Effects of endurance and strength training of cyclists and triathlon athletes on efficiency, economy and VO₂ kinetics

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Abstract The purpose of this study was to evaluate the economy and efficiency of two trained athlete groups of different training status. The subjects were 20 elite athletes composed of the cyclists group (n=10) and triathlon group (n=10). All subjects performed steady state testing at 50, 100, and 150 watts, with ample time to reach resting VO₂ and ventilation values between stages. The efficiency of two groups appears to be quite different, with triathlon competitors displaying superior efficiency values for the transitions from 0 to 50 and 100 watts. This same principle likely explains the economy of the groups, as triathlon competitor was again more economic at 50 and 100 watts. As though this matching of oxygen consumption and workload they can reduce the amount of oxygen deficit that must be repaid post exercise.

Key Words : VO₂ kinetics, steady state, economy, efficiency, endurance training

1. Introduction

Oxygen uptake kinetics is the study of the rate of change in oxygen uptake for a given increase in intensity above the gas exchange threshold [1,2,3]. Mechanisms controlling oxygen uptake kinetics are the
subject of heated debate, from which two major camps emerge.

The first camp believes that oxygen uptake kinetics are determined by the "inertia of intramuscular metabolic processes" [4,5]. The second believes that oxygen delivery is the true source of exercise limitations [6]. Although consensus does not exist for the mechanisms controlling oxygen uptake kinetics, the usefulness of this measure is not in question, as through it economy and efficiency can be computed.

Economy is the energy cost of movement, and efficiency is the mechanical energy production of the movement relative to the metabolic energy used to cause the movement [1]. It has been shown that oxygen uptake increases exponentially to a new steady state after an abrupt increase in intensity while still remaining the ventilatory threshold (VT) [4]. This exponential increase in oxygen uptake makes these values integral for endurance athletes, as those who are more economic/efficient then their similarly trained counterparts require less energy input to power exercise, ultimately producing greater performance output.

Efficiency is a measure of effective movement and is referred to the mechanical energy production of the movement relative to the metabolic energy expended to cause the movement and approximates 30% during exercise. Cycling efficiency has been reported to be in the range of 10-25% [1].

Although many other key factors exist, those that determine exercise performance of a cycling modality in a controlled laboratory setting include cadence and muscle recruitment [7]. Although it has been shown that untrained subjects perform better at a cadence ≤ 50 RPM [8], trained subjects typically adopt higher cadences (80-100 RPM), as this causes reduced fast twitch fiber recruitment, resulting in increased time to fatigue [9]. Intrinsically this makes sense, as muscle force required per pedal revolution is reduced. Therefore, those athletes who can sustain higher cadences for longer periods of time retain a powerful advantage over other competitors. As for muscle recruitment, each muscle has an intrinsic contraction velocity that aligns with peak efficiency for vastus lateralis muscle, with this velocity being 1/3 of maximal contractile speed in type 1 fibers [10,11]. As such, those athletes with greater percentages of type I fibers will prove more efficient, and again, retain a marked advantage.

The primary aim of this study was to evaluate the economy and efficiency of two trained athlete groups of different exercise intensity using cycle ergometer. We hypothesized that triathlon competitors would have characteristically higher economy, efficiency and oxygen uptake kinetics when compared with cyclists. Moreover, this study was selected that cyclists and triathlon athletes because of their power index of < 40% or > 45% have to their aerobic power [12]. Accordingly, the power index appears useful when recommending training protocols.

2. Methodology

Using a 3L syringe, the flow meter was calibrated. Temperature, humidity, and barometric pressure were recorded at the onset of the trial, allowing for proper equipment calibration. The gas analyzers were calibrated against two known gas combinations, employing the Adam software. The Adam Software was used for analysis of breath-by-breath VO2 response to exercise. Maximal oxygen consumption was provided by the LabView software, being produced through analysis of ventilation and the expired fractions of oxygen and carbon dioxide. LabView software was used for data collection, with Prism being used for data analysis.

2.1 Subjects

Ten elite level cyclists competitors (26.4 ± 3.2 yr)
and ten high level triathlon competitors (25.8 ± 6.3 yr) of similar age from the A city area provided an informed written consent to participate in this study. To qualify for the study, all participants were asymptomatic of any illness or disease and were free of any acute or chronic injury, as established by the American College of Sports Medicine participant activity readiness Par-Q health questionnaire. The study was approved by the Institutional Human Research Committee.

2.2 Design

The nature, purpose, and experimental procedures were outlined verbally to each participant; afterward, each subject signed an informed consent form before participating in the study.

Subjects performed steady state testing at 50, 100, and 150 watts, with ample time to reach resting VO₂ and ventilation values between 5 minutes at three different stages. Each lasted for 5 minutes and was followed by 10 minutes’ rest. Subjects were asked to maintain the load (W) for a period of 5 minutes in an attempt at producing steady state VO₂ values [1,13].

2.3 Analysis

The group’s VO₂ steady state values from all exercise loads were examined. Prism was used to curve fitting these values, producing a time constant to half decay. The resulting time constant was doubled, producing time to true steady state values. Curves were separated from data and appended. By analyzing mechanical versus caloric energy expenditure efficiency was computed. By examining VO₂ steady state values economy was deduced.

3. Results

The main characteristics of the cyclists and triathlon training of the athletes are presented in Table 1. No differences were observed in the total training period between both of two groups before the tests.

(Table 1) Main characteristics of the cyclists and triathlon athletes

<table>
<thead>
<tr>
<th></th>
<th>Age (yr)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Total training (yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyclists (N=10)</td>
<td>26.4 ± 3.2</td>
<td>178.4 ± 5.4</td>
<td>65.1 ± 6.7</td>
<td>6.8 ± 2.7</td>
</tr>
<tr>
<td>Triathlon (N=10)</td>
<td>25.8 ± 6.3</td>
<td>177.3 ± 7.9</td>
<td>67.3 ± 5.9</td>
<td>7.1 ± 1.8</td>
</tr>
</tbody>
</table>

Table 2 shows that oxygen consumption, respiratory exchange ratio (RER), energy expenditure, efficiency, and measured and calculated during the cycle ergometer tests. The triathlon competitors group measured significantly more oxygen consumption (2.3 L/min), energy expenditure (10.78kcal/min), and efficiency (25%) at 150 watts.

Figure 1, 2 shows that the Prism results of cyclists and triathlon competitors’s efficiency at 50 (16%: 31%), 100 (23%: 26%), and 150 (21%: 25%). The triathlon group displaying superior efficiency values for the transitions from 50 and 100 watts and more economic at 50 and 100 watts compared with cyclists competitors.

4. Discussion

The purpose of this study was to evaluate the economy and efficiency of two groups of different training status. For this reason this study chose two different athletes groups, as group 1 is an elite cyclists, and group 2 is a moderately high to high level triathlon competitor.

The efficiency of these groups appears to be quite different, with triathlon displaying superior efficiency values for the transitions from 0 to 50 and 100 watts. This is likely to multiple things, including crank length, body position, linear and angular displacements,
Table 2: VO$_2$, RER, energy expenditure, efficiency, and measured and calculated parameters during the cycle ergometer tests. Group 1 (Cyclists)

<table>
<thead>
<tr>
<th>Watts</th>
<th>K * 2 (minutes to steady state)</th>
<th>VO$_2$(L/min)</th>
<th>RER</th>
<th>Kcal/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0.4</td>
<td>0.88</td>
<td>4.89</td>
</tr>
<tr>
<td>50</td>
<td>2.71</td>
<td>1.33</td>
<td>0.71</td>
<td>4.71</td>
</tr>
<tr>
<td>100</td>
<td>2.59</td>
<td>1.63</td>
<td>0.88</td>
<td>4.89</td>
</tr>
<tr>
<td>150</td>
<td>1.89</td>
<td>2.09</td>
<td>0.91</td>
<td>4.94</td>
</tr>
</tbody>
</table>

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<tr>
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<th>K * 2 (minutes to steady state)</th>
<th>VO$_2$(L/min)</th>
<th>RER</th>
<th>Kcal/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0.48</td>
<td>0.92</td>
<td>4.94</td>
</tr>
<tr>
<td>50</td>
<td>2.94</td>
<td>1.33</td>
<td>0.91</td>
<td>4.94</td>
</tr>
<tr>
<td>100</td>
<td>2.32</td>
<td>1.63</td>
<td>0.94</td>
<td>4.73</td>
</tr>
<tr>
<td>150</td>
<td>1.65</td>
<td>2.33</td>
<td>1.04</td>
<td>4.69</td>
</tr>
</tbody>
</table>

Group 2 (Triathlon competitors)

<table>
<thead>
<tr>
<th>Watts</th>
<th>K * 2 (minutes to steady state)</th>
<th>VO$_2$(L/min)</th>
<th>RER</th>
<th>Kcal/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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</tr>
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</table>

velocities and accelerations of body segments, and forces in joints and muscles [8]. As these variables were not measured and are too cumbersome to be thoroughly analyzed in a manuscript of this length, suffice it to say that the difference in efficiency between the two groups was at first surprising (see Table 2). However, after noting the slight advantage in efficiency of cyclists over triathlon competitors in the 0 to 150 watts transition things became clear, as is likely that cyclists were inept at these lower power outputs due to their non-specificity to his true competition performance. The results of this study and previous study indicate that endurance training and running economy with no significant influences on the oxygen uptake patterns in incremental exercise [14,15]. A slow component also showed in pre-pubertal children during high intensity exercise, but was not influenced by weight different [16].

This same principle likely explains the economy of the groups, as triathlon competitors were again more economic at 50 and 100 watts (see Table 2 and Figure 2).
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[Fig. 1] Resulted in cyclists efficiency

[Fig. 2] Resulted in triathlon competitors efficiency

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Likewise, the specificity of the higher power output likely explains the significant reduction in VO₂ seen for cyclists at 150 watts, producing vastly superior economy to triathlon competitors at this output. This significance is astounding, as the 1/3 kcal difference per minute seen between the two groups would quantify to 20 kcal/hour. As such, all other performance variables being equal, triathlon competitors would likely fatigue significantly faster than cyclists. As these power outputs are not as high as would be maintained throughout a traditional even by either subject, it would be interesting to see if this difference in economy remains linear up to each group’s race pace.

One final variable of note is the K constant derived through the Prism software. This constant defines the half time to steady state, and, as such, is a valuable marker of the cardiovascular abilities of each of the groups. As stated previously, it is known that an overshoot of oxygen consumption typically results prior to one reaching steady state, with groups of higher cardiorespiratory training typically display a reduced time to steady state values [4]. A reduction of this overshoot displays a superior adaptation of trained subjects, as through this matching of oxygen consumption and work load they can reduce the amount of oxygen deficit that must be repaid post (or in this case once steady state has been reached) exercise. This value was surprising, as cyclists were superior to triathlon competitors at 50 watts, but triathlon competitors were superior to cyclists at 100 and 150 watts. Accordingly, triathlon competitors would reach steady state faster than cyclists at these higher outputs, resulting in decreased oxygen deficit having to be repaid post exercise. As this reflects the training status of the subjects, it is likely that their training status is not significantly different. Also, no changes were reported during the training period in both endurance and strength training [13]. Several researchers have noted that endurance training led to a significant diminution of the amplitude of the slow component [17,18,19]. However, as trainability can only go so far to overcome genetic factors, there are likely some inherent differences associated with the subjects that we are not able to analyze at this juncture.

Also, although there were widely oscillating values as to VO₂ for each of the steady state plots, it appears that the subjects reached steady state on each workload, as the K constants do not dictate a time constraint of greater than 5 minutes.

5. Conclusion

The findings of the study demonstrate the effects of endurance and strength training athletes on efficiency and economy and VO₂ kinetics. Endurance and strength exercise was effective in decreasing oxygen deficit. Consequently, these heavy exercise may be effective in reaching steady state faster than other exercise training.

On the basis of the results of this study, the following recommendations are made for further studies: crank length, body position, linear and angular displacements, velocities and accelerations of body segments, and forces in joints and muscles; they are also needed to develop effective endurance and strength exercise programs for different age groups or training types.

ACKNOWLEDGMENTS

This work was supported by the research grant of Cheongju University in 2012.

REFERENCES

사이클 선수와 철인3종 선수들의 지구력 및 근력 트레이닝이 효율성 및 경제성과 VO₂ kinetics에 미치는 효과

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