ORIGINAL ARTICLE

Specificity of $\dot{V}O_2$MAX and the ventilatory threshold in free swimming and cycle ergometry: comparison between triathletes and swimmers

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Br J Sports Med 2005;**39**:965–968. doi: 10.1136/bjsm.2005.020404

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Accepted 23 May 2005

Objectives: To compare maximal heart rate (HRMAX), maximal oxygen consumption ($\dot{V}O_2$MAX), and the ventilatory threshold (VT; %$\dot{V}O_2$MAX) during cycle ergometry and free swimming between swimmers and triathletes.

Methods: Nine swimmers and ten triathletes completed an incremental swimming and cycling test to exhaustion. Whole body metabolic responses were determined in each test.

Results: The swimmers exhibited a significantly higher $\dot{V}O_2$MAX in swimming than in cycling (58.4 (5.6) *v* 51.3 (5.1) ml/kg/min), whereas the opposite was found in the triathletes (53.0 (6.7) *v* 68.2 (6.8) ml/kg/min). HRMAX was significantly different in the maximal cycling and swimming tests for the triathletes (188.6 (7.5) *v* 174.8 (9.0) beats/min). In the maximal swimming test, HRMAX was significantly higher in the swimmers than in the triathletes (174.8 (9.0) *v* 184.6 (9.7) beats/min). No significant differences were found for VT measured in swimming and cycling in the triathletes and swimmers.

Conclusion: This study confirms that the exercise testing mode affects the $\dot{V}O_2$MAX value, and that swimmers have very specific training adaptations even compared with triathletes. This may be a function of acute physiological responses combined with the specialist training status of the different athletes influencing maximal cardiac output or oxygen extraction. In contrast, the different training regimens do not seem to influence the VT, as this variable did not differ between the two testing modes in either group.

The concept of whole body maximal oxygen uptake ($\dot{V}O_2$MAX) has received much attention in the literature in terms of its relevance to endurance performance and adaptation to training.[1] At the same time, there have been a number of studies that have investigated the physiological mechanisms that influence $\dot{V}O_2$MAX when measured during an incremental exercise test.[2 3] It is widely accepted that $\dot{V}O_2$MAX is influenced by both central and peripheral factors that affect oxygen utilisation, and for this reason it is accepted as a valid measure of endurance ability.[1]

Because there is a peripheral component to $\dot{V}O_2$MAX, a fundamental question is how the mode of activity and total muscle mass being used during maximal exercise relates to the level of oxygen uptake measured when a progressive exercise test is administered. It has been shown that peak heart rate (HRMAX) in swimming is lower than that obtained during running.[4 5] This is because of the smaller muscle mass involved and different haemodynamics because of the horizontal body position, the decreased effects of gravity, and reflex bradycardia.[6] However, in trained swimmers, $\dot{V}O_2$MAX during swimming is similar to that during running.[2 7] Hence, the training patterns in swimming and lower body activities may influence $\dot{V}O_2$MAX adaptation between different exercise modes.

The variation in training patterns of triathletes in swimming and lower body activities such as cycling and running is great and may influence $\dot{V}O_2$MAX and other physiological responses in different exercise modes.[8] This is related to cross training transfer or the respective transfer of training adaptations between the upper and lower body exercise modes.[9] Cross training and its physiological relevance to $\dot{V}O_2$MAX for triathletes has received relatively little attention in the scientific literature. Some previous studies have indicated that swimming training is not beneficial in terms of whole body physiological adaptations in cycling or running.[9–11] Indeed Millet *et al*[9] highlighted the specificity of swimming training by showing no cross transfer from or to swimming in elite triathletes who also did cycling and running training.

In triathletes, $\dot{V}O_2$MAX measured while swimming is typically lower than while cycling and running, with the difference being related to differences in HRMAX and maximal pulmonary ventilation.[12–14] Other researchers have reported that triathletes who have trained only for triathlons show similar $\dot{V}O_2$MAX and anaerobic threshold values for cycling and running.[15]

A confounding factor in comparisons between $\dot{V}O_2$MAX measured for swimming and cycling in triathletes is the use of a valid testing procedure for the measurement of $\dot{V}O_2$MAX during swimming. Most studies use either tethered swimming coupled to a system of gas analysis or measurement of respiratory gases after an all-out swim.[12 13 16] However, both methods have problems, and gas exchange is difficult to quantify. This may reduce the validity of $\dot{V}O_2$MAX measurements obtained for swimming. Hence, comparison of $\dot{V}O_2$MAX for swimming and cycling or running in triathletes who have only predominantly trained for this sport or in swimmers has not yet been investigated with a valid test for measuring $\dot{V}O_2$MAX during free swimming. Furthermore, pulmonary ventilatory threshold (VT) for swimming has not been compared with that for a lower body activity such as cycling in triathletes and swimmers.

Recently a new ''snorkel'' system was developed and validated for determining oxygen uptake during actual progressive or submaximal swimming tasks.[17] Given the novelty of the snorkel device for measuring the physiological responses in swimming, together with the lack of information on $\dot{V}O_2$MAX for swimming and lower body exercise activity in swimmers and multisport athletes, the aim of this study was to

Abbreviations: HRMAX, peak heart rate; $\dot{V}O_2$MAX, maximal oxygen uptake; VT, ventilatory threshold determine differences in maximal cardiorespiratory measurements between cycling and swimming in swimmers and triathletes. This study was also conducted to establish some of the mechanisms responsible for the differences in $\dot{V}O_{2MAX}$ in swimming and cycling. We hypothesised that $\dot{V}O_{2MAX}$ and VT would be higher in cycling for the triathletes, but this difference would not be evident in the swimmers.

METHODS

Subjects

Nineteen trained athletes gave written informed consent to participate in the study, which was approved by the local research ethics committee. They had a mean (SD) age of 19.6 (4.5) years and body mass of 70.1 (6.8) kg. All of the subjects were familiarised with the test procedures and equipment used in the experiment before the start. Subjects were assigned to one of two groups on the basis of their training: swimmers (n = 9); triathletes (n = 10).

Procedures

Subjects completed two different incremental exercise tests over a one week period. Each test was separated by a minimum of 48 hours, and completed in a randomised order. The first test comprised a progressive incremental swimming test to exhaustion for determination of $\dot{V}O_{2MAX}$ (ml/kg/min), HRMAX (beats/min), and maximal swimming velocity (seconds). Pulmonary VT (% $\dot{V}O_{2MAX}$) was also determined. The second test comprised an incremental cycling test to exhaustion for determination of $\dot{V}O_{2MAX}$, HRMAX, and VT. Peak power output (W) was also determined during this test.

Incremental exercise testing

The incremental swimming test started after a standardised warm up of 400 m of low intensity swimming. The test comprised 5 × 200 m repeats with 15 seconds rest after each repeat. A test protocol of these requirements has previously been used to determine maximal and submaximal physiological variables.[18 19] Swimming velocity for each 200 m (first to fourth 200 m) was progressively increased based on the percentage of the subject's best competition time for 200 m. This was done so that 5–10% increments were made for every 200 m repeat, with the final 200 m swim performed at an expected maximum effort. Velocity during the test was controlled by auditory signals elicited using a waterproof pacing device (Aquapacer, Bristol, UK) coupled with visual marks placed on the bottom of the pool at 12.5 m. The swimming test was performed in a 25 m pool.

The incremental cycle test was completed on an electromagnetic cycle ergometer (Electronic chrono bike 400ES; Air Machine, Cesena, Italy). The test started after a warm up of 100 W for five minutes. The initial power output was 100 W, and the workload was increased by 25 W every two minutes until exhaustion. Exhaustion occurred when the following criteria were met: (*a*) HR approached maximal theoretical HR (220 − age); (*b*) $\dot{V}O_2$ levelled off even with an increase in intensity. Peak power output was defined as the highest mechanical power maintained for one minute.[20] The length of the workloads in the cycle test was used to standardise the total length of the incremental test.

Physiological measurements

Gas exchange during the incremental swimming test was measured breath by breath with a portable system (K4^{b2}; Cosmed, Rome, Italy). The K4^{b2} was connected to a snorkel (Aquatrainer; Cosmed), validated by Keskinen *et al*.[17] The snorkel system can be attached to a portable gas analyser so that an athlete can perform swimming activity without restriction, and breath by breath measurements can be obtained.

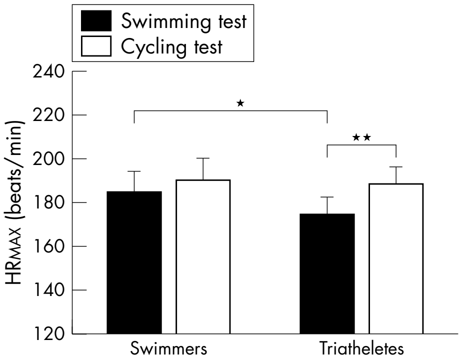

Figure 1 Mean (SD) maximal heart rate (HRMAX) achieved in the incremental swimming and cycling tests in the swimmers and triathletes. **Significant ($p<0.01$) difference between swimming and cycling test; *significant ($p<0.05$) difference between swimmers and triathletes.

During the incremental cycling test to exhaustion, gas exchange was measured by VMax series 29C (Sensormedics Corporation, Yorba Linda, California, USA). Both devices were calibrated according to manufacturer's recommendations before each test. Other studies have compared the validity of the Cosmed system with laboratory based systems.[21] Breath by breath data were reduced to 30 second averages, and $\dot{V}O_{2MAX}$ was determined as the highest 30 second $\dot{V}O_2$ average in either swimming or cycling tests. HR was recorded every second by each metabolic measuring system with a chest belt (Polar Electro, Kempele, Finland) worn by the subject. HRMAX (beats/min) was measured as the highest 30 second average value in the test. VT was calculated using the v slope method and coincided with $\dot{V}O_2$ that elicited the first deflection from linearity in $\dot{V}E/\dot{V}O_2$.[22] VT was expressed as % $\dot{V}O_{2MAX}$ obtained in either the swimming or cycling test.

Statistical analysis

All values are reported as mean (SD). After analysis of normality and homogeneity of variance of the tested samples, correlation coefficients and a two way analysis of variance were used to compare the values from the two incremental tests (swimming and cycling) in the two groups. Significant main effects were subsequently analysed using the Student-Newman-Keuls post hoc test. Statistical significance was accepted at $p<0.05$.

RESULTS

There was a significant difference in age (22.6 (3.6) *v* 16.1 (0.6) years; $p<0.01$) and body mass (72.3 (6.6) *v* 67.7 (6.5) kg; $p<0.05$) between the triathletes and swimmers respectively.

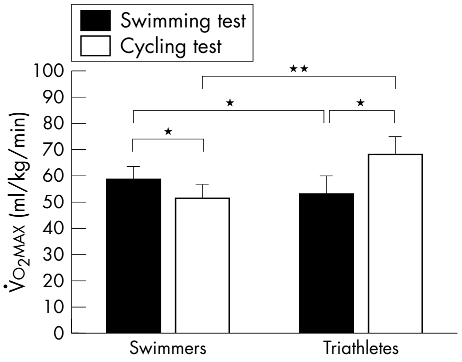

Figure 2 Mean (SD) maximal oxygen uptake ($\dot{V}O_{2MAX}$) achieved in the incremental swimming and cycling tests in the swimmers and triathletes. Significant (**$p<0.01$, *$p<0.05$) difference between swimmers and triathletes. *Significant ($p<0.05$) difference between swimming and cycling test.

HRMAX achieved by the triathletes was significantly higher in cycling than in swimming (fig 1). There was no significant difference for this variable in the incremental swimming and cycling test in the swimmers (fig 1). HRMAX achieved in the swimming test was significantly higher in the swimmers than in the triathletes (fig 1).

$\dot{V}O_2$MAX in the cycling test was significantly ($p<0.01$) higher in the triathletes than in the swimmers (fig 2). However, in the swimming test, $\dot{V}O_2$MAX was significantly ($p<0.05$) higher in the swimmers than in the triathletes. $\dot{V}O_2$MAX was also significantly ($p<0.05$) higher in the cycling test than in the swimming test in the triathletes. The opposite was evident for the swimmers, with $\dot{V}O_2$MAX significantly ($p<0.05$) higher in the swimming test than in the cycling test. There was a significant correlation between $\dot{V}O_2$MAX in cycling and swimming in the swimmers ($r = 0.77$; $p<0.01$) but not in the triathletes.

There was no significant difference in VT in the swimming and cycling tests in either the triathletes or the swimmers (fig 3). There was also a significant correlation between VT measured in swimming and cycling in the swimmers ($r = 0.85$; $p<0.01$) but not in the triathletes. Peak power output in cycling was significantly ($p<0.01$) higher in the triathletes than in the swimmers (350.0 (41.4) *v* 266.7 (30.6) W). There was also a significant difference in maximal swimming velocity in the incremental swimming test in the swimmers compared with the triathletes (146.9 (6.1) *v* 165.2 (8.9) seconds).

DISCUSSION

This experiment was conducted to compare maximal and submaximal physiological responses obtained during an incremental swimming and cycling test in athletes specialising in swimming or triathlon. The results showed that $\dot{V}O_2$MAX was higher when assessed by cycle ergometry compared with free swimming for the triathletes, whereas the swimmers showed a higher $\dot{V}O_2$MAX when assessed during swimming. However, there was no significant difference in VT in swimming and cycling in the two training groups. Hence, the hypothesis that $\dot{V}O_2$MAX and VT would be higher in cycling for the triathletes compared with the swimmers was only partially confirmed.

Physiological responses to incremental exercise tasks are complex, with acute physiological responses influenced by specific long term training adaptations. $\dot{V}O_2$MAX is a function of the O_2 transport system, including pulmonary ventilation, cardiac output, and peripheral muscle O_2 extraction. Long term endurance training in either swimming or cycling may affect these processes and in turn the responses of these components to an incremental exercise task in a different mode of activity. For instance, it has been shown that the level of $\dot{V}O_2$MAX reached during an incremental task is largely influenced by cardiac output.[3] In this study we did not measure cardiac output. However, one component of cardiac output, HRMAX, did show considerable variation between the groups and in each incremental test. Specifically, lower HRMAX in the incremental swimming task compared with cycling closely matched that of $\dot{V}O_2$MAX in the triathletes. Interestingly, this was not the case in the swimmers. Although it would be necessary to examine cardiac output directly, it may well be that other peripheral factors may have influenced the results in the swimmers in response to the two different incremental exercises. In this regard, there is considerable debate as to whether maximal cardiac output is regulated by the central nervous system or is actually influenced more by peripheral oxygen demand.[23] Typically, swimming requires less muscle mass (predominantly upper body), and the different $\dot{V}O_2$MAX and HR responses during swimming for the swimmers and triathletes may also be a function of other factors such as different body position inducing greater hydrostatic pressure and lower perfusion in the capillary bed of the working muscle, resulting in a reduction in both blood flow and oxygen transport. Hence, this may influence peripheral oxygen extraction and the $\dot{V}O_2$MAX value obtained in the two tests. Heat conductance of water is also higher than that of air, which may influence cardiorespiratory responses in swimming.[24] However, in this study we did not find any significant differences between $\dot{V}O_2$MAX and HRMAX in the incremental swimming and cycling tests in the swimmers. Moreover, in this study, cycling $\dot{V}O_2$MAX was lower than swimming $\dot{V}O_2$MAX in the swimmers. This finding is in contrast with that of Holmer,[25] who showed that HRMAX was significantly lower during swimming than during cycling in adolescent and adult swimmers. The contradictory findings may be due to the specific training of swimmers affecting muscle recruitment patterns in both swimming and cycling. It has been suggested that the specifics of training quality and quantity affect muscle recruitment during exercise.[3] It may be that the swimmers were able to use muscles of the upper body during the incremental swimming exercise to the same extent as the lower body during the incremental cycle exercise, the mode of activity to which they were not accustomed. Therefore the responses of the swimmers to the incremental cycling task may have been influenced by peripheral muscle limitations not evident in triathletes, who were more conditioned to cycling activity. However, the criteria of exhaustion were similar in both activities. Therefore the higher $\dot{V}O_2$MAX in swimming may well be due to the specific training induced central and peripheral adaptations in the different athlete groups.

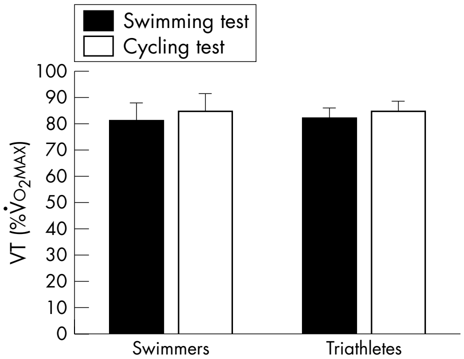

Figure 3 Mean (SD) ventilatory threshold (VT) measured in the incremental swimming and cycling tests in the swimmers and triathletes.

Other studies in triathletes have suggested that physiological responses to an incremental exercise task are influenced by whether training has been performed in one exercise mode or all three—that is, swimming, cycling, and running.[15] In this study we did not quantify training volume/intensity or history, which may be confounding factors in the physiological responses to the incremental exercise tasks in the two groups. This requires further research to establish whether specific training demands and maturity may affect cardiac output or peripheral oxygen extraction, thereby influencing $\dot{V}O_2$MAX and HRMAX in a task that generally elicits a different physiological response in untrained subjects.

VT is an important physiological variable distinguishing endurance performance in athletes and is homogeneous in terms of $\dot{V}O_2$MAX.[1] The ability to sustain a high %$\dot{V}O_2$MAX during an endurance exercise appears to be related to %$\dot{V}O_2$MAX at VT.[1] We expected to find a higher VT in the triathletes during the cycling test, because of their greater experience and efficiency on a bike compared with swimmers. Conversely, we expected a higher VT in swimmers during the swimming test, because of better swimming economy and technique than the triathletes. However, no significant differences between the groups for either test procedure were observed. Most comparisons between

What is already known on this topic

- There are large differences in training patterns for swimming and lower body activities (cycling, running) between triathletes and swimmers
- This influences $\dot{V}O_2MAX$ and other physiological responses in the different exercise modes and is influenced by cross training transfer or the respective transfer of training adaptations between upper and lower body exercise modes

What this study adds

- A comparison of $\dot{V}O_2MAX$ in free swimming and cycling in triathletes and swimmers confirms that swimming adaptations are very specific and that maximal values are obtained in the disciplines for which the subjects have predominantly trained
- The study also establishes some of the mechanisms behind the differences in $\dot{V}O_2MAX$ in swimming and cycling

swim VT and cycle VT have been performed in triathlete populations. In accordance with our results, Miura *et al*[26] found similar swim and cycle VT in male triathletes (70.2% and 71.0% respectively). In contrast, Sleivert and Wenger[27] observed in male triathletes a lower VT in a tethered swim compared with the cycle VT (71.8% *v* 81.4 (1.3)% respectively). Also Albrecht *et al*[28] found a lower swim bench VT (51.6%) in male long distance triathletes compared with their cycle VT (78.8%). Kreider[29] showed the opposite—that is, a higher tethered swim VT compared with cycle VT in competitive triathletes (89% *v* 85% respectively). The measurement of VT in cycling and swimming does not seem to be indicative of performance.

On a technical note, improved technological innovations—for example, the snorkel—have made measurement of metabolism in swimming much easier and more valid. Keskinen *et al*[17] found that the quantitative differences between the snorkel and the standard facemask were almost negligible for practical purposes.[17] Although subjects could only breath through their mouth, not through their nostrils, they did not report any noticeable inconveniences other than a dry mouth at the end of the trials (confirmed by our own observations). Moreover, the use of the snorkel devices was found not to significantly increase total body drag as compared with totally free, unimpeded swimming (confirmed by our own observations). Therefore this study confirms that of Keskinen *et al*[8] and other studies[18] that the snorkel is a valid device for assessing physiological capacity of athletes performing swimming activity.

In conclusion, this study confirms that different exercise testing modes lead to different $\dot{V}O_2MAX$ values, and that swimmers have very specific training adaptations even compared with triathletes. This may be a function of acute physiological responses combined with the specialist training status of the different athletes influencing maximal cardiac output or oxygen extraction. In contrast, the different specific training regimens do not seem to influence VT, as this variable did not differ between the two testing modes in the two groups.

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Competing interests: none declared

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