

SELECTED METABOLIC AND
HEMODYNAMIC RESPONSES TO REPEATED
STEADY-STATE BOUTS OF INDOOR
CYCLING, UTILISING MARGINAL
INCREASES IN MECHANICAL POWER
OUTPUT: CONSIDERATIONS FOR THE
EVALUATION OF INDIVIDUAL
COMPETITIVE ROAD CYCLISTS USING A
PORTABLE ON-BICYCLE COMPUTER

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Introduction

It has been demonstrated by Sanderson, Cavanaugh et al. (1985), and the authors, (1987), that impulse and average net power distributions (W) generated about the pedal spindle and crank arms, vary with individual cyclists, either creating a mechanically desirable circular cycling pattern where the impulse is 'smoothed', or a 'butterfly' distribution indicating unequal force distribution(s) throughout each pedaling cycle.

Based on research performed indoors by Cavanaugh (1985), and Anderson (1986), and this group outdoors at the United States Cycling Federation Camp in Colorado in 1987 and 1988, it appears that techniques employed to reduce the counter-propulsive tangential crank arm forces could possibly improve average net power magnitudes produced by individual elite cyclists outdoors during competition, and thus improve their overall time(s) recorded for selected events.

Telemetric feedback of both the magnitude(s) and location of the negative force component(s) within each leg's pedaling revolution, and display of this information on a handlebar mounted devise is possible

with current technology. Appropriate technology could be designed to improve cycling techniques of individuals should continued research confirm the importance of these parameters.

Our group felt it appropriate to design a portable sprocket computer to measure the instantaneous force pattern for every second or 2ⁿth crank revolution for use both indoors and outdoors, in an attempt to modify existing cycling patterns of elite cyclists if warranted.

The main purpose of the research was to investigate the relationship(s) between mechanical power output (Watts), cardiac output (L/min), heart rate (bpm), and selected non-invasive estimates of ventilatory threshold (V.T.) in an attempt to prescribe repeated 20-30 minute tempo workouts for elite cyclists and professional triathletes.

A secondary purpose was to document and investigate anticipated heart rates, metabolic and bloodflow response pattern differences for individual cyclists between 30 minute indoor bouts of steady-state cycling versus 30 minutes of variable leg speed cycling. The latter were performed to simulate outdoor road racing where bursts of speed are required to remain with the leading pack of riders. These bouts of exercise were equivalent to ventilatory threshold interval workouts.

Initially, 35 road cyclists, including two National champions, cycled to exhaustion using a 4 gear size by 3 leg speed combination of power outputs using a continuous incremental workload $\dot{V}O_2$ with V.T. protocol designed to exhaust subjects in 6 minutes following a 5 minute steady-state warm up at leg speeds between 90 and 120 RPM. Variable gear selection was possible during the test, with the rear portion of each subject's bicycle frame attached to a momentum trainer, the Road Machine.

Blood gases were sampled every 15 seconds using a Sormedics Horizon TM Metabolic Cart programmed in the average mode using measured $F\dot{V}O_2$.

Pedal force patterns were measured with a custom-built self-contained data acquisition package. Low power microprocessor technology implemented a minimum component system. In addition to the processor circuit memory a four channel analog to digital converter and a strain gauge amplifier and sampling control circuit was used. The complete force pattern data acquisition system is contained in the crank sprocket space.

Pedal forces were measured by transducing bending moments produced in the crank arms with pairs of strain gauges installed on the

cranks. The strain gauges provide signals measuring the tangential and lateral pedal force components in each crank arm. Amplified strain gauge signals were sampled by an analog to digital converter and coded to an eight bit measurement of pedal forces. Data sampling was indexed to eight positions by the sampling index systems. Minimum power consumption was achieved by activating the processor only on an event to be sampled as keyed by the pedal position index system. Memory capacity was managed by sampling and storing every $2n^{\text{th}}$ crank rotation where 'n' was selected according to the anticipated length or duration of ride(s) indoors or outdoors.

For this part of the research, the magnitude of maximum power output (W) and duration of ride(s) to exhaustion attained by the top four performers in the group tested at preferred pedal frequencies of 110-120 RPM and power outputs of 315-460 W, and designated T4C, exceeded the power outputs earlier reported by U.S.O.C. when testing top male and female individual pursuiter.

VO_2 max. values for T4C were greater than $80 \text{ ml.kg.min}^{-1}$; some of the highest reported laboratory values for race cyclists. The mean ventilation frequency for T4C of 67.6 breaths/min. was the determining factor in attaining high VE max. values of 194-240 L/min. The ventilatory response pattern for T4C was such that during the initial 5 minute warm up phase, VE was dependent on tidal volume rather than on breath frequency. Subsequently, when both leg speed and gear size were increased simultaneously, this situation reversed, increased in VE becoming frequency dependent. The highest positive correlations between VE and f occurring at power outputs of 315-460 Watts ($r = .86/.91/.88$).

At power outputs of 315-460 W, T4C subjects obtained consistently higher percentage increments in V.E. and H.R. which were matched by similar ml.kg.min^{-1} increments in VO_2 . T4C values for non-invasive estimates of V.T. were consistently high. Less consistency was observed for gas exchange estimates of VO_2 max. The greatest number of significantly high positive zero-order correlations greater than .94 occurred at 460 Watts, with the greatest number of significantly high positive correlations for T4C occurring at power outputs of 315-460 Watts. At 460 Watts the relationships between VE, f, O_2 VE, CO_2 VE, VO_2 (ml.kg.min^{-1}), and heart rate, appeared optimal for T4C.

Subsequently, one member of the United States Junior World's Road Cycling Team, performed two 30 minute indoor rides using the same equipment earlier mentioned plus an exercise doppler.

Continuous non-invasive measurement of bloodflow during rest (pre-warm up, seated on the bicycle), and exercise was obtained.

The continuous wave doppler (Quinton Exerdop) was used to obtain peak accelerations (m/s^2) and velocities (m/s) of blood ejected into a varying diameter aorta, and cardiac output (L/min), stroke volume (% increase above resting value(s); end-diastolic volume, peak flow (L/min), ejection fraction(s) (EDV - ESV), heart rate (bpm), and systolic time ratios (peak ejection time/ventricular ejection time all measurements of ventricular function) were recorded using a BoMed NCCOM3-R7 thoracic electrical impedance (TEP) monitor. Changes in the electrical conductivity of the thorax due to the pulsatile flow of blood through the segment, provided a basis for the TEB technology. Ejection fraction is calculated from the measurement of systolic time intervals (STIs) derived from ECG and TEP waveforms.

Results

An eight inch increase in gear size (89"/81" steady state ride - 'SSR') combined with an increase in average leg speed of 14=18 RPM (110-114 vs 96 RPM attained during 2 minute 'bursts', produced noticeable differences in the following parameters.

A. Mechanical power output - 311W for bursting ride vs 220 W for SSR. For the 89 inch gear, the mean power output (W) generated during the 2 minute burst activity exceeded that value produced during the 4 minute steady state bouts by 50 percent/101 W for an average increase in leg speed of 10% (95-105 RPM). Maximum power generated during the final burst activity was 420 Watts, equivalent to a 114 RPM/3.7 kp. friction-braked ergometer force-velocity combination.

B. Metabolic Cost - Significant increases occurred in favor of the 89 inch gear in:

1. VO_2 as a percentage of maximum = 67% max (53 mls/kg-min) during 4 minute periods, and 73% max. (58 mls/kg-min during 2 minute bursts, versus 40-48 mls/kg-min (50-50% max) for the 81 inch gear. VE was considerably higher for the burst activity run, reaching an average of 97 L/min for the 4 minute periods and 115 L/min during the 2 minute bursts, compared with an average value of 55-77 L/min for the steady state 81 inch gear ride.

2. Heart Rate (bpm) — Average rate for the 81 inch gear was 166, and 179 for the 89 inch bursting run. Maximum heart rates differed considerably; 203 for the 89 inch gear and 173 for the 81

inch gear. Significantly, the average rate attained for the 2 minute bursting activity was 193 RPM, equivalent to 93% of maximum.

3. Bloodflow response — Significant increases in cardiac output occurred above resting on-bicycle levels for both gear sizes (43 L/min vs 4-6 L/min for burst activity, and 23 vs 2.8 L/min for 81 inch gear). During the burst activity, stroke volume increased by 140% above resting level; end-diastolic volume increased by 200%, and the ejection fraction increased by an average of 14-16% above resting level. For the 89 inch gear, during 4 minute exercise bouts the average cardiac output was 6-11 L/min, but this increased to an average value of 32-43 L/min during the 2 minute bursts, an average of 4-5 times resting value.

Conclusions

Within the limitations of the study an 8 inch increase in gear size, and a 14+18 RPM burst-induced average increase in average leg speed resulted in 50% increase in average net power production (W), and induced significant increases in heart rate, ventilation rate (breaths/min) respiratory minute volume (L/min), cardiac output (L/min above resting value), percent utilization of $\dot{V}O_2$ max, and blood lactate (6.6 mMols 5 min post exercise 89 inch gear).

In terms of force production, the portable indoor-outdoor computer designed by members of the group, adequately highlighted individual left and right leg contributions to the total power output and the variations in velocity-dependant force for each leg separately produced at various power outputs.

The data gathered supports the premise that subtle changes in leg speed matched with variable gear selection has considerable effect on the heart rate, cardiac output, ventilatory, and lactate response patterns. If we are to improve individual time(s) for given differences requiring cardiovascular conditioning, to changes in mechanical power output/leg speed/gear size optimal pairings.

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