Comparison of ventilation and lactate threshold in elite athletes

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Summary
The purpose of this investigation was to compare the ventilation and lactate thresholds in elite athletes during incremental exercise test. Research methods: anaerobic threshold was detected with onset blood lactate accumulation and gas exchange methods (ventilation equivalent ratio for oxygen, VE/VO$_2$) due to incremental load tests.

Research results. The power and oxygen consumption at ventilation and lactate thresholds have been compared in 35 elite athletes, who specialized in endurance events by using treadmill, cycle, and rowing incremental tests. The lactate and ventilation thresholds have matched in 48.3% events, in 19.0% the ventilation threshold has been determined previous to the lactate thresholds and the lactate thresholds have been determined previous to the ventilation thresholds in 32.7% cases. The power difference between lactate and ventilation thresholds has been within the range from 33.3 to 54.4 watt and oxygen consumption – from 2.6 to 6.9 ml·min·kg$^{-1}$ (2.6–15.2%). The highest aerobic ability was revealed in athletes with simultaneous lactate and ventilation thresholds.

Conclusion. It is necessity to continue investigations of physiology mechanisms and biochemistry process of aerobic – anaerobic transitional zone for better theoretical understanding of anaerobic threshold nature. Several approaches must be used for correct anaerobic threshold definition of endurance events athletes.

Keywords: anaerobic threshold, oxygen consumption, endurance events, elite athletes.

Introduction
Special performance in endurance events (events lasting more than approximately 5 min and requiring a substantial and sustained energy transfer from oxidative pathways) is determined by the functional reserves and, first of all, reserve capacity of the oxygen transport system (Simon et al., 1986; Sumida, Donovan, 2001; Burneley, Jones, 2007; Robbins et al., 2009; Messonnier et al., 2013; Stanula et al., 2013). The functional reserves of an athlete are determined by such parameters as maximum oxygen uptake and also power output and oxygen uptake at anaerobic threshold (Beaver et al., 1986; Beneke, 1995; Klusiewicz, 2005; Burneley, Jones, 2007; Faude et al., 2009). These indicators are widely used in sports for the monitoring and evaluation of special performance and aerobic capacity of endurance event athletes. The “traditional” methods of anaerobic threshold eliciting are ventilation threshold – the beginning of pulmonary ventilation effectiveness reducing (disproportionate increase in pulmonary ventilation without a corresponding increase in oxygen consumption) and lactate threshold – the beginning of rapid lactate accumulation in blood (Wasserman et al., 1973; Tesch et al., 1982; Reybrouck et al., 1983; Beaver et al., 1986; Simon et al., 1986; Chawalbinska–Moneta et al., 1989; Beneke, von Duvillard, 1996; Thomas et al., 2004; Stanula et al., 2013). Typically using ventilation or lactate threshold to determine the aerobic-anaerobic transition is under similar methods. However, the biochemical and physiological mechanisms of these thresholds are different.

There are various approaches to determine anaerobic threshold by the blood lactate concentration, including: lactate threshold (LT) – the beginning of the rapid increase in blood lactate concentration; onset blood lactate accumulation (OBLA) – lactate concentration fixed point – 4 mmol·L$^{-1}$; maximal lactate steady state (MLSS) – maximum lactate concentration prior to its rapid growth; anaerobic threshold of 1 mmol (1 mmol AT) – in this approach anaerobic threshold is determined by increasing blood lactate concentration of 1 mmol·l$^{-1}$ or more (Tesch, 1982; Heck et al., 1985; Chawalbinska–Moneta et al., 1989; Beneke, 1995; Beneke, von Duvillard, 1996; Faude et al., 2009; Klusiewicz, 2005; Messonnier et al., 2013; Stanula et al., 2013).

Despite the fact that the definition of anaerobic threshold for ventilation and lactate threshold is widely used in sports higher achievements, now research of the mechanisms of its occurrence is an urgent problem for sports science and athletes training practice.

The purpose of this investigation was to compare the ventilation and lactate thresholds in elite athletes during incremental exercise test.
Methods

Thirty-five trained athletes of cyclic sports with age range from 18 to 29 years were studied: biathlon (n = 10); rowing (n = 25). After 5 min of unload warm up athletes performed an incremental test exercise to achieve the maximal oxygen uptake (VO_{2max}) on a treadmill ergometer – Jaeger CareFusion 100-720CE (for biathletes), cycle ergometer Monark Ergomedic E839, and rowing ergometer Concept II (for rowers).

The initial load for the rowing ergometer Concept II was 1.5 W·kg^{-1} of body weight with increasing for 30.0 W on each stage of the test. The initial load for cycle ergometer was 78.5 W with increment of 39.2 W on each stage, cadence – 80 rpm. Initial load for treadmill exercise test was 3.0·s^{-1}, the slope for each stage was increased by 10.

Lactate threshold determination. After each stage of the load, the capillary blood was taking from the finger to determine the lactate concentration. The blood from finger was sampled at the end of each load stage. Blood lactate concentration was determined using a biochemical analyzer Dr.Lange. Testing protocol for treadmill and rowing ergometer reckon for a 30-second stop for blood sampling; for bicycle ergometer testing blood was carried out without stopping of the load.

The lactate threshold has been determined at the beginning of a rapid accumulation of lactate in the blood (Onset Blood Lactate Accumulation, OBLA).

Ventilation threshold determination. The respiratory parameters were registered by gas analyzer Oxycon Mobile and Oxycon Pro each 10 seconds of testing. The CO\textsubscript{2} and O\textsubscript{2} tensions in expiration gas were recorded as well as pulmonary volume (VE, l·min\(^{-1}\)), breath volume (BV, l), breath frequency, BF, l·min\(^{-1}\), FEO\textsubscript{2}, FECO\textsubscript{2}, and some other physiology parameters were registered.

Anaerobic threshold was determined by ventilation equivalent ratio for oxygen (VE/VO\textsubscript{2}) – the effectiveness of pulmonary ventilation reduction.

The heart rate (HR, bpm) was registered using a heart rate monitor Polar RS 800.

Statistical analysis has been led by using Statistica 6.0 software package. The mean values, standard deviations, significance of the differences for independent trials, and conformity of the distribution of the tested variables to the normal distribution were analyzed using the Student (p<0.05) and Kolmogorov tests, respectively.

Results and discussion

The investigation results are reported in Table 1. No substantial (p \leq 0.05) difference of the physiology parameters at lactate and ventilation thresholds has been determined The oxygen uptake at lactate threshold was 40.3 ml·min·kg\(^{-1}\) (76.1% VO\textsubscript{2max}), at ventilation threshold – 39.6 ml·min·kg\(^{-1}\) (75.5% VO\textsubscript{2max}). The investigated thresholds have been detected during similar power outputs: 208.2 watt (66.6% from maximal power outputs during tests) at lactate threshold and 211.3 watt (68.8% from maximal power outputs during tests) at ventilation threshold.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Lactate threshold</th>
<th>Ventilation threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>VO\textsubscript{O}, ml·min·kg(^{-1})</td>
<td>40.3 ± 11.4</td>
<td>39.6 ± 9.7</td>
</tr>
<tr>
<td>VO\textsubscript{O}, % max</td>
<td>76.1 ± 12.1</td>
<td>75.5 ± 9.3</td>
</tr>
<tr>
<td>Lactate, mmol l(^{-1})</td>
<td>4.3 ± 0.7</td>
<td>3.9 ± 1.0</td>
</tr>
<tr>
<td>Power outputs, watt</td>
<td>208.2 ± 62.4</td>
<td>211.3 ± 57.4</td>
</tr>
<tr>
<td>Power outputs, %</td>
<td>66.6 ± 13.5</td>
<td>68.8 ± 10.1</td>
</tr>
<tr>
<td>Heart rate, bpm</td>
<td>162.9 ± 18.9</td>
<td>161.9 ± 16.5</td>
</tr>
<tr>
<td>Pulmonary ventilation, l·min(^{-1})</td>
<td>82.1 ± 16.0</td>
<td>77.4 ± 12.3</td>
</tr>
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</table>

However, individual analysis of data has showed the concurrence of the threshold only in 28 athletes (48.3%); the ventilation and lactate threshold was identified at the same degree of load (LT = VT). In eleven athletes (19.0%) the ventilation threshold has preceded the lactate threshold (VT < LT) and in 19 athletes (32.7%) the lactate threshold has preceded the ventilation threshold (LT < VT) (Table 2).

The most differences between ventilation and lactate thresholds have been identified during incremental cycle test: only in 12 athletes (36.4% observations) investigated thresholds have coincided (the power outputs and oxygen uptake did not differ). The most frequently (57.6% of observations), during incremental cycle test, the blood lactate concentration has indicated the increase of anaerobic mechanisms of ATP generated without the respiratory compensation. For treadmill and rowing ergometer tests the most frequently have been elicited the congruence of lactate and ventilation thresholds (60.0% and 70.0% of observations, respectively), in 40% for treadmill and in 30% cases for rowing ergometer the ventilation threshold have preceded to the lactate threshold (Fig.).
The mean differences in power outputs between lactate and ventilation threshold (VT < LT) have been from 33.3 to 39.2 watt and oxygen uptake – from 2.6 to 5.0 ml·min·kg⁻¹ (5.4 – 8.1% VO₂ max). The lactate blood concentration at ventilation threshold does not exceed 3.4 mmol·l⁻¹ (within 2.6 to 3.3 mmol·l⁻¹). The detected fact of the lactate threshold delay with regard to ventilation threshold probably is caused by delaying of the lactate removing from working muscle to blood.

The highest work performance capabilities also oxygen consumption has been determined in athletes with equal lactate and ventilation thresholds. This proves the most aerobic capacity of these athletes.

The study results have showed the significant difference between lactate and ventilation thresholds in greater part of elite athletes (30 observations or 51.7% cases of all tests) due incremental load test. Conclusion from this experimental data is necessity to continue investigations of physiology mechanisms and biochemistry process of aerobic-anaerobic transitional zone for better theoretical understanding of anaerobic threshold nature.

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**Table 2**

<table>
<thead>
<tr>
<th>Threshold combinations</th>
<th>Threshold</th>
<th>Power outputs, watt</th>
<th>VO₂</th>
<th>Lactate, mmol·l⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ml·min·kg⁻¹</td>
<td>%</td>
<td></td>
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<tr>
<td>Rowing ergometer (n = 10)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LT=VT (n = 7)</td>
<td>LT</td>
<td>314.3 ± 21.7</td>
<td>50.5 ± 5.1</td>
<td>79.6 ± 8.9</td>
</tr>
<tr>
<td></td>
<td>VT</td>
<td>49.4 ± 6.3</td>
<td>49.4 ± 4.8</td>
<td>78.2 ± 11.1</td>
</tr>
<tr>
<td>VT &lt; LT (n = 3)</td>
<td>LT</td>
<td>304.0 ± 21.4</td>
<td>49.4 ± 4.8</td>
<td>80.3 ± 7.6</td>
</tr>
<tr>
<td></td>
<td>VT</td>
<td>270.7 ± 15.8</td>
<td>45.2 ± 5.9</td>
<td>73.7 ± 9.3</td>
</tr>
<tr>
<td>Treadmill (n = 15)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LT=VT (n = 9)</td>
<td>LT</td>
<td>258.3 ± 39.5</td>
<td>52.6 ± 4.8</td>
<td>84.2 ± 4.5</td>
</tr>
<tr>
<td></td>
<td>VT</td>
<td>50.9 ± 5.9</td>
<td>50.9 ± 5.9</td>
<td>81.6 ± 6.2</td>
</tr>
<tr>
<td>VT &lt; LT (n = 6)</td>
<td>LT</td>
<td>261.7 ± 37.7</td>
<td>54.0 ± 5.9</td>
<td>87.0 ± 5.1</td>
</tr>
<tr>
<td></td>
<td>VT</td>
<td>223.7 ± 11.2</td>
<td>49.0 ± 4.4</td>
<td>78.9 ± 5.3</td>
</tr>
<tr>
<td>Cycle ergometer (n = 33)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LT=VT (n = 12)</td>
<td>LT</td>
<td>274.5 ± 19.2</td>
<td>39.1 ± 3.7</td>
<td>90.4 ± 5.8</td>
</tr>
<tr>
<td></td>
<td>VT</td>
<td>40.0 ± 1.9</td>
<td>40.0 ± 1.9</td>
<td>89.5 ± 1.8</td>
</tr>
<tr>
<td>VT &lt; LT (n = 2)</td>
<td>LT</td>
<td>291.4 ± 6.6</td>
<td>33.1 ± 2.9</td>
<td>74.3 ± 4.3</td>
</tr>
<tr>
<td></td>
<td>VT</td>
<td>237.0 ± 2.8</td>
<td>29.2 ± 4.3</td>
<td>62.9 ± 4.5</td>
</tr>
<tr>
<td>LT &lt; VT (n = 19)</td>
<td>LT</td>
<td>196.1 ± 23.2</td>
<td>31.8 ± 3.9</td>
<td>68.5 ± 3.8</td>
</tr>
<tr>
<td></td>
<td>VT</td>
<td>235.3 ± 17.4</td>
<td>31.8 ± 3.9</td>
<td>68.5 ± 3.8</td>
</tr>
</tbody>
</table>

**LT=VT** – lactate and ventilation thresholds are same (identified at same stage of tests loads);

**VT < LT** – ventilation threshold has preceded to the lactate threshold;

**LT < VT** – lactate threshold has preceded to the ventilation threshold.

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**Fig.** Frequency distribution of ventilation and lactate thresholds combination in endurance event elite athletes due incremental test loads using different ergometers.

The difference of power outputs on the average was 39.4 watt, oxygen uptake – 2.6 ml·min·kg⁻¹ (5.6%), heart rate – 15 bpm (139 bpm at lactate threshold and 154 bpm at ventilation threshold, respectively. The first consequence of anaerobic glycolisis is the increase of lactate acid concentration in muscular cells and as a result – in the blood (Coyle et al., 1984; Beaver et al., 1986; Heck et al., 1985; Chawalbinska-Moneta et al., 1989; Soller et al., 2008; Klein et al., 2010; Lorenzo et al., 2011). It is known that lactate acid is more than 99% dissociated and buffered predominantly by the bicarbonate system of the blood. The additional carbon dioxide caused by buffering is exhaled via lungs, resulting in increase in VCO₂ of expiration air. The increase of CO₂ and H⁺ in the blood stimulates the lung ventilation. The blood lactate increasing without lung ventilation rising have been detected only during cycle incremental load test. Probably, this is due to limited muscular mass involved in cycle exercise load.

The study results have showed the significant difference between lactate and ventilation thresholds in greater part of elite athletes (30 observations or 51.7% cases of all tests) due incremental load test. Conclusion from this experimental data is necessity to continue investigations of physiology mechanisms and biochemistry process of aerobic-anaerobic transitional zone for better theoretical understanding of anaerobic threshold nature.
Conclusions

1. The study results have showed the significant difference of power outputs and oxygen uptake at anaerobic threshold detected by lactate and gas exchange methods due incremental load.

2. The most differences between ventilation and lactate thresholds have been identified during incremental cycle test. In 57.6% cases lactate threshold have been detected significantly earlier than ventilation threshold.

3. There are identified different types of thresholds concurrence: the ventilation and lactate thresholds have been identified at the same degree of load (LT = VT), the ventilation threshold has preceded the lactate threshold (VT < LT) and the lactate threshold has preceded the ventilation threshold (LT < VT).

4. For correct anaerobic threshold definition it is important to apply several approaches.

REFERENCES

DIDELIO MEISTRIŠKUMO SPORTININKŲ VENTILIACINIO IR LAKTATO SLENKŠČIŲ PALYGINimas

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SANTRAUKA

Darbo tikslas – palyginti didelio meistriškumo sportininkų, atliekančių nuosekliai didėjantį krūvį, ventiliacinio ir laktato slenkščių duomenis. Anaerobinis slenkstis nustatytas dujų analizatoriumi pagal plaučių ventiliacijos, deguonies ekvivalento ir laktato koncentracijos pokyčius kraujyje (padidėjusio laktato kaupimosi kraujyje pradžia).

Darbe pateikti ir palyginti 35 didelio meistriškumo ciklinių ištvermę ugdančių sporto šakų atstovų atlikamo darbo galingumo ir deguonies vartojimo duomenys ties ventiliaciniu ir laktato slenkščių. Nustatyta, kad 48,3 % tiriamų atvejų ventiliacinis ir laktato slenkščiai sutapo, 19 % atvejų ventiliacinis slenkstis buvo pasiektas anksčiau nei laktato, o 32,7 % atvejų laktato slenkstis buvo pasiektas anksčiau nei ventiliacini. Darbo galingumo skirtumas, pasiekus šiuos anaerobinio slenkščio variantus, siekė nuo 33,3 iki 54,4 W, deguonies vartojimo skirtumas – nuo 2,6 iki 6,9 ml/min/kg (2,6–15,2 %). Didžiausią aerobinį pajiugumą pasiekė tie sportininkai, kurių ventiliacinis ir laktato slenkstis buvo pasiektas kartu.

Tolesnis išsamus organizmo fiziologinių mechanizmų ir biocheminių procesų ties anaerobiniu slenkščiu tyrimas yra aktualus sporto mokslo problema. Siekiant teisingai nustatyti didelio meistriškumo sportininkų, ugdančių ištvermę, anaerobinį slenkstį, tikslinga naudoti keletą jo nustatymo metodų.

Raktažodžiai: anaerobinis slenkstis, deguonies vartojimas, ištvermę ugdantys didelio meistriškumo sportininkai.