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Review

Physiological attributes of triathletes

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Abstract

Triathlons of all distances can be considered endurance events and consist of the individual disciplines of swimming, cycling and running which are generally completed in this sequential order. While it is expected that elite triathletes would possess high values for submaximal and maximal measures of aerobic fitness, little is known about how these values compare with those of single-sport endurance athletes. Earlier reviews, conducted in the 1980s, concluded that triathletes possessed lower $V_{O_2\,max}$ values than other endurance athletes. An update of comparisons is of interest to determine if the physiological capacities of elite triathletes now reflect those of single-sport athletes or whether these physiological capacities are compromised by the requirement to cross-train for three different disciplines. It was found that although differences in the physiological attributes during swimming, cycling and running are evident among triathletes, those who compete at an international level possess $V_{O_2\,max}$ values that are indicative of success in endurance-based individual sports. Furthermore, various physiological parameters at submaximal workloads have been used to describe the capacities of these athletes. Only a few studies have reported the lactate threshold among triathletes with the majority of studies reporting the ventilatory threshold. Although observed differences among triathletes for both these submaximal measures are complicated by the various methods used to determine them, the reported values for triathletes are similar to those for trained cyclists and runners. Thus, from the limited data available, it appears that triathletes are able to obtain similar physiological values as single-sport athletes despite dividing their training time among three disciplines.

Keywords: Triathlon; Bicycling; Exercise test; Physical endurance; Running

Contents

1. Physiological attributes of triathletes

Triathlon is an event comprising the individual disciplines of swimming, cycling and running and is generally completed in this sequential order. Although race distances vary, triathlons of all distances can be considered to be endurance events. The most common measure of aerobic fitness is maximal oxygen consumption ($\dot{V}_{O_2\,max}$) and this has often been proposed as a determinant of endurance success.[1] However, physiological measurements at submaximal workloads have also been shown to be important determinants of endurance performance.[2,3] Thus, while it is expected that elite triathletes would possess high values for submaximal and maximal

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measures of aerobic fitness, little is known about how these values compare with those of single-sport endurance athletes. Such comparisons are of interest to determine if the physiological capacities of triathletes reflect those of single-sport athletes or whether theses physiological capacities are compromised by the requirement to cross-train for three different disciplines; this has obvious implications for the training of triathletes.

Although there have been previously published reviews on the physiological attributes of triathletes,[4,5] these were all published at least 12 yrs prior to the current review. Since these reviews, the sport of triathlon has increased its professionalism and triathletes are more likely to enter the sport as triathletes (with a training background in all three disciplines), rather than being converted from one of the individual sports that comprise a triathlon. Thus, an updated review is required that investigates the physiological attributes of contemporary triathletes and compares this with single-sport athletes. Unlike previous reviews, prior to making such comparisons we will first justify the physiological measures chosen and briefly comment on the use of absolute or relative measures of aerobic fitness. In addition, while previous reviews have concentrated on comparisons of $\dot{V}_{O_2\,max}$ (and sometimes economy), this paper provides an expanded review of the physiological attributes of triathletes and includes measures such as the lactate threshold (LT), the ventilatory threshold (VT) and peak power and velocity.

2. Maximal measures

Successful endurance athletes are characterised by high levels of aerobic power (as measured by $\dot{V}_{O_2\,max}$), which are nearly double that of the untrained individual, and this has often been cited as an important predictor of endurance success among athletes heterogenous for aerobic power.[2,6,7] There are different methods of normalising $\dot{V}_{O_2\,max}$ measures, such as per unit of fat free mass or lower-leg volume.[8] Most commonly however, $\dot{V}_{O_2\,max}$ is expressed in absolute values ($L\,min^{-1}$) or relative to body mass ($mL\,kg^{-1}\,min^{-1}$). As the three events that comprise a triathlon differ in the amount of body mass that must be supported by the athletes and, therefore, in the energy required to maintain body position, different methods for normalising $\dot{V}_{O_2\,max}$ may be required for the different triathlon disciplines.

Although studies have demonstrated that absolute $\dot{V}_{O_2\,max}$ is associated with swimming performance over a distance of 400 m,[9,10] Costill et al.[11] found that relative $\dot{V}_{O_2\,max}$ was more highly correlated ($r = 0.74$ vs. 0.47) with swimming performance over a similar (365.8 m) distance. Furthermore, one study has reported a poor correlation ($r = 0.30$) between absolute $\dot{V}_{O_2\,max}$ and 400-m swim performance.[12] These results are despite similar absolute $\dot{V}_{O_2\,max}$ values between the studies. Therefore, while absolute $\dot{V}_{O_2\,max}$ is more commonly reported among swimmers, relative $\dot{V}_{O_2\,max}$ may be more appropriate when reporting and comparing the $\dot{V}_{O_2\,max}$ of swimmers and triathletes. Indeed, Sleivert and Wenger[13] reported that relative and not absolute $\dot{V}_{O_2\,max}$ was significantly related to swim performance during a triathlon. The analysis of $\dot{V}_{O_2\,max}$ values in triathletes is also complicated by the observation that, when compared to cycling and running, swimming requires a greater degree of specialist training to elicit high $\dot{V}_{O_2\,max}$ values[14] and receives little cross-training benefits from cycling and running.[15]

During cycling, the entire body mass is supported by the bike and therefore a higher absolute $\dot{V}_{O_2\,max}$ would appear advantageous. However, both absolute and relative $\dot{V}_{O_2\,max}$ values of cyclists have typically been reported,[3,16–18] and the most appropriate measure may depend on the type of cyclist being compared. Professional cyclists who are considered "climbers" have a higher relative $\dot{V}_{O_2\,max}$ (and lower body mass) compared to those considered specialist time trialists (time trials are generally conducted over flat courses) despite similar absolute $\dot{V}_{O_2\,max}$ values.[16]

In contrast to cycling, relative $\dot{V}_{O_2}$ during running is constant among individuals for any given velocity.[19] Although Costill[20] reported a relationship between both absolute and relative $\dot{V}_{O_2\,max}$ and running performance, a stronger relationship was found for relative compared to absolute $\dot{V}_{O_2\,max}$ ($r = 0.83$ and 0.59 respectively). Generally $\dot{V}_{O_2\,max}$ values among runners are reported in relative values[2,21–23] as it is recognised that extra body mass is detrimental to running performance.[24]

As triathletes compete in swimming, cycling and running, $\dot{V}_{O_2\,max}$ has often been reported in both relative and absolute values.[13,24–36] However, from the above discussion, it could be argued that the most appropriate means to compare swimmers and triathletes is using relative $\dot{V}_{O_2\,max}$. Furthermore, as the run leg has often been reported to be an important predictor of triathlon performance,[37] the disadvantage of a large body mass on running performance may also render relative $\dot{V}_{O_2\,max}$ more appropriate when comparing the $\dot{V}_{O_2\,max}$ values of cyclists and triathletes. A further consideration is that the athlete may be able to compensate for a low $\dot{V}_{O_2\,max}$ (either absolute or relative) with higher efficiency or economy values.[38] Therefore, although the most appropriate measure for triathletes has not yet been determined, for the purposes of this review, $\dot{V}_{O_2\,max}$, unless otherwise indicated, will refer to the relative value.

Triathletes generally possess high $\dot{V}_{O_2\,max}$ values. Studies that have reported the $\dot{V}_{O_2\,max}$ of triathletes are summarised in Table 1 (see supplementary files). $\dot{V}_{O_2\,max}$ values reported for triathletes during swimming, cycling and running have ranged from 49.9 to 57.7 $mL\,kg^{-1}\,min^{-1}$, 43.6–75.9 $mL\,kg^{-1}\,min^{-1}$ and 49.7–78.5 $mL\,kg^{-1}\,min^{-1}$ respectively for males, and from 38.1 to 45.3 $mL\,kg^{-1}\,min^{-1}$, 48.2–61.3 $mL\,kg^{-1}\,min^{-1}$ and 50.7–65.6 $mL\,kg^{-1}\,min^{-1}$ respectively for female triathletes.

While triathletes possess high $\dot{V}_{O_2\,max}$ values, it has been suggested, in a review paper, that $\dot{V}_{O_2\,max}$ values among triathletes during swimming, cycling and running are less than that of athletes specialising in only one of these exercise modalities.[5] It was suggested that this might be because triathletes carry "extra muscle mass" used in one exercise mode, but not used for another. However, an alternative explanation is that the triathletes in these studies were not truly 'elite', like their counterparts in running, cycling and swimming. Many of the studies reviewed were conducted in the 1980s when triathlon was barely a recognised sport and elite or professional athletes were not being attracted to triathlons. While running, cycling and swimming have been competitive sports on an international level for many years, triathlon is a relatively young event having conducted its first world championship in 1989. One study used a questionnaire completed prior to a triathlon to estimate $\dot{V}_{O_2\,max}$ values for male triathletes.[39] Furthermore, no values for elite male triathletes during cycling and for elite male and female triathletes during swimming were provided. Despite these limitations, the authors concluded that triathletes possessed lower $\dot{V}_{O_2\,max}$ values than other endurance athletes. However, it is unlikely that the review compared athletes of a comparable standard.

Since this earlier review, the physiological profiles of triathletes who are members of national squads and who compete at an international level have been reported.[30,33,34] $\dot{V}_{O_2\,max}$ values have been reported for members of the French,[30] Great Britain[40] and South African[34] national teams. The results are summarised in Table 1. When these values are compared to athletes from cycling[17,41] and running[21] who compete at a similar level, $\dot{V}_{O_2\,max}$ scores are comparable. To the best of our knowledge, the $\dot{V}_{O_2\,max}$ of elite triathletes during swimming has not been reported. However, the results outlined in Table 1 indicate that triathletes who compete at an international level possess $\dot{V}_{O_2\,max}$ values that are indicative of success in endurance-based individual sports at this level.

Triathletes have been reported to possess cycle and swim $\dot{V}_{O_2\,max}$ scores that are approximately 94–97% and 74–86% respectively, of the values achieved during a running test.[13,27,34,42,43] These results are also summarised in Table 1 (see supplementary file) and are consistent with the observation that $\dot{V}_{O_2\,max}$ during running is greater than during cycling, with both values being higher than during swimming $\dot{V}_{O_2\,max}$ measurements, regardless of training background.[44] This may be because running recruits a larger muscle mass than either cycling or swimming. A positive correlation between oxygen consumption and the quantity of active muscle mass during exercise has previously been reported.[45] In addition, running has generally been the training background of many triathletes and they may have not yet made the physiological adaptations to record similar $\dot{V}_{O_2\,max}$ values in the other disciplines. Of the 14 triathletes investigated by Kohrt et al.,[43] 10 were from a running background, while three and one were from swimming and cycling backgrounds respectively. Therefore, although triathletes possess high $\dot{V}_{O_2\,max}$ values, previous studies have observed differences between the individual disciplines, possibly due to the muscle mass involved and/or the training background of triathletes.

These observed differences in $\dot{V}_{O_2\,max}$ scores for the swim, cycle and run appear to be less prominent for triathletes who began triathlon as their first sport. Recently, the physiological profiles of 29 young triathletes (20.9 ± 2.6 yrs) who had trained and competed only in triathlon and not in another single-sport have been reported.[30] It was found that $\dot{V}_{O_2\,max}$ scores were not significantly different between a cycle ergometer and a treadmill run (69.1 ± 7.2 and 70.2 ± 6.2 mL kg^{-1} min^{-1} respectively). The homogeneity of the aerobic capacity of modern triathletes has further been corroborated in a study in which the subjects were eight young triathletes (mean age of 24.0 ± 3.0 yrs) who competed at an inter-regional level.[46] These studies therefore provide some evidence that modern-day triathletes have physiological capacities that are similar between cycling and running. Although neither study investigated aerobic capacity measured during swimming, there is unlikely to be a strong cross-training effect between cycling and running, and swimming.[15]

While $\dot{V}_{O_2\,max}$ is a useful tool to assess maximal aerobic fitness, other measures that can easily be measured on less expensive equipment include peak aerobic power output

Table 1
$\dot{V}_{O_2\,max}$ of national level (elite) triathletes, runners and cyclists.

Author	Subjects	Age (yrs)	Sport	Level	$\dot{V}_{O_2\,max}$ (mL kg^{-1} min^{-1}) Running	Cycling
Hue et al.[30]	M = 6	21.8 ± 2.4	Triathletes	Members of French national team	78.5 ± 3.6	75.9 ± 5.2
Schabort et al.[34]	M = 5 F = 5	23.0 ± 4.0 25.0 ± 7.0	Triathletes	Members of South African national team	74.7 ± 5.3 63.2 ± 3.6	69.9 ± 4.5 61.3 ± 4.6
Millet and Bentley[33]	M = 9 F = 9	24.8 ± 2.6 27.9 ± 5.0	Triathletes	Senior elite triathletes at world championship level	NR	74.3 ± 4.4 61.0 ± 5.0
Laurenson et al.[40]	F = 10	27.1 ± 3.5	Triathletes	Members of Great Britain national squad	65.6 ± 6.0	NR
Billat et al.[21]	M = 5 F = 5	33.4 ± 2.0 32.8 ± 2.8	Marathon runners	Members of French and Portugese Olympic teams	79.6 ± 6.2 61.2 ± 4.8	NR
Padilla et al.[17]	M = 24	26 ± 3.0	Cyclists	Members of a professional road cycling team	NR	78.8 ± 3.7
Lucia et al.[41]	M = 13	24 ± 2.0	Cyclists	Members of a professional road cycling team	NR	75.2 ± 1.6

F = female; M = male; NR = not reported.

Table 2
$\dot{V}_{O_2\,max}$ values (mL kg^{-1} min^{-1}), maximal aerobic velocity (MAV) during treadmill running and peak aerobic power output (W_{peak}) during cycling for triathletes measured during maximal graded exercise tests.

Study	Subjects	Age (yrs)	Standard	Running		Cycling	
				$\dot{V}_{O_2\,max}$	MAV (km h^{-1})	$\dot{V}_{O_2\,max}$	W_{peak} (W)
O'Toole et al.[61]	M = 14	40 ± 11	Ultra-endurance	NR	NR	57.4 ±7.5	340 ± 44 M
	F = 10	31 ± 8				57.5 ±5.6	304 ± 39 M
Schneider et al.[35]	M = 10	27.6 ± 6.3	Highly trained	75.4 ± 7.3	NR	70.3 ± 6.0	376 ± 34 M
Deitrick[24]	M = 7	30.6 ± 5.2	Typical weight	69.9 ± 5.5	NR	60.5 ± 6.2	429 ± 38 L
	M = 7	29.6 ± 4.4	Heavy weight	55.6 ± 4.1		51.9 ± 3.9	491 ± 45 L
Bunc et al.[26]	M = 23	17.7 ± 2.2	Young elites	67.9 ± 5.9	15.2 ± 1.4 [a]	NR	NR
	F = 13	17.1 ± 1.4		56.1 ± 2.4	12.7 ± 0.7 [a]		
Zhou et al.[49]	M = 10	27.4 ± 5.7	Recreational	63.3 ± 2.8	21.1 ± 0.4	61.2 ± 3.2	418 ± 14 M
Bentley et al.[25]	M = 10	24.2 ± 4.2	Recreational	NR	NR	64.7 ± 5.1	352 ± 47 M
Brisswalter et al.[76]	M = 10	26 ± 2	Highly trained	NR	NR	66.4 ± 3.4	376.5 ± 20 S
Schabort et al.[34]	M = 5	23.0 ± 4.0	Elite	74.7 ± 5.3	20.9 ± 0.9	69.9 ± 4.5	385 ± 14 L
	F = 5	25.0 ± 7.0		63.2 ± 3.6	18.0 ± 0.9	61.3 ± 4.6	282 ± 19 L
	Group	24.0 ± 5.5		68.9 ± 7.4	19.5 ± 1.8	65.6 ± 6.3	333 ± 57 L
Hausswirth et al.[77]	M = 10	25.6 ± 4.1	Highly trained	73.3 ± 5.0	20 ± 1.2	NR	NR
Bernard et al.[78]	M = 9	24.9 ± 4.0	Competitive	NR	NR	68.1 ± 6.5	398 ± 25 S
Hue[62]	M = 8	24.7 ± 2.1	Elite	71.8 ± 7.6	22.0 ± 0.7	70.5 ± 6.5	389 ± 38 S
Millet et al.[32]	M = 6	28.3 ± 4.5	Elite long distance specialists	NR	NR	72.3 ± 2.3	401 ± 47 O
Millet and Bentley[33]	M = 9	24.8 ± 2.6	Senior elite	NR	NR	74.3 ± 4.4	385 ± 50 O
	M = 7	19.1 ± 1.5	Junior elite			74.7 ± 5.7	354 ± 21 O
	F = 9	27.9 ± 5.0	Senior elite			61.0 ± 5.0	293 ± 21 O
	F = 6	19.4 ± 1.3	Junior elite			60.1 ± 1.8	268 ± 19 O
Bernard et al.[79]	M = 10	25.2 ± 6.8	Highly trained	NR	NR	61.9 ± 4.1	380 ± 31 S
Bentley et al.[80]	M = 9	25.1 ± 5.8	Highly trained	NR	NR	69.3 ± 3.6	321 ± 28 O

M = male; F = female; NR = not reported; L = Lode electronically-braked cycle ergometer; M = Monark mechanically-braked cycle ergometer; O = Orion electronically-braked cycle ergometer; S = SRM electromagnetically-braked cycle ergometer.
[a] Treadmill at a 5% incline.

(W_{peak}) during cycling, and maximal aerobic running velocity (MAV). However, some caution should be exercised when comparing W_{peak} from different studies as the W_{peak} may vary with the test protocol.[47,48] A number of studies have reported the W_{peak} and the MAV of triathletes at $\dot{V}_{O_2\,max}$ (see Table 2). The determination of W_{peak} and MAV may be an appropriate measure for assessing triathletes as it has been demonstrated that both may not only be predictive of overall triathlon performance but are stronger predictors of performance than $\dot{V}_{O_2\,max}$.[32–34,49]

Despite the difficulty in comparing the W_{peak} among studies, there is some evidence to suggest that W_{peak} may be lower for triathletes compared to cyclists. For example, a W_{peak} value of 440 ± 3.3 W was reported for a group of 14 elite cyclist ($\dot{V}_{O_2\,max}$ 69.7 ± 7 mL kg^{-1} min^{-1}), while Mujika and Padilla[50] reported a W_{peak} of 439 W (range 349–525 W) for a group of 24 professional cyclists with a $\dot{V}_{O_2\,max}$ of 78.8 mL kg^{-1} min^{-1} (range 69.7–84.8). It is however, difficult to make firm conclusions as the $\dot{V}_{O_2\,max}$ of the triathletes was far less than that of the cyclists, and studies that have recruited triathletes with similar $\dot{V}_{O_2\,max}$ values did not report W_{peak}.[30] Nonetheless, these values are higher than the values reported for highly trained or elite triathletes (see Table 2). This suggests that cyclists may have greater efficiency compared to triathletes during cycling. However this difference may not be evident when specialist runners are compared to triathletes. For example, the peak running velocities during incremental treadmill tests for trained ($\dot{V}_{O_2\,max}$ = 65.9 ± 4.6 mL kg^{-1} min^{-1}) and elite (77.7 ± 6.4 mL kg^{-1} min^{-1}) runners have been reported to be 21.2 ± 1.1 and 20.9 ± 1.1 kph respectively. These values compare favourably with those reported by highly trained or elite triathletes in Table 2. This may reflect the training emphasis of elite triathletes and the importance of the run discipline for overall elite triathlon performance.[37]

3. Submaximal performance measures

While $\dot{V}_{O_2\,max}$ describes a maximal limit for aerobic energy production, it has been suggested that parameters measured during submaximal exercise provide better predictors of endurance performance.[2,3] As a consequence, individuals with similar $\dot{V}_{O_2\,max}$ scores can vary greatly in endurance ability depending upon the percentage of their $\dot{V}_{O_2\,max}$ that they can sustain during an event.[2,3,51] Various physiological parameters at submaximal workloads have been used to discriminate between athletes. These include variables such as LT, VT and measures of economy at various workloads or velocities.

The LT has often been cited as a critical workload, as it signifies a work rate beyond which there is an abrupt increase in lactate levels.[52] However, it is difficult to compare the LT of various athletes reported in different studies as a number of different methods have been used to determine LT.[53] Furthermore, although it has been demonstrated that the different methods of computing the LT are correlated,[53] it has also been suggested that the most appropriate test to determine LT may be dependant on the length of the event being investigated.[18] A number of factors, such as variations in aerobic fitness,[2] fiber size[54] and the percentage of type I muscle fibers[55] may be responsible for the differences in LT observed between subjects.

The VT is another submaximal physiological measure that has been associated with endurance performance. The VT has been defined as an increase in the ventilatory equivalent for oxygen ($\dot{V}_E \dot{V}_{O_2}^{-1}$) with no associated increase in the ventilatory equivalent for carbon dioxide ($\dot{V}_E \dot{V}_{CO_2}^{-1}$). This has been termed the ventilatory equivalent method for determining VT.[56] An alternative method for describing the VT is by identifying the point at which there is a steeper increase in $\dot{V}_{CO_2}$ as compared to $\dot{V}_{O_2}$. This is known as the V-slope method for defining VT.[57] Both measures have been reported to result in similar values of VT[58] and have been used interchangeably to describe the VT. This is expected as the ratio between $\dot{V}_E \dot{V}_{CO_2}^{-1}$ and $\dot{V}_E \dot{V}_{O_2}^{-1}$ should be the same as between $\dot{V}_{CO_2}$ and $\dot{V}_{O_2}$. An alternative method used by some authors to define the VT, is the point at which there is an increase in $\dot{V}_E \dot{V}_{CO_2}^{-1}$. Simon et al.[59] has referred to this point as the respiratory compensation threshold (RCT) and reported this to occur at a higher intensity than VT in trained (N=6, 26.8 ± 2.2 yrs, $\dot{V}_{O_2\,max}$ = 63.8 ± 1.3 mL kg^{-1} min^{-1}) and untrained (N=6, 31.0 ± 1.8 yrs, $\dot{V}_{O_2\,max}$ = 35.5 ± 2.3 mL kg^{-1} min^{-1}) individuals.

Submaximal parameters measured during swimming, cycling and running have been shown to be predictive of endurance performance. It has been demonstrated that endurance performance of a group of cyclists homogenous for $\dot{V}_{O_2\,max}$ ($\dot{V}_{O_2\,max}$ = 68.6 ± 1.2 mL kg^{-1} min^{-1}) was associated with a high percentage of $\dot{V}_{O_2}$ at the LT (r=0.90, P<0.001).[3] It has similarly been demonstrated that submaximal values obtained during running tests are also predictive of distance running performance.[2,6] Farrell et al.[6] (N=18, 28 ± 9.0 yrs, $\dot{V}_{O_2\,max}$ = 61.7 ± 7.5 mL kg^{-1} min^{-1}) showed that $\dot{V}_{O_2}$ consumed at a treadmill velocity of 268 m min^{-1} ($r \geq 0.49$), $\dot{V}_{O_2}$ at the LT (mL kg^{-1} min^{-1}) ($r \geq 0.91$) and treadmill velocity at the LT ($r \geq 0.91$) were significantly (P<0.05) related to running performances at distances ranging from 3.2 km to the marathon (42.2 km). This led the authors to conclude that successful distance runners are able to utilise a large fraction of $\dot{V}_{O_2\,max}$ with minimal accumulation of blood lactate. Finally, it has also been reported that, despite no differences in $\dot{V}_{O_2\,max}$ or W_{peak}, a group of highly trained cyclists was able to perform a 40 km time trial significantly faster than a group of highly trained triathletes, partially due to a significantly higher VT.[60] Thus, these studies suggest that submaximal physiological values may be important determinants of endurance performance in a variety of athletes, including triathletes. It should be noted however, that the relationship between physiological measures and endurance performance is often not as clear during triathlon events,[18,80] possibly due to factors such as drafting and the sequential performance of different disciplines.

It is difficult to compare the LT values reported for triathletes as different methods have been used to calculate this value. The LT during running, measured as an exercise intensity that elicits a blood [La$^-$] of 4 mmol L^{-1} (commonly referred to as the onset of blood lactate accumulation or OBLA), has been reported to be 85.1% of $\dot{V}_{O_2\,max}$ for a group of well-trained triathletes (N=14, 29.4 ± 5.1 yrs, $\dot{V}_{O_2\,max}$ = 58.4 ± 1.4 mL kg^{-1} min^{-1}) competing in a half-ironman triathlon.[43] The same group of triathletes exhibited a lower LT as a percentage of $\dot{V}_{O_2\,max}$ during cycling (76.1%) compared with running. This coincided with a lower $\dot{V}_{O_2\,max}$ value for this group during cycling (56.0 ± 1.3 mL kg^{-1} min^{-1}, P<0.05). O'Toole et al.[61] defined the LT as the exercise intensity that elicited an increase in blood [La$^-$] of 1 mmol L^{-1} above that measured during the first work rate. Using this definition, the LT during cycling was 73 ± 2.2% of $\dot{V}_{O_2\,max}$ among a group of ironman triathletes with a similar $\dot{V}_{O_2\,max}$ value (57.4 ± 7.5 mL kg^{-1} min^{-1}). The exercise intensity that elicited a blood [La$^-$] of 4 mmol L^{-1} was also reported and occured at 88 ± 1.2% of $\dot{V}_{O_2\,max}$. Compared to the previously mentioned study by Kohrt et al.,[43] the higher LT at a blood [La$^-$] of 4 mmol L^{-1} reported by O'Toole et al.[61] may be because the subjects in this study were training for the longer ironman event and may have completed more cycle training. Finally, utilising the D_{max} method for LT determination, the LT was approximately 68% of W_{peak} for a group of male, recreational triathletes (N=10, 24.2 ± 4.2 yrs, cycling $\dot{V}_{O_2\,max}$ = 64.7 ± 5.1 mL kg^{-1} min^{-1}) who were training for a local Olympic-distance triathlon.[25] The LT values of single-sport athletes are comparable to these reported values for triathletes. For example, an OBLA value of 90.4 ± 1.1% of $\dot{V}_{O_2\,max}$ has been reported for elite ($\dot{V}_{O_2\,max}$ = 77.7 ± 6.4 mL kg^{-1} min^{-1}) male distance runners while a LT of 75.3 ± 1.5% of $\dot{V}_{O_2\,max}$ was reported for a group of competitive cyclists ($\dot{V}_{O_2\,max}$ = 69.3 ± 1.2 mL kg^{-1} min^{-1}) utilising the equivalent method of O'Toole as outlined above.

The majority of studies investigating submaximal physiological values among triathletes have reported the VT, rather than the LT.[13,26,29,30,32,33,35,49,61–63] VT measures during running and cycling have ranged from 65 to 85% and from 61 to 84% of $\dot{V}_{O_2\,max}$ respectively. Only a limited number of studies have investigated the VT during swimming. One of these studies reported values of 71.8 ± 2.0% and 75.8 ± 4.2% of $\dot{V}_{O_2\,max}$ for males (N=18, 27.7 ± 1.3 yrs, swimming $\dot{V}_{O_2\,max}$ = 49.9 ± 1.4 mL kg^{-1} min^{-1}) and females ($F = 7$, 28.3 ± 2.3 yrs, swimming $\dot{V}_{O_2\,max} = 38.1 \pm 2.4\,mL\,kg^{-1}\,min^{-1}$) respectively.[13]

The large range of values for VT as a percentage of $\dot{V}_{O_2\,max}$ reported for triathletes during running and cycling are probably due to the various methods used to determine VT. Authors who reported lower values of VT as a percentage of $\dot{V}_{O_2\,max}$ (between 60 and 75%) defined VT by means of the V-slope or ventilatory equivalent method.[30,35,61–63] Studies that reported higher values for the VT (80–90% of $\dot{V}_{O_2\,max}$), have actually measured the RCT which is defined as a nonlinear increase in $\dot{V}_E$ with respect to time, $\dot{V}_{O_2}$ or $\dot{V}_{CO_2}$.[13,26,29,32,33,49] Thus, when interpreting VT values it is important to consider the analysis method used.

The VT values reported for the individual disciplines of triathletes are similar to those reported for trained cyclists and runners.[41,59,64] Moreover, the VT values among triathletes are generally lower during swimming compared to cycling, with both being less than running VT values.[13,35,49] This may be related to the mode of exercise[64] or to the observation that $\dot{V}_{O_2\,max}$ values are typically higher during running compared to cycling and swimming. It has been reported that triathletes with similar $\dot{V}_{O_2\,max}$ values for cycling and running also elicit similar VT measures for the two disciplines.[30] It therefore appears that VT values may vary with maximal aerobic fitness within the individual disciplines of a triathlon. Given the similar $\dot{V}_{O_2\,max}$ values between triathletes and single-sport endurance athletes (discussed earlier), this further suggests that VT values are also likely to be similar. However, the paucity of reliable threshold values, especially for swimming, makes comparisons difficult.

4. Summary: the physiological profile of triathletes

Data from triathletes competing at a national level have shown that individual cycling and running $\dot{V}_{O_2\,max}$ values are similar to those observed for athletes competing in individual sports at a similar standard. A number of studies have also reported submaximal physiological values of triathletes. Although comparisons are complicated by the number of definitions which exist for the determination of LT and VT, these values also appear to be similar to other endurance athletes. Thus, it appears that modern-day triathletes are able to obtain similar physiological values as single-sport athletes despite dividing their training time among three disciplines. Moreover, it is suggested that the physiological capacities of modern-day triathletes are similar for cycling and running due to possible cross-training effects between the two, however this effect has not been demonstrated for swimming.

Practical implications

- Triathletes expecting to compete at an elite level may require similar physiological profiles to that of single-sports athletes.
- To achieve these physiological capacities, triathletes should exploit the advantage associated with cross training.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jsams.2009.03.008.

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