Day-to-day changes in oxygen uptake kinetics at the onset of exercise during strenuous endurance training

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Summary. The aim of this study was to assess the effect of strenuous endurance training on day-to-day changes in oxygen uptake (\(\dot{V}O_2\)) on-kinetics (time constant) at the onset of exercise. Four healthy men participated in strenuous training for 30 min·day\(^{-1}\), 6 days·week\(^{-1}\) for 3 weeks. The \(\dot{V}O_2\) was measured breath-by-breath every day except Sunday at exercise intensities corresponding to the lactate threshold (LT) and the onset of blood lactate accumulation (OBLA) which were obtained before training. Furthermore, an incremental exercise test was performed to determine LT, OBLA and maximal oxygen uptake (\(\dot{V}O_2\)\(_{max}\)) before and after the training period and every weekend. The 30-min heavy endurance training was performed on a cycle ergometer 5 days·week\(^{-1}\) for 3 weeks. Another six men served as the control group. After training, significant reductions of the \(\dot{V}O_2\) time constant for exercise at the pretraining LT exercise intensity (\(P<0.05\)) and at OBLA exercise intensity (\(P<0.01\)) were observed, whereas the \(\dot{V}O_2\) time constants in the control group did not change significantly. A high correlation between the decrease in the \(\dot{V}O_2\) time constant and training day was observed in exercise at the pretraining LT exercise intensity (\(r = -0.76; P<0.001\)) as well as in the OBLA exercise intensity (\(r = -0.91; P<0.001\)). A significant reduction in the blood lactate concentration during submaximal exercise and in the heart rate on-kinetics was observed in the training group. Furthermore, \(\dot{V}O_2\) at LT, \(\dot{V}O_2\) at OBLA and \(\dot{V}O_2\)\(_{max}\) increased significantly after training (\(P<0.05\)) but such was not the case in the control group. These findings indicated that within a few weeks of training a rapidly improved \(\dot{V}O_2\) on-kinetics may be observed. This may be explained by some effect of blood lactate during exercise on \(\dot{V}O_2\) on-kinetics, together with significantly improved cardiovascular kinetics at the onset of exercise.

Key words: Exercise training - Blood lactate - Oxygen uptake kinetics

Introduction

It has been well documented that cardiorespiratory and metabolic responses to exercise may be modified rapidly by exercise training. During the first few weeks of training decreases have been observed in blood lactate concentration ([lacte]\(_{b}\)) (Hickson et al. 1981) and heart rate (\(f_c\)) during submaximal exercise (Houston et al. 1979), and increases in lactate threshold (LT) (Gaesser and Poole 1986).

Following a step increase in exercise intensity to a level less than the ventilatory threshold or LT, oxygen uptake (\(\dot{V}O_2\)) increases exponentially (\(\dot{V}O_2\) on-kinetics) to a steady-state. The quantitative evaluation for the exponential function can be expressed and characterized with a single time constant (\(r\)) and time delay (TD) (Linnarsson 1974; Morton 1987; Whipp et al. 1982), if the exercise intensity is moderate. Hickson et al. (1978) have also demonstrated a more rapid \(\dot{V}O_2\) on-kinetics following 10 weeks of training. While it has been well documented that the LT latency increases rapidly during the first 2–3 weeks of training (Gaesser and Poole 1986) and that [lacte]\(_{b}\), may thus be decreased substantially at each exercise intensity after only a few weeks of training (Gaesser et al. 1984), it is uncertain that \(\dot{V}O_2\) on-kinetics is able to adapt as rapidly.

Therefore the present study was designed to chart the concomitant day-to-day changes in \(\dot{V}O_2\) on-kinetics, [lacte]\(_{b}\), and \(f_c\) on-kinetics during training at a constant intensity of exercise.

Methods

Subjects

A group of 12 healthy male students volunteered for this study. They signed an informed consent form after being informed of its purpose and the possible risks. The subjects were then randomly assigned to either a training group (\(n=6\)) or a control group (\(n=6\)). Two subjects in the training group could not continue their training due to illness, thus training group data were obtained from the remaining 4 subjects. The physical characteristics of the subjects are shown in Table 1.
Exercise protocol

Maximal exercise. Each subject, prior to the training period, performed an incremental exercise test (20 W increment every 5 min) using an electrically-braked cycle ergometer (Combi 232c, Tokyo, Japan) until they were exhausted. This procedure was repeated for the training group at the end of each week of training (each Saturday). For the control group, the maximal test was repeated only during the posttraining period.

During the incremental exercise tests, the ventilatory and gas exchange response was measured by a computerized on-line breath-by-breath method (RM-300, Minato Medical Science, Osaka, Japan). Inspired and expired gas volumes were measured using a hot-wire respiratory flow system. Flow signals were electrically integrated during each breath time to calculate minute ventilation (VE). A 2-l syringe was used to calibrate the system; this was linear throughout a flow range of 0-600 l.min⁻¹ of VE. The expired fractions of O₂ and CO₂ were analysed with a zirconium solid electrolyte oxygen analyser and an infrared carbon dioxide analyser (MG-360, Toray Engineering Ltd, Osaka, Japan), respectively. A time delay (gas line transport and analyser dynamic response) relative to the ventilation signal were compensated by the algorithm of Noguchi et al. (1982) to determine breath-by-breath analysis (VE). A time constant of the response, respectively. Thus, A ventilation on-kinetics (O₂ vs time) was decided by an iterative best fit least-squares procedure. According to the approach by Whipp et al. (1982) and Casaburi et al. (1989), the time constant of response (τ) was calculated from equation (1) as:

\[ Y = A (1 - e^{-(t-\tau)/\tau}) \]

where Y is the response of \( \Delta VO_2 \) above the warm-up cycling level, A is the difference of \( \Delta VO_2 \) between the warm-up level and the steady-state response (\( \Delta VO_2,ss \)). τ is the time after the exercise intensity was increased, and TD and r are the time delay and the time constant of the response, respectively. Thus,

\[ \Delta VO_2(t) = \Delta VO_2,ss (1 - e^{-(t-\tau)/\tau}) \]

Capillary blood was sampled from the ear lobe during the constant exercise intensity test once a week. The [la⁻]b was determined in duplicate by a lactate analyser with the enzymatic electrode method as described.

Constant exercise test. To determine the \( \Delta VO_2 \) on-kinetics for step function exercise, two constant intensity exercise tests were performed on the ergometer. The constant exercise test consisted of a 6-min exercise session at an intensity determined from the result of the prior exercise training, exercise until the subjects felt exhausted, preceded by a 3-min warm-up at 20 W and followed by a 3 min cooling-down period at 20 W. The exercise intensity was controlled by a computer. The constant exercise intensity for the study of \( \Delta VO_2 \) on-kinetics was selected at the intensities corresponding to LT and OBLA.

Each subject visited the laboratory in the morning and performed a constant exercise test at an intensity of LT (exercise at pretraining LT intensity). In the afternoon, he performed a constant exercise intensity test at a power output equivalent to the intensity of OBLA (exercise at pretraining OBLA intensity).

Thereafter, training was performed in the evening. The time of day at which the exercise test was performed varied from subject to subject. However, each subject performed the test and took part in training at approximately the same time of day. The subjects performed the exercise test at least 3 h after a meal.

During the constant exercise test respiratory and gas exchange responses were measured with a computerized on-line breath-by-breath method as described above. Breath-by-breath data were stored on a diskette for further analysis. A second-by-second time course was calculated for these data by interpolation between the breath-by-breath response. The group average \( \Delta VO_2 \) time course for each group of subjects was plotted with the use of a minicomputer (PC-9801RA, NEC, Tokyo, Japan).

A single-exponential model was used to fit data for the LT and OBLA exercise intensity (Linnarsson 1974; Morton 1987). The exponential \( \Delta VO_2 \) on-kinetics (\( \Delta VO_2 \) vs time) was decided by an iterative best fit least-squares procedure. According to the approach used by Whipp et al. (1982) and Casaburi et al. (1989), the time constant of response (τ) was calculated from equation (1) as:

\[ Y = A (1 - e^{-(t-\tau)/\tau}) \]

where Y is the response of \( \Delta VO_2 \) above the warm-up cycling level, A is the difference of \( \Delta VO_2 \) between the warm-up level and the steady-state response (\( \Delta VO_2,ss \)). τ is the time after the exercise intensity was increased, and TD and r are the time delay and the time constant of the response, respectively. Thus,

\[ \Delta VO_2(t) = \Delta VO_2,ss (1 - e^{-(t-\tau)/\tau}) \]

Statistical analysis

Results are expressed as a mean value and SD. An analysis of variance was used to evaluate the difference between and within subjects of the two groups induced by training or nontraining respectively. A post-hoc paired Student’s t-test was applied to specify where any determined significance occurred. An unpaired Student’s t-test was used to evaluate the differences between the groups. The Pearson test was used for correlation analysis. A probability level of 0.05 was accepted as significant.

Results

Figure 1 indicates the effect of training on the weekly maximal exercise test. This figure shows \( \Delta VO_2 \) at LT, \( \Delta VO_2 \) at OBLA and \( \Delta VO_2 \)max for the training group and

Table 1. Physical characteristics of the subjects

<table>
<thead>
<tr>
<th>n</th>
<th>Age (year)</th>
<th>Height (cm)</th>
<th>Mass (kg)</th>
<th>Maximal O₂ uptake (ml·kg⁻¹·min⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>SD</td>
<td>mean</td>
<td>SD</td>
</tr>
<tr>
<td>Training group</td>
<td>4</td>
<td>23.5</td>
<td>1.1</td>
<td>170.9</td>
</tr>
<tr>
<td>Control group</td>
<td>6</td>
<td>21.8</td>
<td>1.6</td>
<td>173.0</td>
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</tbody>
</table>