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# HEART RATE AND OXYGEN UPTAKE RECOVERY AND THE LEVEL OF AEROBIC CAPACITY IN MOUNTAIN BIKERS

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**Abstract**
***Introduction.*** Since mountain biking involves exercise of varying intensity, competitive performance may be affected by the rate of recovery. The aim of the current study was to determine whether maximal oxygen uptake is associated with the rate of heart rate and oxygen uptake recovery in mountain bike athletes. ***Material and methods.*** The study examined 29 mountain bikers, including members of the Polish National Team. These athletes specialised in cross-country Olympic (XCO) racing. After undergoing a graded stress test on a cycle ergometer, the subjects were divided into two groups: G1, consisting of athletes with higher aerobic capacity (n = 12; $VO_{2max}$ > 60 ml·kg$^{-1}$·min$^{-1}$), and G2, comprising athletes with lower aerobic capacity (n = 17; $VO_{2max}$ < 55 mL·kg$^{-1}$·min$^{-1}$). Heart rate and oxygen uptake recovery was measured after the graded stress test in a sitting position. ***Results.*** $HR_{max}$ values did not differ significantly between the two groups. $HR_{1'}$, $HR_{2'}$, and $HR_{4'}$ values recorded for G1 were statistically significantly lower compared to those achieved by G2. %$HR_{1'}$, %$HR_{2'}$, %$HR_{4'}$, and %$HR_{5'}$ values were also significantly lower in G1 than in G2. No significant differences were found in oxygen uptake during recovery ($VO_{2\text{-}1',2',3',4',5'}$) between the two groups. Significantly lower %$VO_{2max\text{-}1'}$, %$VO_{2max\text{-}2'}$, and %$VO_{2max\text{-}5'}$ values were observed in G1 compared to those in G2. No significant correlations were found between $VO_{2max}$ per kilogram of body mass and the recovery efficiency index in either group. There was, however, a statistically significant correlation between $VO_{2max}$ and the recovery efficiency index (R = 0.52) in the entire group of athletes (n = 29). ***Conclusion.*** The study showed that the work capacity of mountain bike athletes was associated with the rate of heart rate and oxygen uptake recovery.

**Key words:** maximal oxygen uptake, recovery, heart rate recovery, mountain biking

## Introduction

Mountain biking is characterised by the performance of exercise of varying intensity. This is due to the fact that mountain bikers need to complete uphill sections, requiring high-intensity effort, and downhill sections, during which the power generated by the lower limb muscles decreases. The key parameters which are deemed to determine successful performance in mountain biking include maximal oxygen uptake ($VO_{2max}$), maximal aerobic power [1], power at anaerobic threshold, and work efficiency [2]. Of major importance is also the level of anaerobic capacity [2, 3].

The parameter which is examined the most frequently among the ones mentioned above is maximal oxygen uptake [4]. The $VO_{2max}$ value is additionally significant for the effective repayment of the oxygen debt during recovery [5, 6]. A relationship between oxidative capacity and the rate of recovery after glycolytic exercise was observed by Thomas et al. [7]. A high level of $VO_{2max}$ is associated with features of the muscles that impact lactate metabolism, namely higher levels of myoglobin and enzymes involved in aerobic metabolism as well as a greater number, size, and surface of mitochondria [8, 9]. Furthermore, aerobic training increases, among others, stroke volume, muscle capillarity, blood volume, and hemoglobin concentration [10, 11], which facilitates transporting metabolites produced during intense exercise [6, 12, 13].

As mountain biking involves exercise of higher and lower intensity, performance in biking competitions may be affected by the rate of recovery. Effective recovery can be determined by examining the rate of the decrease in HR values (heart rate recovery, HRR) or $VO_2$ values after the performance of exercise [14]. The faster the recovery is, the sooner the body is ready to undertake high-intensity exercise. An important role is played here by the recovery of phosphocreatine. As observed by Haseler et al. [15], the time of the recovery of this substance depends on the availability of oxygen. Post-exercise recovery consists of two phases [16]. The initial fast phase lasts from a dozen or so seconds to a few minutes and is characterised by a rapid decrease in heart rate and in the amount of oxygen consumed. This is followed by the slow phase, which can last from a few to a dozen or so minutes. Increased post-exercise metabolism is due to the clearance of lactate and hydrogen ions, increased body temperature, the activity of catecholamines, the resynthesis of muscle glycogen, and the resynthesis of proteins [6]. Heart rate recovery is mainly dependent on the activity of the autonomic nervous system [17, 18]. Moreover, it is affected, among others, by the power that is generated at the cost of glycolytic changes and of the concentration of lactate and hydrogen ions in the blood [19]. For this reason, HRR may be associated with maximal oxygen uptake, which allows for greater aerobic power and faster removal of glycolytic metabolites. The rate of recovery is assessed using different methods, that is (a) the absolute difference between the maximal value achieved during exercise and that recorded in the first minute after its completion, (b) logarithmic regression, and (c) indices that include resting, exercise, and recovery values [20, 21].

The aim of the current study was to determine whether maximal oxygen uptake is associated with the rate of HR and $VO_2$ recovery in top Polish mountain bike athletes. It was expected that athletes with higher $VO_{2max}$ levels, who achieved higher power in the graded stress test, were characterised with faster HR and $VO_2$ recovery.

## Material and methods

The study involved 29 mountain bike athletes, including members of the Polish National Team. The subjects specialised in cross-country Olympic (XCO) racing. After undergoing a stress test, the athletes were divided into two groups. This division was made based on a similar criterion to the one used by Ostojic et al. [22]. The first group (G1) consisted of athletes with a higher level of aerobic capacity (n = 12; $VO_{2max}$ > 60 ml·kg$^{-1}$·min$^{-1}$), and the second group (G2) included athletes with lower aerobic capacity (n = 17, $VO_{2max}$ < 55 ml·kg$^{-1}$·min$^{-1}$). It is worth noting that all the members of the Polish National Team were classified into G1, whereas the remaining subjects were in G2. Table 1 shows the values obtained for selected anthropometric features and parameters measured in the graded stress test in both groups.

### *Exercise testing*

Each of the subjects underwent a graded stress test, which was carried out at the Exercise Testing Laboratory of the University School of Physical Education in Wroclaw (PN-EN ISO 9001:2001 certificate). The subjects were requested to avoid strenuous physical effort or to completely refrain from training 48 hours before the test. The measurements lasted one day, and they included the following: the measurement of body height and weight on a WPT 200 medical scale (RADWAG, Poland), the stress test, and the measurement of blood lactate concentration. All the subjects consented to participating in the study in writing and were made familiar with its procedure. They could withdraw from the study at any time. The study was approved by the University Research Ethics Committee and was carried out in compliance with the Helsinki Declaration.

### *Graded stress test*

The graded stress test was carried out on an Excalibur Sport cycle ergometer (Lode BV, Holland), which was calibrated before each test. The test started with a load of 50 W, which was increased by another 50 W every three minutes. The pedalling rate was maintained at the level of 60 revolutions per minute. The test was performed to exhaustion or until the moment when the subject achieved $VO_{2max}$, that is the moment when the value of this parameter stabilised despite further increases in exercise power. After the test was finished, the subject remained seated on the cycle ergometer. Heart rate (HR) was measured using an S810 heart rate monitor (Polar Electro, Finland). The recording of respiratory parameters started 2 minutes before the test and ended 5 minutes after its completion. The subjects breathed through a mask, and expired air was analysed using the Quark system (Cosmed, Italy). The equipment was calibrated with atmospheric air and a gas of the following composition: $CO_2$ – 5%, $O_2$ – 16%, and $N_2$ – 79%. Respiratory parameters were registered breath by breath. $VO_{2max}$ was defined as the highest 30-sec average $VO_2$ value calculated per minute during the graded test. We also determined the subjects' blood lactate concentrations ($La_{3'}^-$) using a photometer (LP 400, Dr Lange, Germany). The blood was taken from the finger pad 3 minutes after the completion of the test.

### *Calculations*

The following parameters were determined based on the values recorded in the graded test: $HR_r$ – resting heart rate before the beginning of the test (bpm); $HR_{max}$ – maximal heart rate (bpm); $VO_{2max}$ – maximal oxygen uptake (mL·kg$^{-1}$·min$^{-1}$); $HR_{1'}$, $HR_{2'}$, ..., $HR_{5'}$ – mean HR in the first, second, third, fourth, and fifth minutes of recovery (bpm); and $VO_{2\text{-}1'}$, $VO_{2\text{-}2'}$, ..., $VO_{2\text{-}5'}$ – mean $VO_2$ in the first, second, third, fourth, and fifth minutes of recovery (bpm). Mean 30-second values recorded between the 31$^{st}$ and 60$^{th}$ second of each minute of recovery were used in the calculations. We also computed the following indices: $\%HR_{1'}$, $\%HR_{2'}$, ..., $\%HR_{5'}$ – percentage heart rate in the first, second, third, fourth, and fifth minutes of recovery with respect to maximal HR in the graded test (%) as well as $\%VO_{2max\text{-}1'}$, $\%VO_{2max\text{-}2'}$, ..., $\%VO_{2max\text{-}5'}$, calculated in an analogous way. Finally, we determined the value of the heart rate recovery efficiency (RE) index (%), using a modified version of the index developed by Klonowicz [20, 23], by means of the following formula:

$$WSR = \frac{HR_2 - HR_3}{HR_2 - HR_1} * 100\ [\%] \tag{1}$$

where $HR_1$ is resting heart rate, $HR_2$ is maximal heart rate, and $HR_3$ is mean heart rate in the fifth minute of recovery.

**Table 1.** Mean ($\bar{x}$) and standard deviation (SD) values of selected anthropometric parameters and parameters measured in the graded stress test in G1 (n = 12) and G2 (n = 17)

| Group | Age (years) | Height (cm) | Body mass (kg) | $HR_r$ (bpm) | $P_{max}$ (W) | $VO_{2max}$ (mL·kg$^{-1}$·min$^{-1}$) | $La_{3'}^-$ (mmol·L$^{-1}$) |
|---|---|---|---|---|---|---|---|
| G1, $\bar{x}$ | 21.92 | 178.83 | 71.58 | 67 | 412.50* | 65.61* | 13.31 |
| G1, SD | ±6.75 | ±4.22 | ±6.03 | ±15 | ±31.08 | ±4.24 | ±2.26 |
| G2, $\bar{x}$ | 20.94 | 179.12 | 74.82 | 72 | 354.12 | 53.16 | 12.46 |
| G2, SD | ±5.20 | ±6.07 | ±9.72 | ±16 | ±42.29 | ±4.45 | ±2.02 |

G1 – athletes with higher aerobic capacity, G2 – athletes with lower aerobic capacity; $HR_r$ – resting heart rate, $P_{max}$ – maximal power in the graded test, $VO_{2max}$ – maximal oxygen uptake, $La_{3'}^-$ – lactate concentration in arterialised blood in the third minute after the graded test; * = statistically significant differences between G1 and G2 at the level of $p < 0.05$.

***Statistical analysis***

The data were analysed statistically using Statistica 12.5. Mean ($\bar{x}$) and standard deviation (SD) values were calculated for each variable. Differences in the mean values of the parameters obtained for the graded test were tested for statistical significance using the Mann-Whitney U test for independent samples. Differences in the parameter values measured during the consecutive minutes of recovery were analysed using repeated measures ANOVA and Duncan's post hoc test. We also calculated Spearman's rank correlation coefficients for selected variables. Statistical significance was set at $p < 0.05$.

## Results

The subjects' age, anthropometric parameters, resting heart rate, and post-exercise blood lactate concentration did not differ significantly between the two groups. The maximal power achieved in the graded test was higher in G1 ($p < 0.001$) (Tab. 1).

$HR_{max}$ values did not differ significantly between the two groups. $HR_{1'}$, $HR_{2'}$, and $HR_{4'}$ values recorded for G1 were statistically significantly lower compared to those achieved by G2 (Tab. 2). $\%HR_{1'}$, $\%HR_{2'}$, $\%HR_{4'}$, and $\%HR_{5'}$ values were also statistically significantly lower in G1 than in G2 (Fig. 1). In G2, we observed a trend ($p = 0.059$) of lower RE index values compared to G1 (Tab. 2).

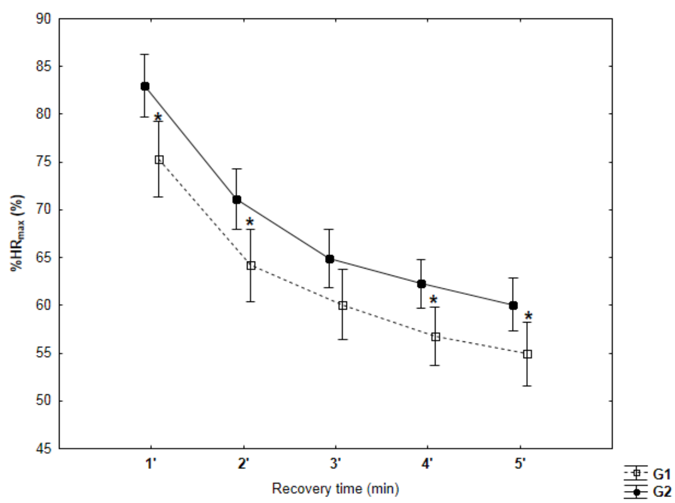
No significant differences were found between the groups in oxygen uptake during recovery ($VO_{2\text{-}1', 2', 3', 4', 5'}$) (Tab. 3). In G1, significantly lower $\%VO_{2max\text{-}1'}$, $\%VO_{2max\text{-}2'}$, and $\%VO_{2max\text{-}5'}$ values were observed compared to G2 (Fig. 2).

No significant correlations were revealed between the relative value of maximal oxygen uptake per kilogram of body mass and the RE index ($R = 0.47$ and $R = 0.46$ for G1 and G2, respectively). However, in the entire group of mountain bikers ($n = 29$), there was a statistically significant correlation between $VO_{2max}$ and the RE index ($R = 0.52$). In both groups, there was a significant correlation between $\%VO_{2max}$ and %HR in the first minute ($R = 0.66$ and $R = 0.59$ in G1 and G2, respectively) and second minute ($R = 0.66$ and $R = 0.67$ in G1 and G2, respectively) of recovery, as well as in the fourth minute of recovery in G1 ($R = 0.59$). In the entire group of subjects, positive correlations were found between $\%VO_{2max}$ and %HR in each recorded minute of recovery, but starting from the third minute, this relationship became weaker ($R = 0.73$ for 1', $R = 0.40$ for 3', and $R = 0.47$ for 5'). Absolute power values did not correlate with the recovery parameters analysed in the study. There was, however, a signifi-

**Table 2.** Mean ($\bar{x}$) and standard deviation (SD) values of heart rate (HR) – maximal values and values in consecutive minutes of recovery in G1 (n = 12) and G2 (n = 17)

| Group | $HR_{max}$ (bpm) | $HR_{1'}$ (bpm) | $HR_{2'}$ (bpm) | $HR_{3'}$ (bpm) | $HR_{4'}$ (bpm) | $HR_{5'}$ (bpm) | RE index (%) |
|---|---|---|---|---|---|---|---|
| G1, $\bar{x}$<br>G1, SD | 188<br>±7 | 141*<br>±14 | 120*<br>±14 | 113<br>±15 | 107*<br>±12 | 103<br>±13 | 70.23<br>±7.04 |
| G2, $\bar{x}$<br>G2, SD | 188<br>±6 | 156<br>±15 | 134<br>±13 | 122<br>±12 | 117<br>±11 | 113<br>±11 | 65.47<br>±11.97 |

G1 – athletes with higher aerobic capacity, G2 – athletes with lower aerobic capacity; $HR_{max}$ – maximal heart rate; $HR_{1'}$, $HR_{2'}$, $HR_{3'}$, $HR_{4'}$, $HR_{5'}$ – mean HR values in the first, second, third, fourth, and fifth minutes of recovery; RE index – recovery efficiency index; * = statistically significant differences between G1 and G2 at the level of $p < 0.05$.



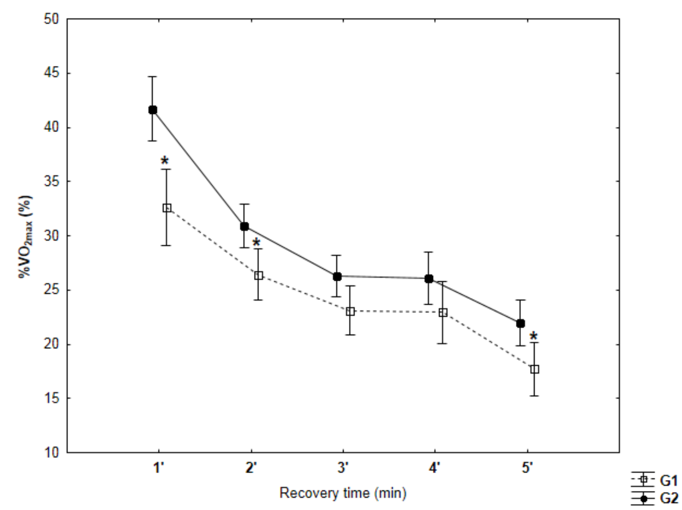

* = statistically significant differences between G1 and G2 at the level of $p < 0.05$.

**Figure 1.** Relative HR values (mean and SD) calculated with respect to maximal values in G1 and G2 in consecutive minutes of recovery

**Table 3.** Mean ($\bar{x}$) and standard deviation (SD) values of oxygen uptake ($VO_2$) in consecutive minutes of recovery in G1 (n = 12) and G2 (n = 17)

| Group | $VO_{2\text{-}1'}$ (mL·kg$^{-1}$·min$^{-1}$) | $VO_{2\text{-}2'}$ (mL·kg$^{-1}$·min$^{-1}$) | $VO_{2\text{-}3'}$ (mL·kg$^{-1}$·min$^{-1}$) | $VO_{2\text{-}4'}$ (mL·kg$^{-1}$·min$^{-1}$) | $VO_{2\text{-}5'}$ (mL·kg$^{-1}$·min$^{-1}$) |
|---|---|---|---|---|---|
| G1,<br>SD | 21.38<br>±2.82 | 17.29<br>±2.46 | 15.10<br>±2.38 | 15.00<br>±2.38 | 11.58<br>±2.42 |
| G2,<br>SD | 21.98<br>±2.84 | 16.39<br>±2.19 | 13.91<br>±1.98 | 13.75<br>±2.00 | 11.59<br>±2.00 |

G1 – athletes with higher aerobic capacity, G2 – athletes with lower aerobic capacity; $VO_{2max\text{-}1'}$, $VO_{2max\text{-}2'}$, $VO_{2max\text{-}3'}$, $VO_{2max\text{-}4'}$, $VO_{2max\text{-}5'}$ – mean $VO_2$ values in the first, second, third, fourth, and fifth minutes of recovery.




* = statistically significant differences between G1 and G2 at the level of $p < 0.05$.

**Figure 2.** Relative $VO_2$ values (mean and SD) with respect to maximal values in G1 and G2 in consecutive minutes of recovery

cant relationship between power per kilogram of body mass and the RE index in the entire group of mountain bikers (R = 0.56).

## Discussion

Mountain biking requires that athletes perform exercise of varying intensity [24]. When the biker is going downhill, low power is required; thus, the rate of recovery may be of importance in this discipline. Our analysis of the efficiency of HR recovery demonstrated that mountain bikers who performed at a higher level (G1) had more rapid recovery after a graded stress test. These results are not in line with the ones obtained in our earlier research involving road cyclists [20]. The discrepancies between the findings of the two studies may be due to the differences in maximal power generated in the graded test and the small size of the samples. However, according to the results of the studies of most other authors [22, 25, 26], a higher $VO_{2max}$ level is related to faster HR recovery. It has been suggested that this relationship is moderate or strong [27, 28]. For instance, Ostojic et al. [22] examined football players who were divided into two groups based on their $VO_{2max}$ values. One group was characterised by maximal oxygen uptake above 60 $mL \cdot kg^{-1} \cdot min^{-1}$, and the second one had a $VO_{2max}$ below 50 $mL \cdot kg^{-1} \cdot min^{-1}$. Heart rate recovery was significantly statistically faster until the 20$^{th}$ second after exercise in the group with higher aerobic power when heart rate was analysed in terms of absolute values and relative values (%HRmax). The rate of heart rate recovery is, similarly as in the case of oxygen uptake, associated with the capacity to generate high muscle power output [29]. In the current study, higher maximal aerobic power values were obtained by G1. A possible explanation for these findings is that engaging in more intense training, which makes it possible to achieve better aerobic capacity, causes changes in the activity of the autonomic nervous system. More highly-trained athletes may have greater parasympathetic stimulation with simultaneous sympathetic withdrawal [30, 31].

A study carried out by Buchheit et al. [32] demonstrated that the activity of the autonomic nervous system depends on the level of anaerobic metabolites (lactate, $H^+$ ions, and orthophosphate) in the muscles as well as on the release of adrenaline and noradrenaline from sympathetic nerve endings. For instance, hydrogen cations delay stimulation, which is associated with slower activation of the parasympathetic nervous system as a result of the metabolic and chemoreflexive responses. No differences were found in post-exercise blood lactate concentrations between the two groups in the study; thus, it may be assumed that the concentration of the products of glycolytic metabolism did not have a significant influence on the results.

Another indicator of high work capacity, apart from heart rate recovery, is oxygen uptake recovery. In the current study, $VO_2$ recovery values did not differ significantly between the two groups in the first five minutes of recovery. It should, however, be added that G1 had a higher mean oxygen uptake value in the graded test. Thus, it was useful to analyse relative values with respect to maximal oxygen uptake. It was found that G1 was characterised by smaller $\%VO_{2max-1'}$, $\%VO_{2max-2'}$, and $\%VO_{2max-5'}$. Faster oxygen uptake recovery can be seen as indicative of more effective replenishment of oxygen reserves by myoglobin and phosphocreatine in the muscles [33]. This may be important in competitive mountain biking, since oxygen deficiency in the muscles during the breaks between efforts restrains the capacity to attain high levels of power [32, 34].

Some studies have reported a relationship between heart rate recovery and oxygen uptake recovery [35]. This was indeed found in our study for both G1 and G2 as well as for the entire group of subjects (n = 29). The strongest association was observed for the first minute of recovery, whereas in the following minutes, this relationship was weaker. Although there was no statistically significant correlation between maximal oxygen uptake and the RE index in G1 or G2, a significant correlation with the RE index was revealed when the maximal oxygen uptake and the work performed were examined for the entire group of mountain bikers (n = 29). It is thus possible that only substantial changes in aerobic capacity are significantly correlated with heart rate recovery, and in groups that are more homogeneous in terms of aerobic capacity, the relationship between $VO_{2max}$ and heart rate recovery is weaker. Therefore, this relationship is worth investigating in a larger group of athletes. What is more, the research conducted by Lamberts et al. [29] showed that in highly trained athletes, intensifying the training helps achieve better performance outcomes, and this is accompanied by higher efficiency of heart rate recovery, but not by changes in maximal oxygen uptake. Thus, it can be concluded that apart from maximal oxygen uptake, there are other factors determining work capacity which are related to the rate of recovery after intense effort. Further research is certainly needed into this issue.

## Conclusions

The work capacity of mountain bikers was found to be associated with the rate of heart rate recovery. The rate of heart rate recovery was higher in the group of athletes with a higher level of aerobic capacity in terms of relative values calculated with respect to $VO_{2max}$.

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