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Oxygen uptake kinetics in trained athletes differing in $\dot{V}_{O_{2\max}}$

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Summary. Previous work has shown that when $\dot{V}_{O_2}$ kinetics are compared for endurance trained athletes and untrained subjects, the highly trained athletes have a faster response time. However, it remains to be determined whether the more rapid adjustment of $\dot{V}_{O_2}$ toward steady state in athletes is due to $\dot{V}_{O_{2\max}}$ differences or training adaptation alone. One approach to this problem is to study the time course of $\dot{V}_{O_2}$ kinetics at the onset of work in athletes who differ in $\dot{V}_{O_{2\max}}$ but have similar training habits. Therefore, the purpose of these experiments was to compare the time course of $\dot{V}_{O_2}$ kinetics at the onset of exercise in athletes with similar training routines but who differ in $\dot{V}_{O_{2\max}}$. Ten subjects ($\dot{V}_{O_{2\max}}$ range 50—70 $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) performed 6-minutes of cycle ergometer exercise at $\sim 50\%$ $\dot{V}_{O_{2\max}}$. Ventilation and gas exchange were monitored by open circuit techniques. The data were modeled with a single component exponential function incorporating a time delay, (T_D); $\Delta \dot{V}_{O_{2t}} = \Delta \dot{V}_{O_{2ss}} (1 - e^{-t - T_D/\tau})$, where τ is the time constant $\Delta \dot{V}_{O_{2t}}$ is the increase in $\dot{V}_{O_2}$ at time t and $\Delta \dot{V}_{O_{2ss}}$ is the steady-rate increment above resting $\dot{V}_{O_2}$. Kinetic analysis revealed a range of $\dot{V}_{O_2}$ half times from 21.6 to 36.0 s across subjects with a correlation coefficient of $r = -0.80$ ($p < 0.05$) between $\dot{V}_{O_{2\max}}$ and $\dot{V}_{O_2}$ half time. These data suggest that in highly trained indicivuals with similar training habits, those with a higher $\dot{V}_{O_{2\max}}$ achieve a more rapid $\dot{V}_{O_2}$ adjustment at the onset of work.

Key words: Oxygen uptake kinetics — $\dot{V}_{O_{2\max}}$ — Exercise metabolism — Trained athletes — Gas exchange

Introduction

Oxygen consumption increases at the beginning of exercise with a time course influenced by work intensity and state of training: the higher the intensity the longer the time course, the greater the level of training the shorter the time course (Hagberg et al. 1978; Hickson et al. 1978; Weltman and Katch 1976; Whipp and Wasserman 1972). Although it appears that training adaptation allows a faster adjustment of O_2 uptake at the onset of work (Hickson et al. 1978) it remains to be determined whether the more rapid adjustment of $\dot{V}_{O_2}$ toward steady state in athletes when compared to untrained subjects is related to maximum aerobic power ($\dot{V}_{O_{2\max}}$) differences or training adaptation alone. Previous studies comparing $\dot{V}_{O_2}$ kinetics between subjects of high and low $\dot{V}_{O_{2\max}}$ have not controlled for differences in the level of training in subjects (Hagberg et al. 1978; Hickson et al. 1978; Weltman and Katch 1976). There are, to our knowledge, no experimental data available to compare the time course of $\dot{V}_{O_2}$ kinetics during exercise in trained subjects differing in $\dot{V}_{O_{2\max}}$. Additionally, previous investigators evaluated $\dot{V}_{O_2}$ kinetics using a single exponential model without a time delay (Hagberg et al. 1978; Hickson et al. 1978; Weltman and Katch 1976). Therefore, the purpose of these experiments was to compare the time course of the rise in $\dot{V}_{O_2}$ toward steady state at the same relative workload in highly trained athletes with similar training routines but who differ in $\dot{V}_{O_{2\max}}$.

Methods

Subjects. Ten male track athletes who gave informed consent were studied after 10 weeks of conditioning. The athletes stud-

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ied used long distance running (~110 km · wk^{-1}) as their primary training method and were selected for study on the basis that they performed similar training routines (i.e., team workouts) but differed in $\dot{V}_{O_{2max}}$. Over the 10 week conditioning period prior to the laboratory tests, the athletes trained 5—6 days per week at exercise heart rates ≥150 bt · min^{-1}. Although the athletes ran the same distances in training, the relative work rates during the workouts could not be controlled and probably differed between athletes. This was not considered a major problem in experimental design since the purpose of these tests were to compare $\dot{V}_{O_2}$ kinetics in trained athletes who differed in $\dot{V}_{O_{2max}}$. Mean characteristics (±SEM) of the subjects were: $\dot{V}_{O_{2max}}$: 58 ml · kg^{-1} · min^{-1} ±2.6; Age: 20.4 years ±0.4.

period prior to the laboratory tests ↑ the athletes trained 5—

Exercise tests. Maximum oxygen uptake was measured during work on a cycle ergometer at a pedaling frequency of 60 rev · min^{-1}. The test began with a 3-min warm-up at 100 W followed by a 2-min recovery period. The progressive test began at a work rate of 100 W with the load being increased at 30 W per min until the subject could not maintain the desired pedal frequency. The criteria of McMiken and Daniels (1976) were applied to determine if $\dot{V}_{O_{2max}}$ had been obtained. Any subject that did not meet the above criteria was retested until the standards were met.

The time course of the increase in $\dot{V}_{O_2}$ following the onset of exercise was examined in each subject several days following the $\dot{V}_{O_{2max}}$ test at a work rate requiring approximately 50% of their $\dot{V}_{O_{2max}}$. All subjects were tested on the same cycle ergometer (Monark) and performed under similar environmental conditions (temperature −16.0—19.0° C; $P_B = 100.1 - 101.2$ kPa; R.H. 58—74%). The participants were asked to limit their activities for 24 h prior to each experiment and reported to the laboratory 6 h postprandial. The test began following a 15-min rest on a verbal command from the investigator. The subjects synchronized their pedaling rate with the sound of a metronome, and the desired resistance on the cycle flywheel was obtained within 5 s after the test began. Duration of the exercise was six minutes.

Measurements of $\dot{V}_{O_2}$. Open circut spirometric techniques using aliquot samples were employed to measure metabolic parameters. Inspired air was drawn through a turbine spirometer (Pneumoscan S-300) which was calibrated (prior to these experiments) by placing the turbine flow meter in series with a 120-liter Tissot spirometer and having subjects inspire through the turbine-Tissot system a various rates of ventilation as described by Welch and Pedersen (1981). Subjects breathed through a low-resistance valve (Rudolph 2700) with the expired gases passing through a 30 cm length of 34 mm diameter tubing into a 30-liter meteorological balloon. Expired O_2 and CO_2 fractions were determined using oxygen (Beckman OM-11) and carbon dioxide (LB-2) analyzer, respectively. They were calibrated before and after each test using reference gases analyzed by the Scholander technique. Expired gas samples were collected in meteorological balloons over the following time periods; one 2-min collection prior to exercise, twelve 15-s samples during the first 3 min of exercise, and three 1 min samples over the last 3 min of work.

Calculations and statistical procedures. To characterize the kinetic behaviour of $\dot{V}_{O_2}$ the data were fit by a non-linear least squares regression to a single exponential model incorporating a time delay (T_D); $\Delta\dot{V}_{O_{2t}} = \Delta\dot{V}_{O_{2ss}}(1 - e^{-t - T_D/\tau})$ where $\Delta\dot{V}_{O_{2t}}$ is the increase in $\dot{V}_{O_2}$ at time t, $\Delta\dot{V}_{O_{2ss}}$ is the steady-state increment above resting $\dot{V}_{O_2}$. This model was chosen on the basis of goodness of fit and has been discussed in detail by Hughson and Morrissey (1982). The justification for the use of a single-component model with a time delay is based on the demonstration that it provides a better fit than models without a time delay which artificially force a regression through the origin. Forcing the regression through the origin will bias the slope of the line and make interpretation of the kinetic response difficult (Hughson and Morrissey 1982).

The first 15 s $\dot{V}_{O_2}$ sample was eliminated from kinetic analysis. At the onset of work, the initial $\dot{V}_{O_2}$ measured via open circuit spirometry does not accurately reflect the $\dot{V}_{O_2}$ response of the exercise task but represents the $\dot{V}_{O_2}$ necessary to replace O_2 stores in the blood that had pooled in nonworking tissue prior to work but was returned upon exercise (Hughson and Morrissey 1982; Krogh and Lindhard 1913). The $\dot{V}_{O_2}$ half time ($\dot{V}_{O_{2t\,1/2}}$) is defined as the length of time to reach one-half of the steady-state $\dot{V}_{O_2}$.

Results

There was a significant ($p < 0.05$; $r = -0.80$) rectilinear relationship between $\dot{V}_{O_{2t\,1/2}}$ and $\dot{V}_{O_{2max}}$ (Fig. 1). The $\dot{V}_{O_{2t\,1/2}}$ among subjects ranged from 36.0 to 21.6 s. Note that the $\dot{V}_{O_{2t\,1/2}}$ for subjects with the greatest $\dot{V}_{O_{2max}}$ (≥60 ml · kg^{-1} · min^{-1}) was less than 25 s. In contrast, the $\dot{V}_{O_{2t\,1/2}}$ for subjects with the lowest $\dot{V}_{O_{2max's}}$ (≤54 ml · kg^{-1} · min^{-1}) was greater than 29 s.

Discussion

The principle finding of this study was that when subjects are matched for training $\dot{V}_{O_{2max}}$ correlated significantly with $\dot{V}_{O_{2t\,1/2}}$ suggesting that the latter may be related to the level of $\dot{V}_{O_{2max}}$ itself as well as other effects of training. The exact mechanism(s) that account for the $\dot{V}_{O_{2max}}$ influence on $\dot{V}_{O_{2t\,1/2}}$ are not clear. It is likely that several factors contribute to the delay in the in-

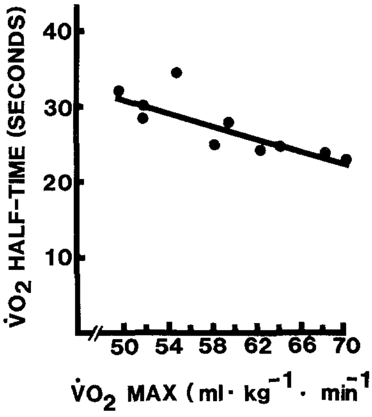

Fig. 1. Correlation between $\dot{V}_{O_{2max}}$ and the time to reach 50% of the steady sate $\dot{V}_{O_2}$ in athletes with similar training habits ($R = -0.80$; $p < 0.05$; $y = -0.544\,X + 58.96$)

crease of $\dot{V}_{O_2}$ to steady state at the onset of exercise. Those components thought to contribute include the time required for the increase in cellular levels of ADP which trigger the rise in oxidative phosphorylation in the mitochondria, the increase in blood flow to the exercising muscle and the desaturation of muscle oxymyoglobin (Astrand et al. 1960; Hickson et al. 1978; Jobsis and Duffield 1967). However, little is known about the relative contributions of the above factors to the $\dot{V}_{O_2}$ time course at the onset of work.

The present study was not designed to investigate the mechanism by which $\dot{V}_{O_{2\,max}}$ affects $\dot{V}_{O_2}$ kinetics but it seems possible that a large aerobic capacity could contribute to either a more rapid O_2 transport or a high rate of utilization. For example, individuals with a high $\dot{V}_{O_{2\,max}}$ have been shown to possess a high percentage of type I (slow twitch) muscle fibers. These fibers are known to be rich in mitochondria which could result in a more rapid adjustment of respiration to meet the energy need (Saltin et al. 1977). Although there is to our knowledge, no experimental data regarding the role of $\dot{V}_{O_{2\,max}}$ in governing the rate at which O_2 is delivered to the muscle at the onset of work, it appears possible that individual differences might result from inherent diversity in circulatory control.

The coefficient of non-determination $(1-r^2)$ reveals that 36% of the common variance between $\dot{V}_{O_{2\,max}}$ and $\dot{V}_{O_{2t\,1/2}}$ remains unexplained suggesting that other variables influence $\dot{V}_{O_2}$ kinetics at the onset of work. However, from present data alone, it is not possible to determine precisely those factors that contribute to this variance. Intuitively, it seems likely that several variables could play a role: for example, although it is clear that individuals with a high $\dot{V}_{O_{2\,max}}$ have well developed cardiorespiratory capacities, it is conceivable that those biological factors which contribute to $\dot{V}_{O_{2\,max}}$ do not represent all those genotype qualities that determine $\dot{V}_{O_{2t\,1/2}}$. Additionally, it is possible that training differences prior to the 10 weeks of group conditioning might explain some of the variance observed.

In conclusion, these data suggest that in highly trained individuals with similar training habits, those with a higher $\dot{V}_{O_{2\,max}}$ achieve a more rapid $\dot{V}_{O_2}$ adjustment at the onset of work. Given the belief that $\dot{V}_{O_{2\,max}}$ is largely determined by genotype (Klissouras 1971; Klissouras et al. 1973), these results imply that $\dot{V}_{O_{2t\,1/2}}$ is influenced, at least in part, by genetics.

References

Astrand I, Astrand PO, Christensen CH, Hedman R (1960) Myohemoglobin as an oxygen store in man. Acta Physiol Scand 48:454—460

Hagberg JM, Nagle FJ, Carlson JL (1978) Transient O_2 uptake response at the onset of exercise. J Appl Physiol 44:90—92

Hickson RC, Bomge HA, Holloszy JO (1978) Faster adjustment of O_2 uptake to the energy requirement of exercise in the trained state. J Appl Physiol 44:887—881

Hughson RL, Morrissey MA (1982) Delayed kinetics of respiratory gas exchange in the transition from prior exercise. J Appl Physiol 52:921—929

Jobsis FF, Duffield JC (1967) Oxidative and glycolytic recovery metabolism in muscle: fluorometric observations on their relative contributions. J Gen Physiol 50:1004—1047

Klissouras V (1971) Heritability of adaptive variation. J Appl Physiol 31:338—344

Klissouras V, Pirnay F, Petit J (1973) Adaptation to maximal effort: genetics and age. J Appl Physiol 35:288—293

Krogh A, Lindhard J (1913) The regulation of respiration and circulation during the initial stages of muscle work. J Physiol [Lond] 47:112—136

McMiken DF, Daniesl JT (1976) Aerobic requirements of maximal aerobic power in treadmill and track running. Med Sci Sports 8:14—17

Saltin B, Henrikson J, Nygaard E, Anderson P (1977) Fiber types and metabolic potentials of skeletal muscles in sedentary man and endurance runners. Ann NY Acad Sci 301:3—29

Welch HG, Pedersen P (1981) Measurement of metabolic rate in hyperoxia. J Appl Physiol 51:725—731

Weltman A, Katch V (1976) Minute-by-minute respiratory exchange and oxygen uptake kinetics during steady state exercise in subjects of high and low max $\dot{V}_{O_2}$. Res Qart 47:490—498

Whipp BJ, Wasserman K (1972) Oxygen uptake kinetics for various intensities of constant load work. J Appl Physiol 33:351—356

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