THE INFLUENCE OF GRADED EXERCISE TEST SELECTION ON PMAX AND A SUBSEQUENT SINGLE INTERVAL BOUT

JEREMIAH J. PEIFFER¹, ROBERTO QUINTANA¹, DARYL L. PARKER¹

¹California State University-Sacramento, Sacramento, CA 95819

ABSTRACT

Peiffer JJ, Quintana R, Parker DL. The Influence of Graded Exercise Test Selection on Pmax and a Subsequent Single Interval Bout. JEPonline 2005;8(6):10-17. Due to the inconsistency in GXT protocols in cycling research, it is necessary to examine the affect of GXT selection on the determination of Pmax and subsequent affects on the time needed to achieve VO₂max. Subjects consisted of 8 trained male cyclists (age: 26 ± 7 yrs, height: 179.1 ± 8.2 cm, weight: 74.4 ± 5.0 kg, VO₂max: 63.3 ± 6.5 ml/kg/min) who completed two GXTs. Both tests started at 70 Watts with one increasing 35 Watts/min until volitional fatigue, and the other increasing 50 Watts/3min until volitional fatigue. Pmax was recorded as the lowest power output that coincided with the initial plateau in VO₂max, defined as a change of no more than ±2 ml/kg/min from a previous recording. Peak aerobic power (Paerobic) was also determined. Subjects then completed two endurance tests at different Pmax values. During the endurance test, time to achieve VO₂max (Tmax), total duration, and the total amount of work were recorded. Pmax as well as Paerobic were significantly lower during the 3 min stage duration GXT (387 ± 27 vs. 342 ± 25 Watts), (424 ± 29 vs. 368 ± 28 Watts)(p<0.05). The percent of Tmax needed to elicit VO₂max was not significantly different between endurance tests (61.80 ± 7.00 vs. 62.10 ± 10.50 %). Total work performed was significantly lower when using Pmax values from the 1 min stage duration GXT (5614.95 ± 1509.48 vs. 9625.57 ± 2244.05 kg/m/min)(p<0.05). GXT protocol had a significant influence over the determination of Pmax and Paerobic. Increases in Pmax lead to substantially lower total interval times. Either GXT produced Pmax values that elicit VO₂max in 60 % of Tmax.

Key Words: Cycling, Training, Power, Work, Endurance
INTRODUCTION

Over the last five years power training within cycling has become increasingly prevalent. With the advent of the SRM (Schoberer Rad meBtechnik, Germany) and Power Tap (Saris/Cycleops Madison WI, USA) power monitoring systems, cyclists are now able to train in ways that once could only be done in a laboratory setting. With power training becoming more available to general cyclists, research in this area has gained momentum. Several researchers have made progress in the area of the most effective method of power training, with high intensity interval training taking center stage as the method of choice (1-4).

Recent evidence suggests that high intensity interval training done at the lowest power output to elicit VO\textsubscript{2}max (Pmax) may be a superior method when the desired effect is an increase in VO\textsubscript{2}max, peak power, and time trial performance (5). Laursen et al. (5) used a system of Pmax training that produced an 8.1% improvement in VO\textsubscript{2}max, a 6.2% improvement in peak power, and a 5.8% improvement in time trial performance in a group of highly trained cyclists. This system of interval training was based on the work of Billat et al. (6) in runners, in which subjects work at the lowest speed to elicit VO\textsubscript{2}max (Vmax), for a calculated amount of time, usually 60% of the total time their runners were able to maintain Vmax (Tmax) (6). Laursen et al. (7) demonstrated that in a group of highly trained cyclists, 74% of Tmax was the appropriate time duration needed to elicit VO\textsubscript{2}max, thus intervals done at Pmax for 74% Tmax should be sufficient to elicit VO\textsubscript{2}max and ultimately the desired training effect in cyclists.

However Bishop et al. (8) showed that in a group of untrained females while cycling, differences in graded exercise test protocols resulted in significantly different peak aerobic power. These findings were later validated in a group of 15 male cyclists performing multiple graded exercise tests using both a one and three minute stage duration protocol. Peak power output was significantly lower in the three minute stage duration test (9). Laursen et al. (5) used a graded exercise test utilizing 15 Watt/30sec increases in power to find Pmax during their study. If differences in peak aerobic power exist with different graded exercise test protocols, it may be inferred that different graded exercise test protocols also produce differences in Pmax. While Laursen et al. (7) demonstrated that 74% of Tmax was appropriate time duration to elicit VO\textsubscript{2}max while working at Pmax from a 30 second stage duration protocol, this may not be the case with a Pmax from an alternative protocol, if in fact Pmax is not consistent.

Therefore, this study was performed to first determine if different graded exercise test protocols produce differences in peak aerobic power and Pmax of trained cyclists. Second, if Pmax is in fact different it may be possible that 60% of Tmax is not the correct duration needed to elicit VO\textsubscript{2}max during a single interval session. Finally, if different graded exercise test protocols produce differences in Pmax, and ultimately difference in time needed to elicit VO\textsubscript{2}max, then it may be possible to achieve VO\textsubscript{2}max while performing less work under one protocol versus another.

METHODS

Subjects

All subjects participating in this study were trained male cyclists (age: 26 ± 7 yrs, height: 179.1 ± 8.2 cm, weight: 74.4 ± 5.0 kg, VO\textsubscript{2}max: 63.3 ± 6.5 ml/kg/min). All subjects had been active in organized racing for at least one year. Subjects were informed both in written and verbal statements of all procedures necessary to complete 2 graded exercise tests and 2 endurance trials. Subjects were also given written documentation of potential risks involved with their participation in this study.
committee for protection of human subjects approved the methods of this investigation prior to the beginning of this investigation.

**Equipment**
During each graded exercise testing session as well as each endurance trial, VO$_2$ data was recorded via an open air gas collection system (Parvo Metabolic Cart UT, USA). Subjects were fitted with a one-way breathing valve (Hans Rudolph), attached to large bore tubing. Exhaled gases were passed through a heated pneumotach, and a gas analyzer to measure CO$_2$ and O$_2$ concentrations. Prior to testing the pneumotach was calibrated for flow rate using a 3 L calibration syringe (Hans Rudoluf) at a range of flow rates. Gas analyzers were calibrated using a medical gas of known concentration (16 % O$_2$ and 4 % CO$_2$).

All testing was completed using an electronically braked cycle ergometer (Lode Excalibur, Netherlands). For both graded exercise tests, as well as both endurance trials, power output was independent of the subject’s cadence. Cycle ergometer calibration was automatically completed within the ergometer via the company’s internal software to meet manufacture’s expectation. Prior to testing, the cycle ergometer was adjusted to mimic each rider’s own bicycle.

**Procedures**

**Graded Exercise Test Procedure**
Prior to participation in each graded exercise test, subjects were instructed to perform a standard warm up to eliminate any differences in test data due to differences in warm up time. Each warm up consisted of three 5 min intervals at 100, 150, and 200 Watts. Subjects were then given up to 5 minutes between the warm up and graded exercise test to stretch or relax. During this time subjects were allowed to drink fluids at their own discretion.

Each subject was required to complete two different graded exercise tests. The first using an adapted protocol similar to Lucia et al. (10) starting at 70 Watts, utilizing one minute stages with increases in power of 35 Watts/min. The second test began with a power output of 70 Watts, and utilized three minute stages, with power increasing by 50 Watts/3min, as adapted from research by Arts et al. (11). For each test, the subject’s VO$_2$max was determined using guidelines set fourth by Laursen et al. (5). Subjects were required to produce a plateau in VO$_2$ or drop of no more than 2 ml/kg/min, reach 90 % of their age predicted heart rate max, and produce a respiratory exchange ratio greater than 1.10. In the event that a subject was unable to reach their VO$_2$max, that subject was re-tested with at least one day between tests.

Peak aerobic power output (Paerobic) was determined as the highest power recorded during the graded exercise tests and was determined according to the equation; $\text{Paerobic} = W_{com} + (t/t\text{stage} \times W)$ where $W_{com}$ represents the highest wattage output that the subject was able to maintain for a complete stage, $t$ is the amount of seconds into the unfinished stage, $t_{\text{stage}}$ is the stage duration, and $W$ is the wattage increase during the unfinished stage (12). Pmax was determined as the lowest power output that resulted in a plateau in VO$_2$max with a change of no more than 2 ml/kg/min (1). Pmax was recorded as the highest completed stage, plus the fraction of time needed to produce the plateau in VO$_2$max. During each graded exercise test the subjects were required to remain seated. Subjects were not allowed to stand and pedal at any time during the tests. With each test being easily distinguishable from one another, the two graded exercise tests were randomized by flipping a coin in order to eliminate order of test affects on power outputs (13).

**Endurance Protocol**
Subjects reported to the laboratory on two separate occasions and were given a standard 10 min warm up at 70% of the subject’s Pmax from the corresponding graded exercise test. This warm up was consistent with the warm up used by Billat et al. (6), to ensure that subjects received identical
warm up prior to each endurance trial. Upon the completion of the standardized warm up, subjects were given one minute of unloaded pedalling before the start of each endurance trial. During this time subjects were fitted for gas collection.

The protocol for each subject was similar to that used by Billat et al. (6). Each endurance trial started with the subject pedalling against a zero resistance. Resistance was increased, every five seconds, by 16.6% of the subject’s Pmax. After 25 s of resistance increases all subjects were at a resistance equal to the Pmax from each corresponding graded exercise test.

The point at which subjects reach their Pmax was deemed time zero. From this point a stopwatch was started and time was recorded. The total time that each subject was able to sustain each different Pmax was determined as the Tmax for that Pmax. During this time subjects were not allowed to stand up on the ergometer, in order to more accurately depict a typical interval session on the subject’s own bicycle. Time was stopped when the subject was no longer able to maintain at least 40 rpm. During each endurance trial expired gas was collected, and the time point during the endurance trial of the highest plateau in VO$_2$ within 2 ml/kg/min from the corresponding VO$_2$max test was recorded as a percentage of Tmax.

**Statistical Analyses**

All data obtained was interpreted using Statistica data analysis software. Differences in peak aerobic power and Pmax between 1 min versus 3 min stage graded exercise tests were determined using an ANOVA. Differences in Tmax, total work, as well as differences in percent time to achieve VO$_2$max were evaluated using the pairwise t-test. All descriptive data was expressed as means ± standard deviations. Results were considered significant when p was ≤ 0.05.

**RESULTS**

*Graded Exercise Test Data*

Paerobic and Pmax both showed significant differences during the two graded exercise tests. Peak aerobic power was significantly higher during the one minute graded exercise test protocol (Paerobic$_1$) versus that during the 3 min stage duration graded exercise test protocol (Paerobic$_3$) (424 ± 29 versus 368 ± 28 Watts) (p<0.05). Pmax was also found to be significantly higher during the 1 min protocol (Pmax$_1$) versus the 3 min protocol (Pmax$_3$) (387 ± 27 versus 342 ± 25 Watts) (p< .05) (Figure 1).

%Tmax Needed To Reach VO$_2$max

Although changes in graded exercise test protocol did elicit differences in Pmax values, these changes did not result in significant differences in the percent of time needed to obtain VO$_2$max while working at each distinct Pmax (Table 1).

**Work**

The amount of work completed utilizing the Pmax$_1$ power (Work$_1$) was significantly lower than the work done when utilizing the Pmax$_3$ power (Work$_3$) (5614.95 ± 1509.48 vs. 9625.57 ± 2244.05 kg/m/min) (Figure 2).
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Figure 1. Graded exercise test data. * Significant difference between 1 versus 3 min graded exercise tests (p ≤ 0.05).

Figure 2. Work completed during endurance tests. * Significant difference from Pmax 1, p ≤ 0.05.

DISCUSSION

The difference in Paerobic produced from the one minute stage duration graded exercise test protocol versus the three minute stage duration protocol (56 Watts) supports finding of Bishop et al (8) who showed while using a group of untrained women a significantly different Paerobic (56.5 Watts) when utilizing two different graded exercise test protocols. Also, these finding help validate those of Ammen et al (9) who found a significant difference (49 Watts) in Paerobic between a one versus three minute stage duration graded exercise tests in trained males. This study as well as those by Ammen et al. (9), and Bishop et al. (8) lead to increasing the understanding of differences in
peak aerobic power that can occur as the result of the utilization of different graded exercise test protocols over a broad range of populations.

Differences in Paerobic need to be taken into account in cycling research. Often researchers compare athletes based on physiological data. For example, Padilla et al. (14) tested "professional cyclists" and found average VO\textsubscript{2}max values of 5.36 ± .47 L/min and average Paerobic values of 431 ± 42.6 Watts, while using a protocol with four minute stages. However, Lucia et al. (15) while also examining "professional cyclists" found their average VO\textsubscript{2}max to be 5.2 ± 0.2 L/min with average Paerobic values of 521 ± 21.5 Watts while using a graded exercise test with one minute stages. These two studies further support our findings and demonstrate how differences in protocol can lead to inaccurate interpretation of subject data. In this instance both studies utilized "professional cyclists", however our data suggests that it was the protocol used and not differences in athletes that produced conflicting Paerobic powers.

Further problems can arise if graded exercise test data is used in pacing strategies. Past research from our laboratory suggests that individuals are capable of maintaining 70% of their Paerobic from a one minute stage duration graded exercise test for at least the duration of a 20 km time trial (Unpublished observation). If however one were to use 70% of Paerobic from a three minute stage duration test to pace themselves, this power would be much lower than that person is be capable of maintaining and would lead to a sub-optimal performance in a 20 km time trial.

The second power related finding of this study was the significantly higher Pmax value when comparing those from a 1 min versus 3 min stage duration graded exercise test (Figure 1). Pmax has been used as an exercise intensity because of the ability to reach VO\textsubscript{2}max while at this power (1,16). It is assumed that Pmax is a power output above VT\textsubscript{2} in which the slow component of VO\textsubscript{2} inevitably pushes oxygen consumption to maximal levels (17).

As observed from this study, as graded exercise test stage duration increased there was a decrease in Pmax. It could be possible that with a stage duration of four minutes as has been used Padilla et al. (14) there could be a false plateau in VO\textsubscript{2}max and thus the interpretation of Pmax would be less than actual. In these instances the termination of the graded exercise test could produce Pmax values sub-VT\textsubscript{2}. Although the VO\textsubscript{2} slow component would have an affect on oxygen consumption at these power outputs this would not lead to maximal values. Instead, exercise at these power outputs would lead to submaximal plateaus in VO\textsubscript{2} (17). For interval training reliant on the obtainment of maximal oxygen consumption these power outputs would be suboptimal and could possibly limit the training effect.

Results from this study indicate that the utilization of 60% Tmax while working at Pmax is the correct time frame needed to elicit VO\textsubscript{2}max, regardless of whether Pmax was recorded from a one or three minute stage duration graded exercise test (Table 1). This data contradicts that of Laursen et al. (7) in which 43 well trained cyclists completed Pmax intervals done at Pmax values acquired from half minute stage duration graded exercise tests. They observed that most athletes reach VO\textsubscript{2}max no sooner than 74% of Tmax. Our data suggests that 60% of Tmax is an appropriate duration to reach VO\textsubscript{2}max while using either a Pmax from a one or 3 min stage duration graded exercise test. However Laursen et al. (7) did suggest that 95% of VO\textsubscript{2}max could be reach in 60% of Tmax, which was also observed by early research on runners exploring the VO\textsubscript{2} kinetic during work done at Vmax (18).

Laursen et al. (7) suggests that although his subjects were unable to reach VO\textsubscript{2}max at 60% of Tmax that this time duration would still be acceptable for performing intervals with VO\textsubscript{2}max as the desired
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Although the primary interval done at Pmax for 60% of Tmax may not end in the obtainment of VO$_2$max, subsequent intervals would most likely reach VO$_2$max (10,19). However, our study suggests that 60% of Tmax may be adequate enough to have all intervals done with VO$_2$max as the end effect would lead to interval sessions with longer accumulative times spent at VO$_2$max thus increasing the desired outcome of those intervals. The sample size of this study was relatively small, 8 subjects, and future expanded research may be needed to determine the cause of differences in the percent of Tmax needed to reach VO$_2$max between our study and that of Laursen et al (7).

Finally, our study was the first of its kind to demonstrate that changes in Pmax affect the amount of work needed to reach VO$_2$max during an interval session (Figure 2). When working to 60% of Tmax, intervals done at Pmax$_1$ required 42% less total work than those at Pmax$_3$. This difference in total work completed could be of great significance during a cyclist’s normal training routine. Within a normal training regime, volume of training is the major factor leading to “over reaching” and ultimately “over training” (20). Therefore, the ability to perform Pmax interval training at the higher Pmax$_1$ could decrease the risk of “over reaching” or “over training” and allow cyclists to obtain the desired effect of interval training without the large volume of training.

CONCLUSIONS

Graded exercise test protocol selection should be examined when the desired outcome is to obtain power related data. Although changes between a one versus 3 min stage duration graded exercise test showed no changes in VO$_2$max, Paerobic power as well as Pmax were markedly lower while using the longer test. This difference could affect not only the characterization of cyclists, but it may also have negative impacts on both training and performance.

Although Pmax was found to be affected by protocol selection it seems that intervals done with the intention of reaching VO$_2$max can still be accomplished using Pmax, from the longer graded exercise test. While the lower Pmax values did lead to increases in total time that a cyclists was able to maintain this power. It seems that a set ratio, 60%, is still an appropriate duration to lead to the obtainment of VO$_2$max during these types of intervals, regardless of the Pmax used.

Finally, for any cyclists the fear of “over reaching” or “over training” is real. Unfortunately cyclists need to maintain large volumes of training for a large portion of the year to remain competitive throughout a season. However, it is volume that may in fact lead to “over reaching” or “over training”. Therefore the necessity to complete high intensity intervals with as little volume as possible is important. This study suggests that intervals done at Pmax values from a 1 min stage duration grade exercise test will give a cyclist the chance to receive the benefits from this type of training without the volume that would be associated with lower Pmax values from a longer graded exercise test.

Address for correspondence: Jeremiah Peiffer: School of Exercise Biomedical and Health Science. Edith Cowan University: Joondalup Campus, 100 Joondalup Drive, Joondalup, Western Australia. Phone: 61 8 6 304 5097. Fax: 61 8 6 304 2805. Email: jpeiffer@student.ecu.edu.au

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