\( \dot{V}O_2 \) slow component and performance in endurance sports

For almost 80 years, physiological studies have attempted to explain endurance performance and to develop ways of improving it by training. Performance for a runner can be represented by the relation of his/her personal power (velocity) to time to exhaustion (time limit).  

There are particular velocities that delineate intensity domains which are determined by oxygen uptake (\( \dot{V}O_2 \)) and blood lactate response versus time. We are going to use them to define the slow phase of \( \dot{V}O_2 \) kinetics \( \dot{V}O_2 \) slow component) which only appears during intense exercise.

A high range of work can be identified at which there is a sustained increase in blood lactate and a decrease in arterial pH with time. These responses decline back towards a baseline value. Oxygen uptake increases in a monoeponential way and stabilizes at about 80% in high level marathon runners for at least an hour and a half of continuous exercise. After that time, it is possible for oxygen consumption to increase because of thermo-regulatory constraints, and this increase is called the "\( \dot{V}O_2 \) drift". This intensity of exercise corresponds to the velocity that can be sustained during a marathon and is equal to about 80% of the velocity associated with \( \dot{V}O_{2\text{MAX}} \) determined in an incremental test—that is, \( \dot{V}O_{2\text{MAX}} \). During this type of exercise both lipids and carbohydrate are used as fuel.

At a higher intensity, the maximal lactate steady state occurs when the rate of appearance of blood lactate equals the rate of its disappearance. \( \dot{V}O_2 \) stabilizes after three minutes at about 85% \( \dot{V}O_{2\text{MAX}} \). This corresponds to the highest velocity that an athlete can sustain for an hour (85% \( \dot{V}O_{2\text{MAX}} \) for a well trained endurance athlete); carbohydrate (and lactate even) is the main substrate for this exercise.

At a higher intensity, at about 90% \( \dot{V}O_{2\text{MAX}} \), the rate of appearance of blood lactate exceeds the rate of disappearance and therefore blood lactate increases. After the first monoeponential increase in \( \dot{V}O_2 \), there is a second increase after about three minutes which is defined as the \( \dot{V}O_2 \) slow component. \( \dot{V}O_2 \) reaches a delayed steady state which is higher than the \( \dot{V}O_2 \) requirement estimated from the relation between \( \dot{V}O_2 \) and moderate work rate. For instance, in this case the athlete can run at 90% \( \dot{V}O_{2\text{MAX}} \) and reaches and stabilizes at 95% \( \dot{V}O_{2\text{MAX}} \) at the sixth minute of exercise (time to exhaustion at this velocity being about 10–15 minutes). This corresponds to the so called "critical power" which is the vertical asymptote of the hyperbolic relation between power (velocity) and time. Time limit at the critical velocity is reduced to less than 30 minutes because of rapid glycogen depletion. The critical velocity is the highest velocity below its maximal level (\( \dot{V}O_{2\text{MAX}} \)) at which oxygen consumption can reach a steady state.

Above this critical velocity, during high intensity exercise, neither \( \dot{V}O_2 \) nor blood lactate can be stabilised, and both rise inexorably until fatigue ensues, at which point \( \dot{V}O_2 \) reaches its maximum value.

The initial very small component (phase 1), resulting from a sudden change in the venous return in combination with a small change in the mixed venous gas tension, is not fitted into the following equation. In fact, the parameters for the oxygen uptake kinetics were obtained from a two component exponential model in which the first component accounted for the fast component (phase 2) and the second component accounted for the slow component (phase 3). The oxygen uptake kinetics are described as a function of time by the following equation:

\( \dot{V}O_2 (t) = A_0 \) (baseline) + \( A_1 \) (1-e^{-\tau_1 t}) (fast component) + \( A_2 \) (1-e^{-\tau_2 t}) (slow component)

where \( A_0 \) is the resting baseline value, \( A_1 \) and \( A_2 \) are the amplitudes for the two components, \( \tau_1 \) and \( \tau_2 \) are the time constants for the two components, and \( TD \), and \( TD \), are the time delays from the onset of exercise for the two components.
Hence, the so called \( \dot{V}_O_2 \) slow component is the second amplitude (\( A_2 \)) of the increase in \( V_O_2 \) that appears at \( T_D \). This second amplitude represents about 10% of the first (\( A_1 \)) and depends on the absolute intensity of exercise because \( V_O_2 \) is regulated by the split of ATP and phosphocreatine.\(^{14} \) The value of the \( V_O_2 \) slow component can reach 500 ml/min and is generally considered to be significant when the value is above 200 ml/min. To avoid the use of this complicated equation which necessitates the use of software such as Sigma plot (SPSS), the \( V_O_2 \) slow component can be identified as described initially by Whipp and Wasserman\(^{15} \) by calculating the difference in \( V_O_2 \) measurements between the 6th and 3rd minute or, if the exercise is performed until exhaustion, between the third and last minute.\(^{13} \)

The appearance of this slow \( V_O_2 \) component is mainly due to the recruitment of fast fibre type II fibres with fatigue.\(^{16} \) It has been shown that type II fibres have a phosphate to oxygen ratio that is 18% lower than in type I fibres, probably because of a greater reliance on the \( \alpha \)-glycerophosphate shuttle than the malate-aspartate shuttle.\(^{17} \) Therefore more oxygen is required to produce the same level of ATP turnover and sustain a given power output. This other 15% is due to an increase in cardiac and ventilation work. Training decreases the \( V_O_2 \) slow component at the same absolute velocity, mainly because of an increase in the distribution of type I fibres and an increase in mitochondrial and capillary density.\(^{18} \) A decrease in the \( V_O_2 \) slow component can also appear for the same relative velocity (in \( \% V_O_2 \text{MAX} \)) because of an increase in the maximal lactate steady state.\(^{19} \) However, during intense exercise, the amplitude of the \( V_O_2 \) slow component is not linked to endurance at all. Moreover, it has been reported that triathletes that had a low \( V_O_2 \) slow component in running compared with cycling had the same endurance time in these two types of exercise (at 90% of the power or velocity associated with \( V_O_2 \text{MAX} \)). These triathletes also had the same maximal lactate steady state at 32% of velocity or power associated with \( V_O_2 \text{MAX} \) in running and cycling.

Endurance training decreases the \( V_O_2 \) slow component at the same velocity.\(^{20} \)\(^{21} \) Personal data on high intensity training have shown that the decrease in the \( V_O_2 \) slow component at the same absolute intensity (90% \( V_O_2 \text{MAX} \)) is not correlated with any improvement in performance (endurance time at this velocity (+ 40% of time limit)).

A more interesting fact about this \( V_O_2 \) slow component phenomenon is for training at \( V_O_2 \text{MAX} \) as it creates a broad range of exercise intensities for which \( V_O_2 \text{MAX} \) will occur, provided that the exercise is continued to the point of exhaustion.\(^{7} \)

Hence, it may be possible to describe a new relation between time spent at \( V_O_2 \text{MAX} \) (dim \( V_O_2 \text{MAX} \)) and velocity \( V_O_2 \text{MAX} \): percentage of the velocity associated with \( V_O_2 \text{MAX} \) determined in an incremental test (\( v/V_O_2 \text{MAX} \)). The relation between time to exhaustion at \( V_O_2 \text{MAX} \) and velocity follows a function that has a peak around 30\% \( V_O_2 \text{MAX} \) in well trained runners who have no or a very low value for, the \( V_O_2 \) slow component (<200 l/min). In less well trained subjects, the \( V_O_2 \) slow component means that they spend longer sustaining \( V_O_2 \text{MAX} \) at 90% \( V_O_2 \text{MAX} \) than at 100% \( V_O_2 \text{MAX} \).\(^{22} \)\(^{25} \)\(^{26} \) However, fit endurance athletes have to run at close to 40% \( V_O_2 \text{MAX} \) to elicit \( V_O_2 \text{MAX} \) because they have no \( V_O_2 \) slow component.\(^{21} \)

Therefore, in training, if the aim is to elicit \( V_O_2 \text{MAX} \), it may be useful to determine the velocity for which time spent at \( V_O_2 \text{MAX} \) is maximal.\(^{21} \) To determine at which oscilling the longest time at \( V_O_2 \text{MAX} \) is obtained during continuous exercise, the critical velocity at \( V_O_2 \text{MAX} \) can be determined using the critical power model. Instead of total time limit run, only the time run at \( V_O_2 \text{MAX} \) is plotted against the distance run at \( V_O_2 \text{MAX} \). The slope of this plot is the critical velocity at \( V_O_2 \text{MAX} \). This relation between \( V_O_2 \) time at \( V_O_2 \text{MAX} \) and velocity can be used to determine the velocity that elicits the longest time to exhaustion at \( V_O_2 \text{MAX} \).\(^{27} \) This velocity is not significantly different from \( v/V_O_2 \text{MAX} \) determined from an incremental protocol, but is significantly higher than the critical velocity classically determined using a two parameter critical power model and the total distance-time.\(^{28} \)

The existence of this \( V_O_2 \) slow component phenomenon raises the question of how athletes can adapt their training to improve performance. In fit runners, who are not at a high level (\( v/V_O_2 \text{MAX} = 19 \text{ km/h} \)), eight weeks of training at high intensity was shown to remove the \( V_O_2 \) slow component at the same absolute velocity (V Billat, A Demeule, J Slawinski and JP Koralsztein, unpublished work). This was because \( V_O_2 \text{MAX} \), increased, and at the same velocity was at a lower percentage of \( V_O_2 \text{MAX} \) than before training. The time limit at this previously high intensity training was doubled (20 – 10 minutes). At the same relative velocity to \( V_O_2 \text{MAX} \), the \( V_O_2 \) slow component was comparable with that before training, which means that this high intensity training (twice a week) has to be calibrated at least every two months in this case.

In conclusion, the \( V_O_2 \) slow component phenomenon, which was first described by Margaria et al in the sixties\(^{29} \) and then by Whipp and Wasserman in the seventies,\(^{30} \) has been widely focused on in the nineties. In the light of this, it should be possible in the next five years to use the knowledge to diversify training and to explore endurance training effects and fitness.

**VÉRONIQUE L BILLAT**

University Lille 2, Centre de médecine du sport CCAS
75010 Paris, France

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