STUDIES IN PHYSICAL CULTURE AND TOURISM
Vol. 17, No. 2, 2010

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DIFFERENCE IN MAXIMAL OXYGEN UPTAKE (VO_2max) DETERMINED BY INCREMENTAL AND RAMP TESTS

Key words: maximal oxygen consumption, ventilatory threshold, incremental test, ramp test.

ABSTRACT

The purpose of this study was to compare maximal oxygen uptake and ventilatory threshold values in elite cyclists during incremental and ramp tests. The research material included ten male elite cyclists; body height 182.6±6.1 cm; body mass 70.2±5.5 kg; body fat 8.8±3.2%. The experiment had two phases, separated by one day of active recovery. During the first phase, the incremental test (T_{40x3}) was carried out to determine VO_2max, ventilatory (VAT) and lactate thresholds (LT) in each subject. The protocol began with a work load of 120 W which was increased by 40 W every 3 min until volitional exhaustion. During the second phase, each athlete performed a ramp ergocycle test (T_{30x1}) (30 W per 1 min) where work load increased linearly (0.5 W per s) until volitional exhaustion, to establish VO_2max. Values of VO_2max determined by the T_{30x1} test were significantly ($p<0.05$) higher than those determined by the T_{40x3} exercise protocol. The same tendencies were also observed in values of maximal work load (WR_{max}), maximal minute ventilation (VE_{max}), maximal respiratory ratio (RER_{max}) and maximal heart rate (HR_{max}). Values of WR_{max}, VE_{max}, RER_{max}, HR_{max} were significantly ($p<0.05$) higher in the T_{30x1} protocol in comparison to the T_{40x3}. WR_{VAT} during the T_{30x1} were significantly ($p<0.05$) higher than WR_{VAT} at T_{40x3}. This was also true for values of WR_{VAT} at the T_{30x1} and WR_{LT} during the T_{40x3}.

INTRODUCTION

Measurement of maximal oxygen uptake (VO_2max) is one of the oldest and most common measurements in the diagnosis of sport performance and efficiency of ergogenic aids. VO_2max is defined as the point at which oxygen uptake reaches a peak and plateaus or increases slightly in response to increased work rate. There are several concepts of standardized tests to measure VO_2max, but the incremental step test is one of the most popular. Buchfuhrer [3] found that the value of VO_2max is protocol dependent. They examined several protocol possibilities and reported that duration of exercise may influence VO_2max values. They suggested that the "fast" protocols with large work rate increments per minute caused subjects to terminate the test before achieving their VO_2max, which could be related with insufficient muscle strength to accommodate the large work load increases during the final stages of the test. Likewise slow test protocols (longer than 20 min) may cause lower VO_2max values. In this case the decrease is the effect of a significant rise in core temperature, which causes a redistribution of cardiac output and as a consequence less blood flows to the working muscles. Also slow protocols are very exhausting and require high motivation of the tested subject during the final stage of the test. Some authors [3] suggest that in order to evaluate

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true VO_2max intermediate speed protocols are needed (a test should not last more than 12-15 minutes). In practice, very often during this exercise protocol also the anaerobic threshold is determined. Therefore increasing work load increments should be optimal, since greater values would not allow for a precise determination of the anaerobic threshold. Thus in elite athletes the time of the test could be extended up to 20-25 minutes.

Another, popular test used in the evaluation of VO_2max is based on the ramp protocol were work load increases linearly with subject's exhaustion. Some authors [1] during this test, attempt to determine the ventilatory or lactate thresholds, but according to findings of Stockhausen et al. [14] and Heck [9], a stage duration between 6 and 10 min is necessary to reach an equilibrium between arterial blood lactate and muscle lactate concentration. Similar results were obtained by McLellan et al. [12] who observed that protocols using increments shorter than 5 min were not sufficient for lactate diffusion from the intramuscular compartment to plasma since lactate diffusion is partly limited by the capacity of transports.

This conclusion is confirmed by results of our previous study [7], which showed that the length of stage increment for optimal lactate diffusion should be longer than 5 min. We observed a significant increase in lactate concentration between the 5^{th} and 10^{th} min of the MLSS effort. However, according to Kindermann et al. [11], a workload duration of 3 min is sufficient for the assessment of LT, although equilibrium is not reached yet, because longer stages during the incremental test may increase the length of the test and reduce VO_{2max}. This means that the work load at the lactate threshold, which is one of the most common indices of aerobic capacity and endurance performance in athletes, determined by the ramp test will be higher in comparison to the incremental test.

The purpose of this study was to compare maximal oxygen uptake and ventilatory threshold values in elite cyclists during the incremental and ramp tests.

METHODS

The research material included ten male elite cyclists; body height 182.6±6.1 cm; body mass 70.2±5.5 kg; body fat 8.8±3.2%. All of the tested athletes possessed current medical examinations confirming proper health status and the ability to perform exhaustive exercise. The research project was approved by the Ethics Committee for Scientific Research of the Academy of Physical Education in Katowice.

The research was conducted during the competitive season thus the values of aerobic capacity were at maximum or near maximum levels. The experiment had two phases, separated by one day of active recovery. At the beginning of the first phase, initial values of body mass and body composition (fat free mass – FFM, percent of body fat – Fat%, total body water – TBW) were evaluated with the use of electrical impedance (InBody 220, Biospace). Then, the incremental step test (T_{40x3}) was carried out to determine VO_2max, ventilatory and lactate thresholds (LT) in each subject. The protocol began with a work load of 120 W which was increased by 40 W every 3 min until volitional exhaustion. According to the authors of this paper the load increment of 40 W per each step is optimal for determination of the anaerobic threshold but it extends the time of the test protocol, which may effect VO_2max values. Maximal work load (WR_{max}) during this protocol was calculated from the following formula: $WR_{max} = WR_p\ [t_u/D_{s\ x}\ WR_i]$ [2], were WR_p – previous finished work load, t_u – time (s) of the uncompleted work load, D_s – duration (s) of each stage, WR_i – increase in work load during each stage.

At the beginning and the end of each workload during the T_{40x3} test, capillary blood samples were drawn to determine lactate concentration. These values allowed us to determine the lactate thresholds by the D-max method proposed by Cheng et al. [4] for each athlete. The ventilatory threshold was determined by the V-slope method, which was assessed as the first breaking point from linearity of carbon dioxide output (VCO_2) plotted against oxygen uptake (VO_2). Capillary blood samples were also drawn in the 3^{rd}, 6^{th}, 9^{th} and 12^{th} min of recovery to determine lactate utilization.

During the second phase, each athlete performed a ramp ergocycle test (T_{30x1}) (30 W per 1 min) were work load increased linearly (0.5 W per 1 s) until volitional exhaustion, to establish VO_2max. Each ramp test was started with a resistance set at 30 W and pedal frequency was individual. In this phase, capillary blood samples were drawn to determine lactate concentration before and immediately at the end of the T_{30x1} as well as after the 3rd, 6th, 9th and 12th min. During the T_{40x3} and T_{30x1} protocols the following variables were constantly registered: heart rate (HR), minute ventilation (VE), oxygen uptake (VO_2) and expired carbon dioxide (CO_2), respiratory ratio (RER), breath frequency (BF) (MetaLyzer 3B-2R, Cortex).

All tests were performed on an ergocycle Excalibur Sport (Lode). Seat and bar height of the cycle ergometer were set according to each subject. Maximal oxygen uptake (VO_2max) was assessed by the attainment of the following criteria: (1) a plateau in VO_2 with increases in work load ($\Delta VO_2 \leq 150$ ml/min at VO_2peak; (2) maximal respiratory exchange ratio (RER) ≥ 1.1. All breath-by-breath gas exchange data were time-averaged using 15 s intervals to examine the oxygen plateau.

The obtained data was analyzed statistically with the use of Statistica 8.0. The results were presented as arithmetic means (x) and standard deviations (SD). To determine the significance of differences between variables of applied exercise protocols, the Wilcoxon's test was applied. The level of statistical significance was set at $p<0.05$.

RESULTS

The T_{40x3} and T_{30x1} test results, as well as the significance of differences between variables are presented in Table 1.

The results showed significant ($p<0.05$) differences between VO_2max determined by the T_{40x3} and T_{30x1} protocols. Values of VO_2max determined by the T_{30x1} test were significantly ($p<0.05$) higher than those determined by the T_{40x3} exercise protocol (Fig. 1). The same tendencies were also observed in values of maximal work load (WR_{max}), maximal minute ventilation (VE_{max}), maximal respiratory ratio (RER_{max}) and maximal heart rate (HR_{max}). Values of WR_{max}, VE_{max}, RER_{max}, HR_{max} were significantly ($p<0.05$) higher in the T_{30x1} protocol in comparison to the T_{40x3} in tested cyclists. The statistical analysis also indicated that there were significant ($p<0.05$) differences between work loads at the ventilatory thresholds (WR_{VAT}) during the T_{40x3} and T_{30x1} tests. WR_{VAT} during the T_{30x1} were significantly ($p<0.05$) higher than WR_{VAT} at T_{40x3}. This was also true for values of WR_{VAT} at the T_{30x1} and WR_{LT} during the T_{40x3}, but differences between WR_{VAT} and WR_{LT} determined by T_{40x3} were non-significant. (Tab. 1, Fig. 2). The analysis of changes of lactate concentration immediately after the cessation of both tests and during the recovery period (after 3rd , 6th , 9th and 12th min) indicates that values of LA during the recovery period after the T_{30x1} test were significantly ($p<0.05$) higher than after the T_{40x3}; however, these differences were non-significant.

Table 1. The incremental (T_{40x3}) and ramp test (T_{30x1}) results in male cyclists

	Incremental test (T_{40x3})		Ramp test (T_{30x1})		
	Mean ± SD	Min. – Max	Mean ± SD	Min. – Max	Significant difference
WR_{max} (W)	399.8±38.5	360–453	479.6±34.4	440–524	***
VO_2 max (l/min)	4.77±0.35	4.26–5.23	4.96±0.31	4.65–5.48	***
VO_2 max (ml/kg/min)	68.2±2.04	65–71	70.6±3.3	66–75	***
VCO_2max (l/min)	5.26±0.53	4.7–5.91	5.85±0.44	5.1–6.3	***
RER_{max}	1.15±0.04	1.09–1.22	1.19±0.06	1.11–1.26	***
VE_{max} (l/min)	173.8±13.88	160.8–195.1	187.9±9.3	176–202.5	***
BF_{max} (1/min)	51.2±2.1	48.9–54	54.9±1.7	53.2–58	***
HR_{max} (bpm)	186±3.73	181–191	188±4.2	182–193	***
WR_{LT} (W)	288±16.8	280–320	–	–	
WR_{VAT} (W)	280±26.6	240–320	316±24.5	290–350	***
LA_{max} (mmol/l)	7.73±1.79	5.37–10.1	7.66±1.32	5.4–9.2	NS
$LA_{3'}$ (mmol/l)	8.46±1.82	5.47–10.42	8.71±1.82	5.8–11.2	***
$LA_{6'}$ (mmol/l)	7.55±1.88	4.3–9.76	7.8±1.73	4.8–9.8	***
$LA_{9'}$ (mmol/l)	6.62±1.71	3.65–8.26	7.01±1.6	4.1–8.1	***
$LA_{12'}$ (mmol/l)	5.89±1.71	2.92–7.4	6.46±1.6	3.5–7.5	***
Time (min:s)	21±3:50	18–25	14:42±0:55	13:30–16	***

*** $p<0.05$; NS – non-significant

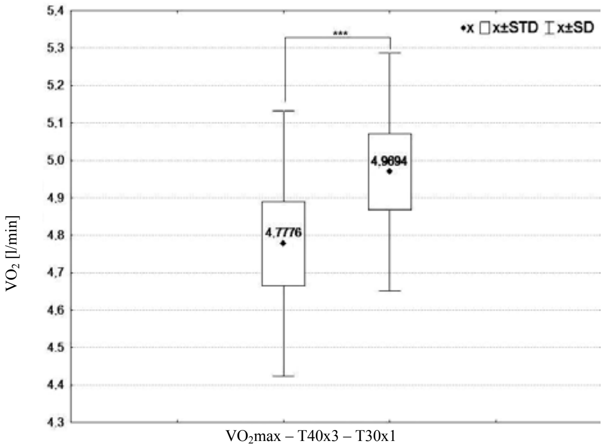

Figure 1. The average values of maximal oxygen uptake (VO_2max) determined by the incremental (T_{40x3}) and ramp tests (T_{30x1}); *** – significant differences at p<0.05

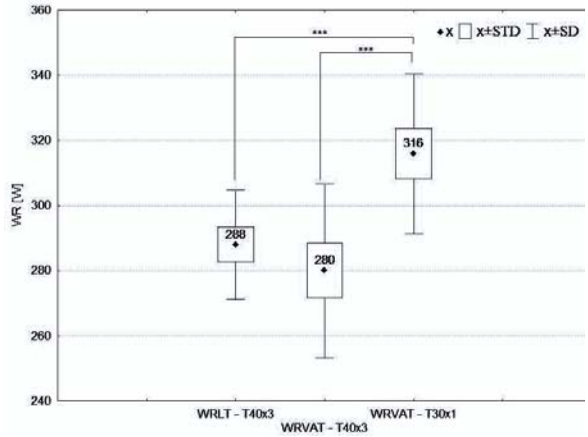

Figure 2. The average values of work load at the ventilatory (WR_{VAT}) and lactate thresholds (WR_{LT}) determined by the incremental (T_{40x3}) and ramp tests (T_{30x1}); *** – significant differences at p<0.05

DISCUSSION

The primary aim of the present investigation was to determine the differences in maximal oxygen uptake (VO_2max) and ventilatory threshold during the incremental and ramp tests.

Previous reports [8, 13] in this area suggest that VO_2max values are similar during incremental cycle ergometer exercise tests regardless of the rate of work increase during ramp-pattern testing [3]. This data was also confirmed by a study of Amann et al. [1] who showed insignificant differences in values of VO_2max determined during incremental (50 W per 3 min) and ramp tests (25 W per 1 min), yet there was a tendency for higher VO_2max values during the ramp test.

The results of the present study are confirmed in a previous report of Buchfuhrer et al. [3]. The statistical analysis showed significant differences in values of VO_2max determined by the T_{40x3} and T_{30x1} protocols. VO_2max values determined by the T_{30x1} were significantly higher ($p<0.05$) by 3.9% than those obtained in the T_{40x3} test. In our opinion these differences are connected indirectly with the increment of work load during the test protocol, but most of all with the duration of protocols. It is worth noticing that all subjects attained the criteria of reaching VO_2max during the incremental and ramp tests, but analysis of such variables as VCO_2max, RER_{max}, VE_{max}, BF_{max}, and HR_{max}, during both tests allowed to draw a conclusion that fatigue during the T_{40x3} had a significant influence on mental fatigue and the motivation of the tested subjects. Significantly higher values of WR_{max} during the T_{30x1} test were most likely caused by a major recruitment of type II fibers, which consume more oxygen then type I fibers [6].

To compare our results with those of Amann et al. [1] who showed insignificant differences in values of VO_2max determined during the incremental and ramp tests, one must consider the duration of tests in which there were no significant differences (mean 6:18 vs. 2:50 min). The differences were related to work load in used the exercise protocols, as well as in the subjects, which in our study had a significantly greater work capacity (higher values of $WR_{max,}$ VO_2max in both tests). In the exercise protocol used by Amann et al. [1] the workload started at a power output of 100 W and was increased every 3 min by 50 W until exhaustion. Very often during this exercise protocol the anaerobic threshold is determined to evaluate sport performance and the effects of training programs. Results of our and previous studies allow us to conclude that a rapid increase of work load in both the step and ramp tests does not allow for determine the anaerobic threshold accurately. We observed that WR_{VAT} during the T_{30x1} were significantly higher (by 12.8%) than WR_{VAT} during the T_{40x3}, as well as WR_{VAT} during the T_{30x1} were significantly higher (by 9.7%) than WR_{LT} during the incremental T_{40x3} and WR_{VAT} during T_{30x1}.

This increase in WR_{VAT} values during the T_{30x1} may be explained by lactate diffusion from the intramuscular compartment to plasma, which depends on the capacity of the monocarboxylic (MCT) transporters [10]. The work load increments applied in the ramp exercise protocol, most likely failed to equilibrate lactate concentration, and its measurements in the blood plasma at each sample may not yield the value of intramuscular lactate. As a consequence, the rise in pCO_2 in the blood which is responsible for the increase in ventilation was delayed. This phenomenon may be confirmed by a significant post-exercise increase in lactate concentration observed in our study during the recovery period after both tests. The lactate concentration measured during the recovery period after the T_{30x1} test was significantly higher than after the T_{40x3} exercise protocol. These findings were confirmed by McLellan et al. [12], who observed that in protocols with load increments less than 5 min, lactate diffusion from the intramuscular compartment to plasma is insufficient and partly limited by the capacity of the MCT transporters. In another study Chicharro et al. [5] also reported significant differences ($p<0.05$) between mean values of ventilatory and lactate thresholds when both were expressed in values of heart rate, work load or VO_2 during the ramp test.

It was concluded that values of VO_2max are depended of the increment of work load during the test protocol and on the duration of the test protocol. Also the ventilatory and lactate thresholds determined by the ramp test should not to be used to determine intensity zones for endurance training.

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