST time and blood lactate response to the solo routine.

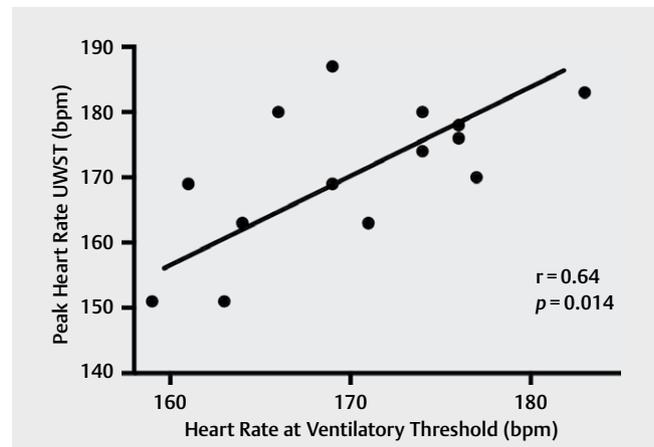
To the authors' knowledge, this is the only study that compared $\text{VO}_{2\text{max}}$ obtained on a cycle ergometer to AS performance. The $\text{VO}_{2\text{max}}$ presented in this study ($48 \pm 4 \text{ mL} \cdot \text{kg} \cdot \text{min}^{-1}$) is similar to that of Bante et al. [12] ($42.8 \pm 3.1 \text{ mL} \cdot \text{kg} \cdot \text{min}^{-1}$ in senior athletes (age: 22.6 ± 0.2 years) and $37.6 \pm 4.1 \text{ mL} \cdot \text{kg} \cdot \text{min}^{-1}$ in junior athletes (age:



► **Fig. 1** Relationship between the maximal aerobic capacity determined on a cycle ergometer ($\text{VO}_{2\text{max}}$ ($\text{mL} \cdot \text{kg} \cdot \text{min}^{-1}$)) and performance time (seconds) of the underwater swim test (UWST).



► **Fig. 2** Relationship between mean element score (10-point scale) and cycle ergometer-determined aerobic capacity (VO_{2max} (mL/kg/min)).



► **Fig. 3** Relationship between peak heart rate (beats per minute (bpm)) of the underwater swim test (UWST) and heart rate (bpm) at ventilatory threshold.

13.8 ± 0.9 years)) and Chatard et al. [3] (52.4 ± 4.9 mL · kg⁻¹ · min⁻¹ before a 5-week training intervention, 50.1 ± 3.6 mL · kg⁻¹ · min⁻¹ after a 5-week training intervention). During whole-body exercise, such as treadmill running and swimming, a greater amount of skeletal muscle mass is engaged when compared to cycling [19]. The variances in methodology may account for some of the discrepancy between the VO_{2max} obtained in this study and varying levels of aerobic fitness across the three populations. Roby et al. [13] found a mean VO_{2max} of 43 mL/kg/min when measured in tethered swimming which did not differ to a group of untrained individuals. Whilst it is typically difficult to induce a valid maximal physiological response in tethered swimming, it was suggested that aerobic capacity was not a factor in AS performance. Similar to the results of the present study, Poole, Crepin, and Sevigny [14] correlated cycling VO_{2max} with scores during a solo routine ($r = 0.41$, $p = 0.06$) with the authors concluding that aerobic capacity was an important factor during an AS routine. Yamamura et al. [11] confirmed this finding and found performance scores in a group of well-trained AS athletes correlated with relative VO_{2max} (50.8 ± 2.8 mL/kg/min) when tested in a swimming flume ($r = 0.71$, $p < 0.05$). Most recently, Sajber et al. [15] used a variation of the land-based multi-stage shuttle test (MSST) in a 25 m pool and found the total duration of the MSST strongly correlated with AS performance score at a national championship ($r = -0.81$), indicating the longer the swim time the higher the score. Whilst it is difficult to compare the results of this study to previous work, the results of the present study confirm the importance of VO_{2max} in AS. Previous work by Chatard et al. has demonstrated improvements in AS performance with changes in VO_{2max} [3]. Therefore, future studies should look to further examine the significance of VO_{2max} in different level artistic swimmers and means of improving this metric for overall AS preparation.

This study is one of two known studies to examine the relationship between BL_a and performance in AS. In this study, the BL_a response observed after the UWST (7.2 ± 1.9 mmol · L⁻¹) and after the simulated solo (8.7 ± 2.1 mmol · L⁻¹) are similar to that observed by Rodríguez-Zamora et al. [4] (7.3 ± 2.0 mmol · L⁻¹) during the technical solo, free solo, technical duet, free duet, technical team,

and free team routine. Our findings indicate appearance of blood lactate during a simulated competition is similar to that observed during a real competition. In addition, the findings of the current study suggest there is a considerable glycolytic energy contribution to a simulated solo routine with lactate production a key determinant of the ability of a swimmer to perform complex movements in a routine. Therefore, means of improving the lactate response to an AS performance is an important consideration in the preparation of an artistic swimmer.

In this study there was a significant correlation between UWST time and the performance in the simulated solo event. This is an interesting finding that indicates a performance test incorporating periods of conventional high-intensity swimming and underwater swimming is a factor in high-level AS performance. Usually freestyle swim performance can be attributed to the role stroke mechanics play in overall freestyle and form swim speed [20–22], that role being of greater importance in competitive swimming than overall fitness [20–22]. However, it is possible that the AS population were better able to combine the periods of swimming and underwater exercise, and this task replicated the (general) demands of AS. Therefore whilst the impact of stroke mechanics are not in question in competitive swimming [20–22], this performance task represents a valid approach to assess an AS athlete and can be used routinely in training, but the relationship is still under investigation [23].

This study demonstrates that VO_{2max} in cycling and the blood lactate response to exercise are important and linked parameters that influence AS performance. The positive correlation between VO_{2max} and element scores during a simulated solo routine, and the negative correlations between BL_a and element scores suggest coaches and sport scientists working with AS athletes may elect to prescribe training to improve VO_{2max} and metabolic efficiency. These training methods may include high-intensity training with the goals of improving aerobic capacity. However further research is required to examine different dryland training interventions as

well as the reliability and validity of testing methods including the UWST used in this study.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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