MAXIMUM OXYGEN UPTAKE AND POST-EXERCISE RECOVERY IN PROFESSIONAL ROAD CYCLISTS

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ABSTRACT

Purpose. The aim was to investigate the relationship between aerobic fitness as ascribed by maximum oxygen uptake (VO_{2max}) and post-exercise recovery after incremental exercise to volitional exhaustion. **Methods.** A sample of 17 professional cyclists (age 17.4 ± 3.1 years; VO_{2max} 61.1 ± 7.2 ml/min/kg) were recruited. A graded exercise test was administered on a cycle ergometer. Upon termination, the participants remained seated, and oxygen uptake (VO_2), minute ventilation (VE), and heart rate (HR) were measured in the 1st, 3rd, and 5th minute of recovery. **Results.** Post-exercise VO_2 dynamics revealed a 69% and 80.9% reduction from VO_{2max} in the 1st and 5th minute, respectively. HR decreased only by 41% of HR_{max}, in the 5th minute of recovery. A positive correlation between the differential rate of recovery for VO_2 and VO_{2max} indicated a dependency between aerobic fitness and recovery potential. Correlative strength decreased with time, and by the 5th minute of recovery a significant correlation was evidenced only between VO_2 and VE. **Conclusions.** As recovery potential is associated with the aerobic fitness level, training effects may be monitored based on the recovery of VO_2 and HR to pre-exercise values.

Key words: physical capacity, maximum oxygen uptake, post-exercise recovery, road cyclists

Introduction

Aerobic fitness is defined as the ability to transport and utilize oxygen (consumption) and therefore generate energy during exercise [1]. The level of aerobic fitness is influenced by many factors, including cardiorespiratory function, age, sex, and training status. It is generally accepted that the maximum value of oxygen uptake registered during incremental exercise (VO_{2max}) is a reliable physiological variable that can quantify aerobic fitness and endurance and serve as an indicator of performance in long-term submaximal efforts [2]. In the athletic realm, individuals with higher VO_{2max} values possess definite physiological advantages over those with lower values [3].

Energy production during exercise is time- and intensity-dependent and based on two distinct albeit integrated metabolic processes – the anaerobic (phosphagen and glycolytic pathways) and aerobic energy systems. The former is the dominant in short-duration high-intensity exercise, in which adenosine triphosphate (ATP), phosphocreatine, and muscle glycogen serve as the sources of energy. The latter is the prime energy source in low- and moderate-intensity efforts, as well as during recovery intervals between successive efforts, and is contingent on numerous supply- and demand-side determinants, including stroke volume, mitochondrial volume density, myoglobin concentration in muscle fibre, aerobic enzyme activity responsible for ATP resynthesis, and blood haemoglobin level [4].

Post-exercise recovery involves a series of complex mechanisms, dependent on the type of exercise stimuli (exercise mode and volume) and the body's compensatory response to the said exercise. It is characterized by an initial rapid phase, lasting from 10 seconds to several minutes, followed by a slower recovery phase, which lasts from a few minutes to several hours [5]. Generally, the rapid recovery phase involves a sudden decrease in VO_{2max} and heart rate (HR); during the phase, the majority of intramuscular ATP and phosphocreatine depleted during exercise is resynthesized. In turn, the slow phase is marked by increased metabolism.

Heart rate attenuation in the initial phase following peak exercise is due to a combination of increased parasympathetic reactivation alongside sympathetic withdrawal. The rate of this reduction is termed heart rate recovery (HRR), and faster reduction is strongly associated with cardiovascular health and fitness level [6]. HRR is sensitive to training effects and is known to improve particularly in response to submaximal exercise, or efforts in which oxidative metabolism serves as the dominant energy source in ATP resynthesis [7–9].

The literature has indicated a relationship between the HRR and VO_{2max}, in which the rate of recovery to pre-exercise levels is faster in individuals with VO_{2max} above 60 ml/kg/min [6]. Tomlin and Wenger [5] indicated that athletes with high VO_{2max} presented elevated activities of various enzymes involved in oxidative energy provision, as well as increased mitochondrial and myoglobin content. These biochemical effects allow for improved oxygen transport and utilization during exercise. In combination with enhanced ATP, phosphocreatine, and creatine kinase deposits, a working muscle

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can generate more energy during exercise utilizing the oxidative and phosphagen energy systems. This reduces the relative anaerobic lactic contribution to exercise and minimizes energy expenditure needed for the removal of lactate and hydrogen ion accumulation, which may speed the post-exercise recovery process.

While VO_{2max} is considered by exercise physiologists to be the gold standard measure of cardiovascular fitness, strongly correlated with performance during aerobic endurance exercise [1], it has been suggested that a more objective measure of monitoring change in training status is analysis of the autonomic nervous system response, particularly parasympathetic reactivation, to a given training load as it is responsible for conserving energy expenditure and reducing blood pressure and HR to the pre-exercise levels. Buchheit et al. [10] observed that autonomic control of cardiac activity depended to a large extent on the elevated concentrations of post-exercise metabolites (lactate [LA], H^+, phosphate anion $[P_i]$) resulting from anaerobic energy production and also hormones (epinephrine and norepinephrine) secreted as an effect of heightened sympathetic nervous activity. This mechanism accordingly modulates vagal restoration and is itself associated with reduced post-exercise parasympathetic activation.

For the above reasons, investigators have appropriated VO_{2max}, HR, and minute ventilation (VE) kinetics as important indicators in the non-invasive assessment of training adaptations, aerobic fitness, and cardiovascular function [11, 12]. The aim of the present study was to further elucidate the associations between aerobic fitness as determined by VO_{2max} and the rate of recovery via HR measurement in young well-trained cyclists.

Material and methods

The study involved 17 road cyclists recruited from national and professional-level cycling teams. The minimum training experience was 3 years and many of the participants trained twice daily. The participants' characteristics are presented in Table 1.

All the procedures were conducted in laboratory conditions in the Exercise Laboratory of the University School of Physical Education in Wrocław, Poland (PN-EN ISO 9001:2001 certified). After anthropometric parameters were determined, the participants per-

formed a graded exercise test on a Excalibur Sport cycle ergometer (Lode BV, The Netherlands). Before use, the device was calibrated with special software. A standardized testing protocol was executed, in which the starting workload of 50 W was increased by 50 W every 3 minutes while maintaining a minimum cadence of 60 rpm [2]. The test was performed until volitional exhaustion or attainment of VO_{2max}. Upon concluding the test, each participant remained seated on the ergometer for 5 minutes for recovery.

Respiratory function (VO_2 and VE) on a breath-by-breath basis was recorded 2 minutes prior to and 5 minutes after the test termination, with the use of a Quark b2 gas analyser (Cosmed, Italy). The analyser was calibrated before use with a reference gas mixture of CO_2 (5%), O_2 (16%), and N_2 (79%). HR was continuously measured with a S810 heart rate monitor (Polar Electro, Finland). Data were averaged over 30-second intervals. Measures of VO_2, VE, and HR selected for analysis included the maximum values and those recorded in the 1st, 3rd, and 5th minute of recovery. The absolute (Δ_{max}) and percentage decrease (%) between the maximum value and the values in the 1st ($\Delta_{max-1'}$ and $\%_{-1'}$), 3rd ($\Delta_{max-3'}$ and $\%_{-3'}$), and 5th ($\Delta_{max-5'}$ and $\%_{-5'}$) minute of recovery were calculated, as was the relative value ($\%X_{max}$) of VO_2, VE, and HR in the 5th minute of recovery with respect to the maximum value. To aid the quantification of recovery dynamics, a differential rate of recovery (ROR) for VO_2, VE, and HR was also calculated using the maximum, resting, and 5th minute of recovery values [13].

$$WSR_{HR} = \frac{HR_2 - HR_3}{HR_2 - HR_1} \cdot 100 \ [\%],$$

where: $HR_1 - HR_{rest}$, $HR_2 - HR_{max}$, $HR_3 - HR_{5'}$, $WSR_{HR} - HR_{ROR}$.

$$WSR_{VO_2} = \frac{VO_22 - VO_23}{VO_22 - VO_21} \cdot 100 \ [\%],$$

where: $VO_21 - VO_{2rest}$, $VO_22 - VO_{2max}$, $VO_23 - VO_{2-5'}$, $WSR\ VO_2 - VO_{2ROR}$.

$$WSR_{VE} = \frac{VE_2 - VE_3}{VE_2 - VE_1} \cdot 100 \ [\%],$$

where: $VE_1 - VE_{rest}$, $VE_2 - VE_{max}$, $VE_3 - VE_{-5'}$, $WSR_{VE} - VE_{ROR}$.

Table 1. Anthropometric and physiological characteristics of the sample, expressed as mean ($\bar{x}$) and standard deviation (SD)

	Age (years)	Body height (cm)	Body mass (kg)	BMI (kg/cm²)	VO_{2max} (l/min)	VO_{2max}/kg (ml/kg/min)	HR_{max} (bpm)	VE_{max} (l/min)
$\bar{x}$	17.4	178.1	69.2	21.8	4.1	61.1	193.2	165.9
SD	3.1	7.1	7.9	2	0.4	7.2	7.5	20.1

BMI – body mass index, VO_{2max} – absolute maximum oxygen uptake, VO_{2max}/kg – relative maximum oxygen uptake, HR_{max} – heart rate maximum, VE_{max} – maximum minute ventilation

Correlations between the maximums and recovery values of the respiratory and physiological variables were assessed with the use of Spearman's rank correlations. All the statistical analysis was performed with the Statistica 10.0 software (StatSoft, USA). Statistical significance was defined at $\alpha = 0.05$.

Results

The analysis of post-exercise VO_2 dynamics revealed that the greatest decrease occurred in the 1st minute of recovery (at 69% of VO_{2max}). The reduction in VO_2 at the subsequent time points was similar, with the oxygen uptake in the 3rd and 5th minute of recovery amounting to 75% and 80% of VO_{2max}, respectively (Figure 1).

A partially similar situation was observed in regard to HR. Here, an evident decrease was observed in the 1st and 3rd minute of recovery as compared with HR_{max} (26% and 38% decrease, respectively), although the difference between the 3rd and 5th minute was relatively minor (only 3% of HR_{max}) (Figure 2).

When considering VO_2, VE, and HR, the concurrent decrease in HR was temporally slower than the former variables. In the 5-minute recovery period, HR decreased by 41% of HR_{max}, whereas absolute (l/min) and relative (ml/kg/min) VO_2 decreased by 80.9% and 80.57%, respectively, and VE decreased by 78.9% as compared with the recorded maximums (Figure 3).

The initial analysis revealed very strong correlations between VO_{2max} and $\Delta VO_{2max-1'}$, $\Delta VO_{2max-3'}$, and $\Delta VO_{2max-5'}$. The relationships between the VO_2, HR, and VE variables are presented as a correlation matrix in Table 2. Strong correlations were found between VO_2 and HR, as well as VE, particularly in the percentage decrease from the maximum value to those in the 1st ($\%_{-1'}$) and 3rd ($\%_{-3'}$) minute. This indicates that the greater the decrease in VO_2, the bigger the reduction in HR and VE. The significant correlations among the measures recorded in the 3rd minute of recovery were weaker than
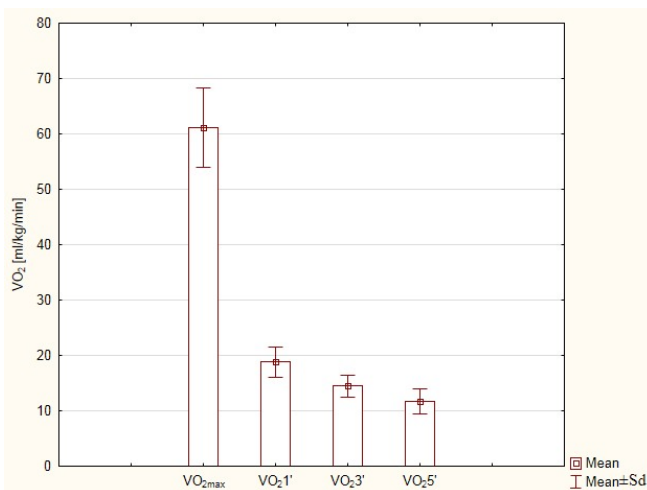

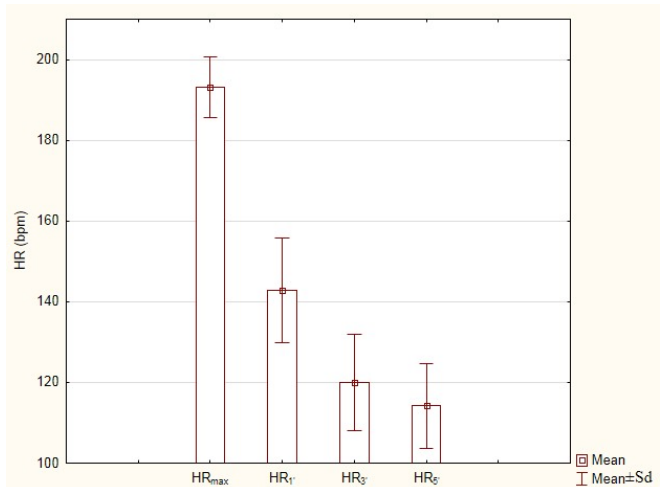Figure 1. VO_{2max} and VO_2 in the 1st, 3rd, and 5th minute of recovery

Figure 2. HR_{max} and HR in the 1st, 3rd, and 5th minute of recovery
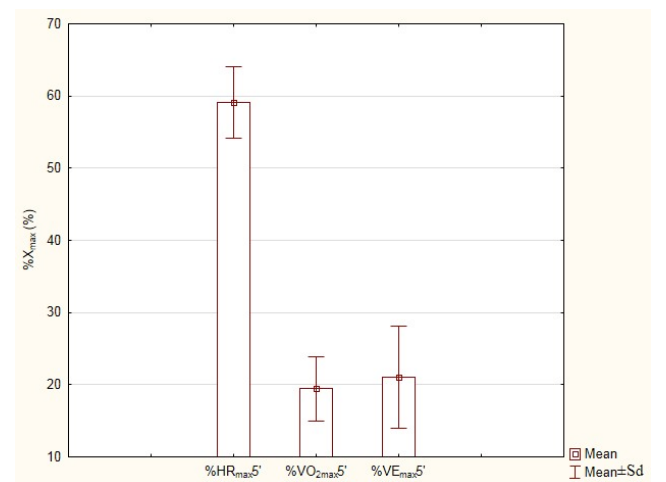

Figure 3. Percentage decrease in VO_2, VE, and HR in the 5th minute of recovery as compared with the recorded maximums

those in the 1st minute, excluding the correlation between the percentage decrease in VO_2 and VE ($r = 0.66$), which was weaker in the 1st minute of recovery ($r = 0.52$). In the 5th minute of recovery, the only significant correlations were between a few of the VO_2 and VE variables. No significant associations were observed between any of the rate of recovery differentials (ROR).

Discussion

The aim of the present study was to evaluate the relationships between VO_{2max} as an physiological indicator of aerobic fitness and the rate of recovery for HR, VO_2, and VE following a graded exercise test.

Strong positive correlations were observed between VO_{2max} and $\Delta VO_{2max-1'}$, $\Delta VO_{2max-3'}$, and $\Delta VO_{2max-5'}$. They suggest that a high level of aerobic fitness is associated with a faster reduction in oxygen uptake upon concluding the exercise. A similar finding was reached by Durocher et al. [3]. It is worth noting that among the 3

Table 2. Correlations between the VO_2 (ml/kg/min), VE, and HR variables

Variable	VO_{2max}	$VO_{2-1'}$	$VO_{2-3'}$	$VO_{2-5'}$	$\Delta VO_{2max-1'}$	$\Delta VO_{2max-3'}$	$\Delta VO_{2max-5'}$	$\%VO_{2-1'}$	$\% VO_{2-3'}$	$\% VO_{2-5'}$	VO_{2ROR}
HR_{max}	–0.02	0.08	–0.19	–0.34	–0.03	0.09	0.15	–0.26	0.22	0.19	0.29
$HR_{-1'}$	–0.09	0.45	0.25	0.01	–0.33	–0.18	–0.01	–0.66*	–0.32	–0.03	0.24
$HR_{-3'}$	–0.20	0.20	0.04	–0.16	–0.37	–0.25	–0.08	–0.55*	–0.27	–0.02	0.27
$HR_{-5'}$	–0.23	0.13	0.01	–0.01	–0.35	–0.22	–0.13	–0.47	–0.19	–0.13	0.10
$\Delta HR_{max-1'}$	0.11	–0.39	–0.45	–0.15	0.29	0.26	0.06	0.51*	0.54*	0.13	–0.06
$\Delta HR_{max-3'}$	0.20	–0.24	–0.32	0.07	0.36	0.30	0.11	0.41	0.51*	–0.01	–0.16
$\Delta HR_{max-5'}$	0.22	–0.20	–0.25	–0.11	0.36	0.27	0.15	0.36	0.41	0.11	–0.01
$\%HR_{-1'}$	0.09	–0.40	–0.46	–0.17	0.28	0.25	0.05	0.53*	0.55*	0.14	–0.05
$\%HR_{-3'}$	0.29	–0.21	–0.13	0.17	0.46	0.36	0.16	0.53*	0.44	–0.02	–0.22
$\%HR_{-5'}$	0.21	–0.14	–0.11	0.00	0.35	0.23	0.11	0.35	0.26	0.08	–0.06
HR_{ROR}	0.03	–0.37	–0.33	–0.12	0.21	0.12	–0.06	0.52*	0.36	0.13	–0.03
VE_{max}	0.39	–0.11	–0.27	–0.01	0.50	0.42	0.31	0.38	0.30	0.11	–0.06
$VE_{-1'}$	0.04	0.39	0.42	0.05	–0.13	–0.11	0.02	–0.49*	–0.30	–0.07	0.02
$VE_{-3'}$	0.15	0.33	0.55*	0.03	0.02	0.00	0.11	–0.33	–0.40	0.05	0.11
$VE_{-5'}$	0.12	0.08	0.27	0.21	–0.21	–0.27	–0.14	–0.28	–0.34	–0.25	–0.22
$\Delta VE_{max-1'}$	0.39	–0.25	–0.23	0.03	0.56*	0.50*	0.34	0.65*	0.57*	0.15	–0.03
$\Delta VE_{max-3'}$	0.41	–0.19	–0.25	0.00	0.55*	0.50*	0.35	0.62*	0.59*	0.17	–0.06
$\Delta VE_{max-5'}$	0.52*	–0.08	–0.01	–0.05	0.64*	0.58*	0.46	0.60*	0.52*	0.26	0.12
$\%VE_{-1'}$	0.26	–0.36	–0.33	–0.02	0.45	0.40	0.22	0.70*	0.52*	0.15	–0.04
$\%VE_{-3'}$	0.04	–0.45	–0.61*	0.02	0.24	0.22	0.01	0.59*	0.66*	–0.02	–0.18
$\%VE_{-5'}$	0.28	–0.18	–0.23	–0.04	0.41	0.41	0.24	0.49*	0.45	0.15	0.08
VE_{ROR}	0.34	–0.05	–0.15	–0.02	0.46	0.47	0.29	0.35	0.45	0.16	0.16

* correlations statistically significant at $p < 0.05$
VO_2 – maximum oxygen uptake, HR – heart rate, ROR – rate of recovery, VE – minute ventilation

variables selected for the analysis, VO_2 and VE were found to decrease considerably faster than HR. The literature provides opposing results, with many studies reporting that the time-course of VO_2 and VE recovery is significantly greater than that of HR [14–18]. These studies indicate that the return to pre-exercise levels can in fact require several hours. This discrepancy can be explained by the relatively short period of recovery under observation (5 minutes) compared with the aforementioned studies.

The significant relationships observed in the 1st minute of recovery indicate that the greater the decrease in HR, the bigger the reduction in VE and VO_2. The time course shows a downward trend in regard to correlative strength, as by the 3rd minute of recovery weaker correlations were observed as compared with the 1st minute, and by the 5th minute of recovery only very weak correlations remained. This may indicate that the associations between these variables are similar only in a short-term observation (first 3 minutes of recovery). At later times points, the only significant correlation was observed between the relative and absolute VO_2 and VE, although this finding affirms that these two variables are largely interdependent, as proposed by Tocco et al. [19]. It is also important to note that no statistically significant relationships were found between aerobic fitness (assessed by VO_{2max}) and HR, implying that both variables need to be independently monitored when studying training effects.

The present investigation has some limitations with reference to the adopted procedure. Firstly, the participants remained seated during the recovery period when VO_2, VE, and HR were assessed. The works of Larson et al. [20], Ostojic et al. [6], and Buchheit et al. [21] record enhanced HRR in the supine position compared with an active or seated position. Secondly, VO_2, VE, and HR were all measured within the first 5 minutes of recovery. However, several investigators have reported that complete recovery may require several hours following strenuous exercise (as in a graded exercise test) [5, 15]. Thirdly, some differences may have arisen owing to the influence of different potentiating factors [6, 22–24]. Many of the previously cited studies assessed the effects of a training prescription in various populations, where exercise testing and the assessment of the physiological and respiratory function were preceded by several weeks of training. The present study involved well-trained cyclists with intensive training schedules but without the administration of specific training intervention, which may limit the interpretation of the results.

Conclusions

The positive correlation between the differential rate of recovery for VO_2 and VO_{2max} confirms the relationship between aerobic fitness and recovery potential. The percentage decreases in VO_2, HR, and VE were correlated

only in the 1st and 3rd minute of recovery and indicated a downward trend in which the greater the decrease in VO_2 was, the bigger the reduction in HR and VE turned out. The only significant correlation observed in the 5th minute of recovery was between the relative and absolute VO_2 and VE. The lack of association between aerobic fitness, as determined by VO_{2max}, and HRR suggests that both variables ought to be independently monitored when studying training effects.

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