Chapter 6

Estimating gross efficiency during and after high intensity exercise
An approach to estimating gross efficiency during high intensity exercise

Abstract

Gross efficiency (GE) is coupling power production to propulsion and is an important performance determining factor in endurance sports. Measuring GE normally requires measuring oxygen uptake ($\dot{V}O_2$) during submaximal exercise. In this study a method is proposed to estimating GE during high intensity exercise. Nineteen subjects completed a maximal incremental exercise test and two GE tests (1 experimental and 1 control test). The GE test consisted of 10 min cycling at 50% peak power output (PPO), 2 min at 25 W, followed by 4 min at 100% PPO, 1 min at 25 W, and another 10 min at 50% PPO. GE was determined for the 50% PPO sections and was, for the second 50% PPO section, back-extrapolated, using linear regression, to the end of the 100% PPO bout. Back-extrapolation of the GE data resulted in a calculated GE of 15.8 ± 1.7% at the end of the 100% PPO bout, in contrast to 18.3 ± 1.3% during the final 2 min of the first 10 min at 50% PPO. In conclusion, back-extrapolation seems valuable in providing more insight in GE during high intensity exercise.
Introduction

Understanding human performance requires understanding power production and power dissipation. Although the maximal oxygen uptake ($\dot{V}O_2^{\text{max}}$) and the oxygen uptake ($\dot{V}O_2$) at the ventilatory threshold (VT) are important, recent attention has focused on the coupling of power production to propulsion, i.e. gross efficiency (GE). Measuring GE requires measuring oxygen uptake ($\dot{V}O_2$) during submaximal exercise, at intensities below VT, and assuming that submaximal GE is representative of GE and aerobic power production ($P_{\text{aer}}$) during high intensity exercise. Increases in the cost of ventilation ($\dot{V}E$), temperature, other homeostatic disturbances, as well as changes in muscle fiber recruitment makes assuming a constant GE questionable. Passfield and Doust showed that GE was lower after moderate intensity exercise and there have been attempts to quantify efficiency during high intensity exercise.

Knowledge of GE during intense exercise makes it possible to quantify $P_{\text{aer}}$. If $P_{\text{aer}}$ is subtracted from total power output (PO), then anaerobic power output ($P_{\text{an}}$) can be calculated. Summated over the duration of a fatiguing task, the anaerobic capacity can be estimated (see Chapter 4B). Conceptually similar is the maximal accumulated oxygen deficit (MAOD), this approach is based on the PO-$\dot{V}O_2$ relationship during submaximal exercise.

A new approach to estimating GE during high intensity exercise, is to measure GE during recovery following high intensity exercise, and back-extrapolate GE values to estimate GE at the end of high intensity exercise. Therefore, the aim of this study was to measure GE prior to and during recovery following a high intensity exercise bout and to estimate GE during high intensity exercise.

Methods

Nineteen (11 men, 8 women) subjects (recreational to national level athletes in a variety of sports; none competitive cyclists) provided written informed consent. The protocol was approved by the local ethics committee. The average peak power output (PPO), the highest exercise intensity step attained during the maximal incremental exercise test, was $298 \pm 38$ W and $234 \pm 17$ W for men and women, respectively, representing $3.9 \pm 0.5$ W·kg$^{-1}$ and $3.7 \pm 0.3$ W·kg$^{-1}$.

All subjects completed a maximal incremental exercise test and on separate days, randomly ordered, two experimental tests on a cycle ergometer (Excalibur Sport, Lode Medical Technology, Groningen, The Netherlands). The experimental test started with 10
min at 50% PPO (warm-up), followed by 2 min at 25 W, a 4 min high intensity bout at 100% PPO, 1 min at 25 W, and 10 min at 50% PPO (recovery). In the control condition, exercise during the “4 min high intensity bout” was replaced by 4 min at 50% PPO. The 1 min at 25 W immediately after the 4 min at 100% PPO was included to allow \( \dot{V}O_2 \) to drop below the level at 50% PPO. Pedaling frequency was ~80 rpm. Respiratory gas exchange was measured using open circuit spirometry with 30 s data integration (AEI, Pittsburgh, PA, USA). GE was computed every 30 s from external PO and gas exchange data, only measurements with a RER \( \leq 1.0 \) were included. To estimate GE at the end of 4 min 100% PPO, a linear regression line was fitted through the GE data of the last 8 min of the 10 min recovery. The best fit line was back-extrapolated to the end of the 100% PPO bout.

**Results**

\( \dot{V}O_2 \) during the experimental trials is displayed in Figure 6.1. There was no significant difference in \( \dot{V}O_2 \) between both warm-up periods. \( \dot{V}O_2 \) during the 100% PPO bout was significantly higher than during the control 50% PPO bout, and remained elevated during the entire recovery period. Similar results were observed for heart rate (HR) and \( \dot{V}E \). GE was not significantly different between trials during the warm-up, but was significantly decreased following the 100% PPO ride versus the control 50% PPO bout. GE recovered towards control values during recovery, but was still lower after 10 min (Figure 6.1). Back-extrapolation of GE to the end of the 100% PPO ride yielded a predicted GE of 15.8 ± 1.7% vs. 18.3 ± 1.3% during the final 2 min of the first 10 min at 50% PPO. The magnitude of the decrease in GE throughout recovery was well-correlated with the higher \( \dot{V}E \) (r = 0.91).
An approach to estimating gross efficiency during high intensity exercise

Chapter 6

Figure 6.1 Mean responses during the control (solid line) and high intensity (dashed line) rides for oxygen uptake ($\dot{V}O_2$; A), heart rate (HR; B), ventilation (VE; C) and gross efficiency (GE; D). The 100% PPO work bout and control ride took place from min 12-16. GE at the end of the warm-up was 18.3%, while GE back-extrapolated to the end of the 100% PPO bout was 15.8%.

Discussion

To the degree that one is willing to accept back-extrapolation of the GE recovery curve, the results suggest that GE may be meaningfully lower during heavy exercise than previously thought. This suggests that the assumption of a constant GE during heavy exercise, (e.g. time trials)\(^6\) may be questionable. An unknown part of the decrease in calculated GE during recovery is due to an elevated $\dot{V}O_2$, caused by the anaerobic work done during the 100% PPO ride. With the described method it is not possible to discriminate between this phenomenon and the effects of fatigue on GE. However, using a 1 min period at 25 W immediately following the 100% PPO bout allowed $\dot{V}O_2$ to decrease below that during the warm-up period, which we believe allows the $\dot{V}O_2$ measured during the recovery period to be representative of the metabolic cost of riding at 50% PPO.

To illustrate the impact of a non-constant GE during a high intensity exercise bout, we computed the aerobic and anaerobic contribution based on a constant GE (18.3%), and on a variable GE (based on 18.3% at the start of exercise and 15.8% at the end of exercise), assuming that GE declines in proportionally and reciprocally with VE during the high intensity bout (Figure 6.2). Using the observed PO of the 100% PPO bout (271W), observed overall $\dot{V}O_2$, and varying GE, we calculated $P_{aer}$ during each minute of the ride.
and compared this $P_{\text{aer}}$ to $P_{\text{aer}}$ calculated assuming a constant GE (Figure 6.2). The differences in calculated $P_{\text{aer}}$ and $P_{\text{an}}$ is striking, particularly late in the ride when the variable GE is most different from the constant GE. The calculated anaerobic capacity (17.9 vs. 23.7 kJ) is 32% larger when a variable GE is assumed. In conclusion, the results of this study suggest that this new approach to estimating GE provides more insight in GE during high intensity cycling exercise and may result in better understanding of aerobic and anaerobic contributions during heavy exercise.

**Figure 6.2** The change in gross efficiency (GE) across the 4 min 100% PPO bout (A). The aerobically produced power ($P_{\text{aer}}$, represented by circles) and anaerobically produced power ($P_{\text{an}}$, represented by triangles; B) calculated on the basis of an assumed constant GE of 18.3% (solid line) vs. a variable GE (dashed line).
References
