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Original paper

Exercise at given percentages of VO_{2max}: Heterogeneous metabolic responses between individuals

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Abstract

Purpose: Given percentages of VO_{2max} are widely used for training and study purposes although they might not result in homogeneous metabolic strain. Therefore, the homogeneity of metabolic responses to prolonged exercise at fixed percentages of VO_{2max} should be investigated. *Procedures:* Twenty-one healthy male subjects (29 ± 5 years, 77 ± 8 kg, VO_{2max}: 59.9 ± 11.8 ml min^{-1} kg^{-1}) performed two incremental tests to exhaustion on a cycle ergometer to determine VO_{2max}. Subsequently, two 60 min tests at 60 and 75% VO_{2max} were conducted in randomised order. VO_2 was kept constant by adjusting the work rate. Blood lactate (La) responses as primary outcome variable to quantify metabolic strain were assessed. *Findings:* Mean La was 2.1 ± 1.1 mmol l^{-1} (min–max: 0.7–5.6 mmol l^{-1}) during the 60% VO_{2max} test and 4.6 ± 1.9 mmol l^{-1} (min–max: 2.2–8.0 mmol l^{-1}) during the 75% VO_{2max} test. The coefficients of variation of La amounted for 52.4 and 41.3% during the 60 and 75% VO_{2max} test, respectively. La responses did not differ significantly between three subgroups of the subjects (N = 7 with VO_{2max} < 55 ml min^{-1} kg^{-1}, N = 7 with VO_{2max} 55–65 ml min^{-1} kg^{-1}, and N = 7 with VO_{2max} > 65 ml min^{-1} kg^{-1}; $P \geq 0.08$). *Conclusion:* Altogether, prolonged exercise at given percentages of VO_{2max} leads to inhomogeneous metabolic strain as indicated by the large variability of La responses. This holds true even in subgroups of similar aerobic capacity. Thus, intensity prescription for endurance training and study purposes should not be solely based upon percentages of VO_{2max} when a comparable metabolic strain is intended.

Keywords: Oxygen consumption; Lactic acid; Physical conditioning; Human; Physical endurance

1. Introduction

Maximum oxygen uptake (VO_{2max}) is usually considered to be the most important indicator of endurance and cardiocirculatory function.[1] For training purposes, VO_{2max} is often used as a reference, i.e. exercise intensity is prescribed as percentage of VO_{2max}. This becomes apparent when examining the large number of training studies in which percentages of VO_{2max} serve as training prescriptions.[2–4]

In terms of targeted endurance training, athletes and coaches are striving for a defined metabolic strain to achieve predictable adaptive response. However, several study findings suggest that training intensities expressed as fixed percentages of maximal ergometric values might not result in intraindividually homogeneous metabolic responses. So far, most of these data sets come from graded exercise tests.[5–8] Using graded cycling protocols, Katch et al.[5] showed that the metabolic stress at 60, 70, and 80% of maximal heart rate (HR_{max}) as related to the anaerobic threshold was not constant across subjects. Weltman et al.[7,8] arrived at the same conclusion when conducting graded treadmill tests and using different lactate thresholds as criteria for the homogeneity of physiological responses to exercise at fixed percentages of HR_{max}, heart rate reserve (HRR), and VO_{2max}. Meyer et al.[6] examined endurance athletes who conducted progressive cycle tests to exhaustion and demonstrated that fixed percentages of VO_{2max} and HR_{max} corresponded to wide ranges of exercise intensities as defined in relation to lactate levels and

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the individual anaerobic threshold (IAT). It remains questionable whether these results are transferable to prolonged endurance exercise.

Outcomes of prolonged exercise tests have so far only been presented as side aspects of studies with a different focus that were conducted with trained[9] or highly trained[10] cyclists. Aiming at elucidating why competitive cyclists with similar VO_{2max} differ in their cycling performance, Coyle et al.[10] examined prolonged cycling tests at 88% VO_{2max} to exhaustion. The analysis revealed differences in time to exhaustion that were associated with the lactate threshold (LT). However, LT was not a precise predictor of exercise duration. In a study by Orok et al.[9] prolonged exercise tests of 60 min or until exhaustion at constant work rates corresponding to about 40, 60, and 80% VO_{2max} were performed by seven trained cyclists to test whether the blood lactate concentrations at the end of 3 min exercise stages of an incremental test accurately reflect steady state responses. A diffuse pattern of varying lactate increases and different times to exhaustion were reported for the 80% VO_{2max} test.

Prolonged exercise tests at reasonable training intensities as given percentages of VO_{2max} have never been conducted before to thoroughly investigate the metabolic responses that occur during an endurance training session or in a study using such exercise prescriptions. Therefore, the aim of this study was to describe the metabolic response to prolonged exercise at given percentages of VO_{2max}.

2. Methods

After VO_{2max} had been determined, 60 min of cycling exercise at 60 and 75% VO_{2max} were observed in subjects with a wide range of aerobic capacity while monitoring work rate by means of oxygen uptake (VO_2) measurements. Sixty and 75% VO_{2max} are frequently used training intensities within the range of exercise recommendations of the American College of Sports Medicine.[11] Metabolic responses to exercise were described by means of blood lactate concentrations (La). Furthermore, maintainability of the tests and the presence of lactate steady state conditions were observed.

A total of 21 healthy male subjects ($N = 7$ with "lower" aerobic capacity (LOW): $VO_{2max} < 55$ ml min^{-1} kg^{-1}, $N = 7$ with "medium" aerobic capacity (MEDIUM): VO_{2max} 55–65 ml min^{-1} kg^{-1}, and $N = 7$ with "high" aerobic capacity (HIGH): $VO_{2max} > 65$ ml min^{-1} kg^{-1}) participated in this study. Anthropometric data of the subjects are given in Table 1. Participants gave their written informed consent according to the rules of the institutional review board. Before exercise testing, they were subjected to a medical check up to ensure the absence of health risks.

Each participant performed four tests. Initially, one stepwise and one rampwise incremental cycling test to exhaustion were conducted on separate days in randomised order. VO_{2max} was determined as the higher VO_2 either from the rampwise or the stepwise incremental test to make sure that "real" VO_{2max} values were recorded independent of day-to-day variances[12] and the exercise protocol.[13] Subsequently, two prolonged exercise tests at 60 and 75% VO_{2max} were conducted in randomised order. They started with a three min warm-up and work rate was then adjusted until the intended VO_2 was reached. From that moment, subjects cycled for 60 min or until exhaustion. Power output was adjusted to maintain VO_2 constant by means of continuous VO_2 monitoring. Capillary blood samples for the determination of La were taken and HR was recorded at rest, after 10, 20, 30, 40, and 50 min, and after cessation of exercise. All testing was performed on the same electrically braked cycle ergometer (Lode Excalibur, Groningen, The Netherlands).

During all tests, gas exchange data were measured continuously by means of a metabolic device (Meta Max II, Cortex, Leipzig, Germany) and heart rate (HR) was recorded by means of a telemetric system (Polar S 610, Polar Electro, Kempele, Finland). Capillary blood samples for the determination of La (enzymatic-amperometric method, Greiner, Flacht, Germany) were taken from the hyperaemised earlobe. Criteria for determination of VO_{2max} were: (i) maximal blood lactate concentration (La_{max}) > 8 mmol l^{-1} and (ii) achievement of HR_{max} > 200 minus age.[14] Oxygen uptake reserve (VO_2R) was calculated as difference between VO_{2max} and VO_2 while sitting on the cycle ergometer quietly before the onset of exercise. The IAT was determined from the stepwise incremental exercise test according to Stegmann et al.[15] Lactate steady state conditions during the prolonged exercise tests were considered to be present if La increased for less than 1 mmol l^{-1} between the tenth exercise min and the last blood sample according to a definition for constant work rates by Beneke.[16] This criterion could not be investigated in

Table 1
Anthropometric and ergometric performance data of the subjects.

	Age (years)	Height (cm)	Mass (kg)	P_{max} (W kg^{-1})	VO_{2max} (ml min^{-1} kg^{-1})	HR_{max} (min^{-1})	La_{max} (mmol l^{-1})
TOTAL	29 ± 5	179 ± 6	77 ± 8	4.6 ± 1.2	59.9 ± 11.8	192 ± 9	11.0 ± 2.0
LOW	30 ± 5	178 ± 6	80 ± 10	3.3 ± 0.7[bb,ccc]	46.5 ± 7.8[bb,ccc]	189 ± 5	9.7 ± 1.9[c]
MEDIUM	30 ± 6	180 ± 5	79 ± 5	4.9 ± 0.5[aa]	62.1 ± 1.9[aa,c]	192 ± 10	10.9 ± 1.5
HIGH	27 ± 5	181 ± 7	71 ± 6	5.7 ± 0.7[aaa]	71.2 ± 5.6[aaa,b]	194 ± 11	12.4 ± 2.0[a]

Data are presented as means ± S.D. (TOTAL: $N = 21$; LOW, MEDIUM, and HIGH: $N = 7$ in each group).
Significantly different from LOW: [a]$P < 0.05$, [aa]$P < 0.01$, [aaa]$P < 0.001$.
Significantly different from MEDIUM: [b]$P < 0.05$, [bb]$P < 0.01$, [bbb]$P < 0.001$.
Significantly different from HIGH: [c]$P < 0.05$, [cc]$P < 0.01$, [ccc]$P < 0.001$.