

## Does the Friel Anaerobic Threshold Test Accurately Detect Heart Rate Deflection in Trained Cyclists?

WILLIE K YUEN†<sup>1</sup>, SHAD R. SCHREINER†<sup>1</sup>, DONALD L. HOOVER‡<sup>2</sup>, JANICE K. LOUDON‡<sup>1</sup>, and SANDRA A. BILLINGER‡<sup>1</sup>

<sup>1</sup>Georgia Holland Research Laboratory, Department of Physical Therapy Education and Rehabilitation Science, University of Kansas Medical Center, Kansas City, KS, USA

<sup>2</sup>Department of Physical Therapy Education, Rockhurst University, Kansas City, MO, USA

‡Denotes professional author, †Denotes graduate student author

---

### ABSTRACT

*Int J Exerc Sci 4(3) : 164-175, 2011.* The Friel Anaerobic Threshold Test (FATT) has been used to determine anaerobic threshold (AT). The FATT suggests AT occurs near the heart rate deflection point (HRDP) at a rating of perceived exertion (RPE) of 17. Purpose: The primary purpose of this study was to determine 1) whether the HRDP could be determined using the FATT, 2) examine differences between HRVT and HR that coincided Borg's rating of perceived exertion (RPE) of 17, and 3) if riding position (hoods or aero) would influence performance. Methods: Fourteen male cyclists ( $30.4 \pm 7.41$  years of age;  $151.8 \pm 60.4$  cycled miles/week) participated in the study. Each subject performed the FATT on two occasions within one week. Results: The findings of this study suggest that the FATT can determine HRDP in trained cyclists while riding in the hoods position but not the aero position. No significant difference was found between the hoods and aero position for HRVT as measured by the metabolic cart. Our data suggest that HR at an RPE of 15 more accurately reflects the HRVT than the RPE of 17. A low, non-significant correlation was found for both the hoods and aero (0.41 and 0.44, respectively;  $p > 0.20$ ) for the HR at RPE of 17. Conclusion: The findings of this study suggest that the FATT can determine HRDP in trained cyclists. However, HRDP was identified in the cyclists preferred riding position. When performing the FATT, HRVT at an RPE of 15 should be used to estimate VT over the suggested RPE of 17.

**KEY WORDS:** Computrainer™, lactate threshold, tempo training, maximal steady state, anaerobic capacity

### INTRODUCTION

Anaerobic threshold (AT) is defined as an "intensity of exercise, involving a large muscle mass, above which measurement of oxygen uptake cannot account for all of the

required energy" (39) and is an important physiological characteristic in most sports. This is because, all other things being equal, a higher AT allows an athlete to maintain a faster pace or speed over longer distances or periods of time. In addition, coaches and

## FRIEL ANAEROBIC THRESHOLD TEST

athletes often have great interest in determining AT for training purposes during the season. If an individual determines his AT, this can guide training intensities throughout the season. For example, engaging in exercise at or below his AT can be considered a “moderate intensity” whereas exceeding the AT threshold would be equated to training at intense levels (39). Finally, AT may be improved through specific training regimens (30). Therefore, accurately assessing AT consequently holds the interest of coaches and athletes interested in integrating scientific evidence into their training and periodization models (13).

AT may be assessed using a wide variety of laboratory methods, including such measures as ventilatory threshold (VT), heart rate deflection point (HRDP), and onset of blood lactate accumulation (4, 6, 8, 18, 33). At submaximal exercise intensities, there is a linear relationship between work intensities and HR. However, at higher intensities, the HR can deflect or rise above the linear response which is termed HRDP (41). During exercise, an increase in workload results in a concomitant increase in ventilation. Further, VT is defined as the point during an incremental exercise test at which there is an increase in “ventilation disproportional to the increase in workload” (39). VT can be determined by a non-invasive method of gas analysis using a metabolic cart. If the HR at VT is similar to the HRDP, then these measures could be used interchangeably between field and clinical laboratory tests to identify AT.

Most coaches and athletes lack access to regular laboratory testing to acquire VT or onset blood lactate accumulation values, leaving many of them to rely upon field

tests of AT using HRDP. Field tests for AT are estimated in order to 1) assess the transition point from aerobic metabolism to primarily anaerobic metabolism and then to 2) integrate this physiological concept into training models. A number of authors, including Conconi (11, 12), Sleamaker (38), and Friel (21) have proposed AT field tests for general assessment of endurance activities but most specifically for cycling. Nearly all such AT field tests are based upon the linear relationship which exists between heart rate (HR) and workload at submaximal exercise intensities (36). While the AT testing protocol proposed by Conconi has received considerable attention in the scientific literature (4, 6, 9, 25, 35, 37) many of these other AT field tests have not undergone validation testing in which the given AT protocol is compared against commonly accepted laboratory methods.

A review of the literature within the area of exercise and sport science resulted in no scientific studies assessing the effectiveness of Friel’s anaerobic threshold test (FATT), which has been described in a number of non-scientific lay publications (19-23).<sup>1</sup> This field test involves completing a time trial on the Computrainer™ as a means of determining the cycling speed at which HRDP occurs. If no HRDP is evident upon graphing, Friel suggests using the speed which corresponds to an RPE of 16 or 17 for determination of AT. The FATT protocol is easily completed using instrumentation available to many cyclists and triathletes, thus a validation study of this protocol might prove valuable for the many coaches and athletes who lack access to regular laboratory testing.

Similarly, some scientific evidence suggests that riding position influences riding efficiency (2, 14, 28, 42), which may plausibly influence the transition point between primarily aerobic to primarily anaerobic metabolism during high intensity cycling. Integrating this issue in a study may also prove valuable for coaches and athletes, particularly as it relates to the different riding positions many cyclists and triathletes use to train and compete.

This study had three specific aims. The primary purpose of this study was to determine whether the HRDP could be determined using the FATT. It was hypothesized that during the FATT there would be a strong relationship ( $r > 0.80$ ) between 1) HRDP and 2) HR at ventilatory threshold (HRVT) as assessed and determined by the metabolic cart. Since the HRDP isn't always detectable by graphing, our second aim was to test for differences between HRVT and HR at the speed that coincided with Borg's rating of perceived exertion (RPE) of 17, as suggested by Friel. We hypothesized that HRVT would be significantly lower than the HR at an RPE of 17. The third aim was to determine if the cyclist's riding position (hoods or aero) would influence either 1) performance on the FATT or 2) perceived effort during testing as measured by RPE. We hypothesized that participants would 1) have a higher HRVT in the aero position than in the hoods cycling position and 2) report greater perceived effort in aero position than in the hoods cycling position. We speculated that in an unfamiliar riding position such as aero, the participants would work harder and therefore perceived exertion would be higher at the given workload.

## METHODS

### *Participants*

Fourteen trained amateur cyclists (age:  $30.4 \pm 7.41$  yr, weight:  $79.3 \pm 9.1$  kg, average mileage:  $151.8 \pm 60.4$  miles per week) were recruited from cycling teams around the Kansas City metropolitan area. The cyclists rode throughout the year, and all participated regularly in amateur cycling competitions on the regional level. Data collection was performed at the Georgia Holland REACH (Research in Exercise and Cardiovascular Health) Laboratory at the University of Kansas Medical Center. Participants were asked to refrain from caffeinated beverages or eating within two hours prior to the testing sessions. The research project received approval from the Human Subjects Committee. In addition, institutionally approved informed consent was obtained in writing before participation in the study.

Each participant came to the laboratory on two separate occasions, bringing his own road bike and clipless cycling shoes for the testing sessions. During the first visit to the laboratory, participants completed a Health Status Questionnaire and a Physical Activity Readiness Questionnaire (PAR-Q). All participants denied cardiovascular disease, neuromuscular impairments, pulmonary disease or impairments that would affect performance on their cycling tests. Prior to the FATT, anthropometric and resting physiological measures (i.e., blood pressure, heart rate) were taken.

### *Protocol*

The study was a within subject design to examine the HRVT and HDP during a maximal effort exercise test. We used two cycling positions (hoods and aero) on two different days. The exercise test was terminated at volitional fatigue or when the

## FRIEL ANAEROBIC THRESHOLD TEST

exercise testing criteria were reached (1). Variables of interest for this study were heart rate, oxygen uptake, RPE, and speed.

All participants completed the FATT to maximal effort on two separate occasions using either the 1) "hoods" or 2) aero position. The order of the conditions was randomized. Prior to the trial for the aero position, the participants' bikes were fitted with a set of adjustable clip-on aero bars (Deda Elementi SLR, Campagnola Cremasca, Italy). The aero position was standardized across participants by aligning the clip-on bars parallel to the ground and aligning the fore/aft position. The participants' acromion process was positioned directly above the olecranon process. No changes were made to the participant's bike fit or positioning for the hoods condition. In addition, the rear tire pressure was standardized for all participants by inflating the rear tire on the respective bike to the maximum recommended pressure (kPA) listed on its sidewall. Both testing conditions were completed within 5 to 7 days for each participant and were controlled for time of day.

### *FATT.*

Once the bike was set-up, the participants completed a 10 minute warm up at 100 W on their bicycles attached to the CompuTrainer™ Lab Pro 3D (Racermate, Seattle, WA), which set the work rate. The CompuTrainer™ is valid and reliable for use as an electronically-braked ergometer (15, 17), and has been used in previous research studies (10, 27). The CompuTrainer™ was calibrated per manufacturer instructions prior to each cycling protocol.

After the warm-up session, each participant was instructed to pick a gear ratio to use throughout the entire exercise test as described in the FATT protocol. Participants used a gear ratio set-up comprised of a 53-tooth on the front chain ring and 13-16 on the rear one. As a way of standardizing the riding conditions, the participants used the identical gear ratio set-up for both riding conditions.

The ParvoMedics TrueOne® 2400 open circuit spirometry system (Parvo Medics, Sandy, UT) was used for collection and analyses of expired gases continuously using a 2-way rebreathing valve (Hans Rudolph, Kansas City, MO) and a nose-clip. The sampling technique was a 15-second averaging of the data. Prior to testing, the ParvoMedics metabolic cart was calibrated according to the manufacturer's directions. Heart rate was monitored continuously during the FATT using the Polar Vantage XL heart rate monitor (Polar Electro, Kemple, Finland). Borg's Rate of Perceived Exertion (5) was recorded at the end of each one-minute stage.

Each participant completed the FATT using the protocol as described by Friel (21). Briefly, participants were instructed to start the test at 16 mph. Every minute, participants were cued to increase speed by 0.5 mph, increasing solely through an increase in pedaling cadence. Participants were instructed to remain seated throughout the trial. During each data collection session, one member of the research team monitored the participant's velocity to ensure that he followed the protocol as described, and another member of the research team monitored the participant's physiologic performance. Testing was terminated at the point in

## FRIEL ANAEROBIC THRESHOLD TEST

which the criteria described by Friel were met (19-23), the participant was unable to maintain or increase speed as dictated by the protocol, or by voluntary termination of the test. Upon completion of the exercise test, the participant was instructed to complete an active cool-down, continuing to pedal at a self-selected pace and resistance for a 10 minute period.

### *Determination of HRDP and VT.*

The HRDP was determined by the methods described by Friel (21). Briefly, the participant's average speed at the each time interval was cubed and then plotted on the X-axis and HR was plotted on the Y-axis. An automated detection of VT (using the V-slope method) was performed using predetermined equations embedded into the ParvoMedics metabolic cart software. HR and oxygen uptake at VT were recorded and used for statistical analysis.

### *Statistical Analysis*

Windows Excel (Windows, Microsoft, Inc., Redmond, WA) and SPSS 17.0 (SPSS, Inc., Chicago, IL) were used for data collection and statistical procedures. Paired t-tests were conducted to determine within group differences for the variables of interest in the hoods and aero position. The FATT uses an RPE of 17 to determine the HRDP for training. Therefore, Pearson product correlation coefficient was used to assess the relationship between 1) HR at VT and 2) HR at RPE of 17. Statistical significance was set a priori at  $p \leq 0.05$  for all analyses.

## RESULTS

All fourteen individuals enrolled in the study completed both cycling exercise tests. No significant differences were found for the physiologic data at maximal effort

between the "hoods" and "aero" cycling positions (Table 1). In addition, no significant differences were found at VT as measured by the metabolic measurement system between the positions for HR (hoods:  $150.1 \pm 12.8$  bpm vs. aero:  $153.3 \pm 10.7$  bpm;  $p = 0.20$ ) or oxygen uptake (hoods:  $3.0 \pm 0.40$  L \* min<sup>-1</sup> vs. aero:  $3.1 \pm 0.33$  L \* min<sup>-1</sup>;  $p = 0.50$ ).

### *FATT and HRDP and VT.*

The HRDP was visibly discernible for the hoods riding condition (Figure 1) but not for the aero riding condition (Figure 2). Assessing solely the hoods cycling position, a significant difference was found between mean HRDP and HRVT ( $161.8 \pm 12.9$  vs.  $150.1 \pm 12.9$  bpm;  $p = 0.008$ , respectively). Further, assessing the hoods position, HRDP had a weak, non-significant relationship with HRVT ( $r = 0.39$ ,  $p = 0.17$ ).

Table 1. Participant Demographics and Physiologic Performance Variables at Maximal Effort during Cycling Test. All values are reported mean  $\pm$  SD

	Hoods	Aeros	p value
Age (years)	30.4 $\pm$ 7.4		
Weight (kg)	79.3 $\pm$ 9.1		
Weekly Cycling Distance(miles)	151.8 $\pm$ 60.4		
VO <sub>2</sub> Max	54.1 $\pm$ 6.0	52.9 $\pm$ 5.7	0.14
RER Max	1.2 $\pm$ 0.04	1.2 $\pm$ 0.03	0.17
VE Max	150.8 $\pm$ 21.1	156.0 $\pm$ 27.8	0.34
HR Max	179.6 $\pm$ 9.4	179.9 $\pm$ 8.2	0.67

Statistical significance:  $p \leq 0.05$ ; paired t-tests for comparison between hoods and aero cycling position

## FRIEL ANAEROBIC THRESHOLD TEST

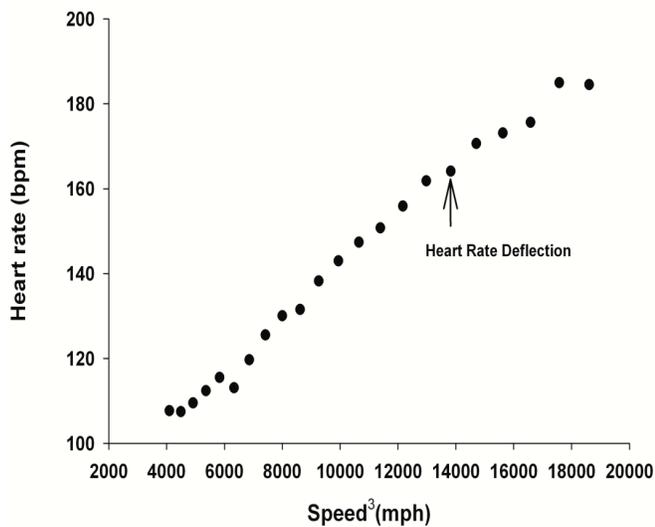


Figure 1. Heart rate deflection point in hoods position.

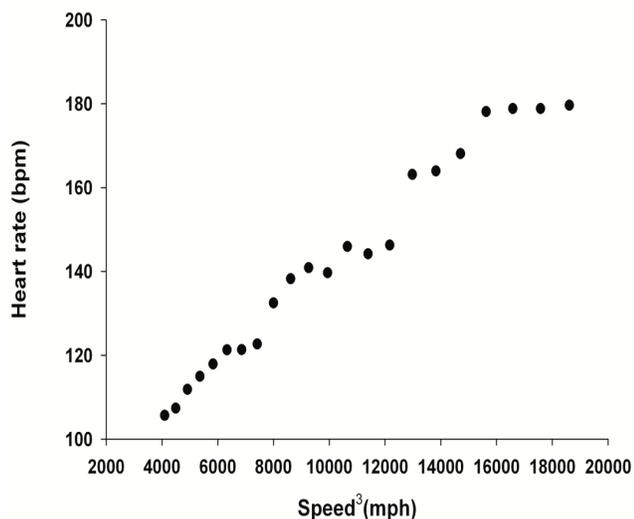


Figure 2. Heart rate deflection point in aero position

### *HRVT and HR at RPE of 17.*

Next, we compared the values for HRVT to values for HR at RPE of 17, which according to Friel is the RPE most likely associated with detecting AT if a HRDP is not discernible through graphing. Since Friel recommends using the HR at RPE of

17, we decided to test whether HR at RPE of 17 was significantly different from  $HRVT_{hoods}$ . We found that the mean  $HRVT_{hoods}$  ( $150.1 \pm 12.8$ ) was significantly lower than HR at RPE of 17 ( $164.9 \pm 9.4$ ) ( $p = 0.001$ ).  $HRVT_{hoods}$  and HR at RPE of 17 were not significantly correlated ( $r = 0.42$ ,  $p = 0.14$ ). Similarly,  $HRVT_{aero}$  was significantly lower than at an RPE of 17 ( $153.3 \pm 10.7$  vs  $164.4 \pm 9.5$ , respectively,  $p = 0.002$ ).

Since the HR values were significantly different and non-significant relationships were found between HRVT and an RPE of 17, we examined the relationship between HRVT to other RPE values. We found the strongest relationships between HRVT and HR at an RPE of 15. We determined that a moderate, significant relationship existed between  $HRVT_{hoods}$  and HR at RPE of 15 ( $r = 0.61$ ,  $p = 0.01$ ), and the  $HRVT_{hoods}$  was not significantly different than the HR at RPE 15 ( $p = 0.47$ ). The relationship between  $HRVT_{aero}$  and HR at RPE 15 was present but not as strong ( $r = 0.47$ ,  $p = 0.09$ ).

While we found differences between HRVT and HR at RPE of 17, we also chose to explore whether the HRDP was significantly different from the HR at RPE 17, and we found that HRDP was not significantly different from the suggested RPE of 17 ( $p = 0.29$ ). However, differences were found when the HRVT was compared to HR at RPE 15 ( $p < 0.01$ ). Therefore we assessed the relationship between these outcome variables. The HRDP showed a moderate and significant relationship with  $HR_{hoods}$  at RPE 17 ( $r = 0.60$ ,  $p = 0.02$ ) but was not significantly correlated with HR at RPE 15 ( $r = 0.54$ ,  $p = 0.05$ ). We also found that by the point in the test that the cyclists had reached HR at the RPE of 17, they had

## FRIEL ANAEROBIC THRESHOLD TEST

reached 84.2% and 82.1% of their  $\text{VO}_2$  max in the hoods and aero position, respectively. Conversely, HRVT was found to be at a lower percentage of  $\text{VO}_2$  max in both the hoods (70.7%) and aero (72.8%) cycling position.

### *FATT Riding Position and RPE.*

Finally we found that cycling position during the FATT did not influence perceived exertion in trained cyclists. The cyclist's perceived exertion occurred at similar HR during both cycling positions. There was a significant correlation between HR recorded at an RPE of 17 ( $r = 0.78$ ,  $p = 0.001$ ) and an RPE of 15 ( $r = 0.69$ ,  $p = 0.007$ ) between the two cycling positions (hoods and aero). However, no significant differences were found between mean values for HR at RPE 17 (hoods:  $164.9 \pm 9.4$  bpm vs. aero:  $164.4 \pm 9.5$  bpm,  $p = 0.74$ ) and HR at RPE 15 (hoods:  $152.2 \pm 11.4$  bpm vs. aero:  $154.4 \pm 10.0$  bpm,  $p = 0.37$ ). See Figure 3 for visual representation of HR during the riding conditions.

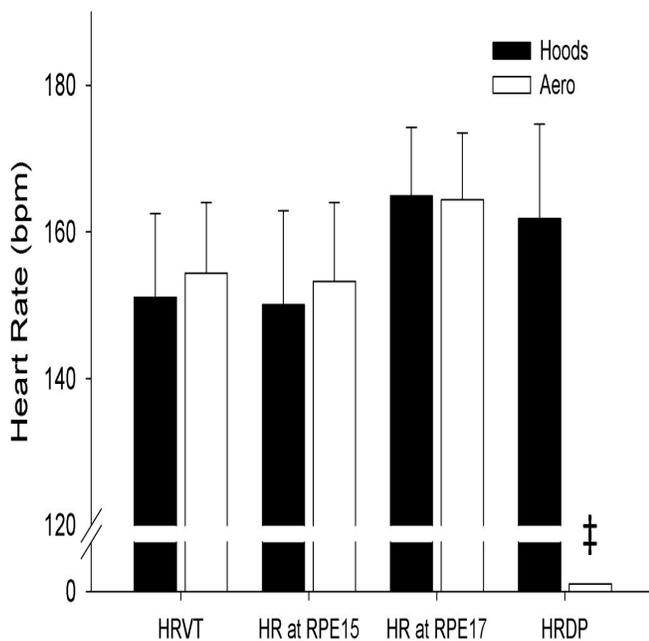


Figure 3. Heart rate response between hoods and aero riding conditions. Error bars represent standard deviation. ‡ HRDP was not discernable by visual inspection for the aero position. No significant differences were found.

## DISCUSSION

The primary purpose of this study was to determine whether the HRDP could be determined using the FATT. We also tested for differences between HRVT and HR at speed that coincided Borg's rating of perceived exertion (RPE) of 17. Finally, we examined physiologic responses to the FATT in trained cyclists in two cycling positions (aero and hoods). We compared the values gathered during this cycling field test, using both the HRDP and RPE of 17 as suggested by Friel if the HRDP is not evident by visual inspection, to those values collected using laboratory methods. The primary findings of this study are that the HRDP could be determined using the FATT for trained cyclists when they ride in their preferred position (hoods). Second, we found that HRDP is poorly correlated with HRVT during the FATT and that VT occurs much earlier during the FATT when compared to the HR at an RPE of 17. These findings support work that suggests HRVT occurs earlier than does HRDP during incremental to max exercise (26). Each of these findings has implications for cycling-related training and competition.

### *FATT and HRDP and HRVT*

The determination of HRDP is a widely used technique for identifying AT during laboratory and field testing (4, 6). The FATT uses the HRDP methodology, requiring the tester to plot the HR (horizontal axis) collected during the 0.5 mph increments in speed (speed<sup>3</sup> on the vertical axis) during the course of this specific cycling test.

However, our findings suggest that the HRDP was identified in this cohort of trained cyclists during this field test but only in the hoods position. Thus, these findings suggest that coaches and cyclists may confidently use the FATT to determine HRDP provided that they use the position the cyclist is most familiar with to complete the testing. Conversely, these findings also suggest that the FATT may not accurately measure the HRDP if cyclists ride in a position other than the hoods, such as riding in the aero position. This finding certainly has practical ramifications, as cyclists often complete time trials in the aero position and typically ride the entire trial at physiological intensities at or near AT (3, 10). Similarly, triathletes also typically complete the entire cycling portion of a triathlon in the aero position. Thus coaches and athletes should likely use caution when applying the FATT to riding conditions such as time trials or triathlon, as the athletes in this study demonstrated slightly different HR characteristics in the aero position.

We are unclear to the explanation for not being able to identify the HRDP in the aero cycling position. However, one possible suggestion is likely the specificity principle, as this concept applies not only to issues such as substrate utilization (16), mode of exercise (44), or intensity of training (31), but to gross motor programs (32) as well. The aero position was not the preferred cycling position for the participants in this study, as all reported using this position infrequently at best during training or competition. For our participants who did little or no training in this position, they demonstrated more of a stair-stepping progression (Figure 2) in HR versus a linear response (Figure 1) when they rode in the

aero position. Therefore, neuromuscular efficiency when riding at high intensity may be less optimal when riding in a different hand position (28). This possible explanation for the lack of a discernable HRDP in the aero position might be easily tested by completing a follow up study using essentially the same design but that includes cyclists and triathletes who regularly train using the aero position.

Determination of VT is also widely used laboratory technique (8, 33) for assessing AT, or the transition from aerobic metabolism to largely anaerobic metabolism. We found that a weak relationship existed between HRDP and HRVT for both the hoods and aero positions, suggesting that the determination of AT using the FATT warrants further consideration. Studies have found that the HRDP only occurs in a certain number of individuals and that when it does, it significantly overestimates directly measured lactate threshold (40, 41). In addition, there are many factors that contribute to increased ventilation during exercise that may affect the breakpoint in which VT occurs and the concurrent HR (39). This may be the reason that in our study there was only a weak relationship between HRDP and HRVT ( $r = 0.39$ ). One area that warrants further consideration in using the FATT would be collection of blood samples to determine the onset of blood lactate accumulation. Using the onset of blood lactate accumulation in combination with our current outcome measures may have provided additional information regarding AT during the FATT.

#### *HR at VT and HR at RPE of 17*

The instructions for FATT indicate that an RPE of 16 to 17 may be used should a rider

not demonstrate a discernable HRDP during the test (19, 21, 23). In this study, we found that the HR at an RPE of 17 correlated with HRDP when the trained cyclists rode in the hoods position. This positive finding is beneficial for coaches and cyclists performing these field tests, allowing them to adapt a training regimen that is best suited for the individual cyclist. The findings of this study also supported our hypothesis that HRVT would be significantly lower than HR at an RPE of 17 during the FATT. Since an RPE of 17 is near the criteria for maximal effort (1), we speculated that HR at RPE of 17 would be significantly higher than HRVT. Furthermore, when we were examining our data, we found that HR at RPE of 15 was significantly related to HRVT in both the hoods and aero position. This finding has clinical implications: the recommended RPE of 16 to 17 on the FATT may prompt riders to train at a slightly higher intensity than may be actually necessary to reach AT. In turn, this may prompt a rider to train at a slightly higher intensity during some training sessions, and this could conceivably contribute to greater risk of over-reaching or over-training. In other words, the difference in a target RPE may cause a rider to train at a slightly higher intensity than is actually necessary in order to stimulate a training effect, and this may make it more challenging for the cyclist to adequately balance the dynamic which exists between the physiological stress of training and the recovery necessary for adaptation to occur (29, 43).

Also, we found that when using HR at RPE of 17, the participants were demonstrating values which correspond to approximately 82% of  $\text{VO}_2$  max, suggesting that the participants are highly trained but not elite,

as untrained individuals typically reach this point somewhere between 50 to 70% of  $\text{VO}_2$  max and elite cyclists reach AT somewhere between 85-90% of  $\text{VO}_2$  max (7). These findings suggest that the participants in this study can use a relatively high percentage of maximal oxygen consumption for long periods while training or competing, and this has value for all types of amateur cycling performance.

#### *FATT Riding Position and RPE*

In this study we found no significant differences between the “hoods” and “aero” cycling positions regarding the physiological data at maximal effort. No differences were found using the metabolic measurement system for oxygen uptake, suggesting that  $\text{VO}_2$  max, or aerobic capacity, in the group was unaffected by the differences in riding position. Similarly, no differences were found for HRVT for the two positions. This is an interesting finding in light of the variability of findings in recent studies that assess the influence of body position on VT during cycling (24, 34).

We also found that neither HR at RPE of 15 nor HR at RPE at 17 was significantly different when comparing the cyclists’ performance in the hoods and aero positions. This finding suggests that the cyclists did not seem to the rate the exercise intensity any differently during these two riding conditions. This finding is interesting in light of Borg’s studies (5) linking HR to perceptions of effort and the fact that the participants in this study demonstrated greater HR variability when they rode in the aero position. In other words, the participants demonstrate greater variability in their HR response during the aero position but not a corresponding change in the reported RPE values. This may suggest

that the Borg scale perhaps lacked measurement sensitivity while the participants rode in this position, which for them was a relatively novel one. Further study is needed to clarify this point in order to substantiate this observation.

#### *Practical Application*

The findings of this study suggest that the FATT can determine HRDP in trained cyclists while riding in the hoods position. However, coaches, trainers and cyclists should acknowledge that the accuracy of predicting AT using the FATT declines when cyclists are tested in a relatively novel riding position, such as using aero bars. Further, the HR values at an RPE of 15 during the FATT should be used to estimate ventilatory threshold over the RPE of 17 as suggested by Friel. Using an RPE of 17 may overestimate the target heart rate range used in the training regimen of the cyclists. Further studies are needed to examine the validity of using either the HRDP or HRVT for estimating AT and to determine the cause of the variability in the HRDP found between the cycling positions when performing the FATT.

<sup>1</sup> The Friel Anaerobic Test is described in a number of sources, but it is described slightly differently in each one. Consequently, as a means of delimiting this study and minimizing the potential for confusion, the protocol used in this experimental design is the testing protocol described by Friel in his 2004 publication. This protocol differs slightly from the protocols described in *The Cyclist's Training Bible (3<sup>rd</sup> ed)* and *The Triathlete's Training Bible (2<sup>nd</sup>)*, which were in print at the time the present study was designed and implemented. Newer editions of these widely available books were published in 2009 at roughly the time this study was implemented, and these newer editions also differ slightly in their description of the FATT.

## REFERENCES

1. ACSM, *Guidelines for Exercise Testing and Prescription*. 8th ed, ed. M. Whaley. Philadelphia, PA: Lippincott Williams & Wilkins, 2009.
2. Ashe, M.C., Scroop, G.C., Frisken, P.I., Amery, C.A., Wilkins, M.A., and Khan, K.M., Body position affects performance in untrained cyclists. *Br J Sports Med*, 37(5): 441-444, 2003.
3. Atkinson, G., Peacock, O., Gibson, A.S.C., and Tucker, R., Distribution of power output during cycling - Impact and mechanisms. *Sport Med*, 37(8): 647-667, 2007.
4. Bodner, M.E. and Rhodes, C., A review of the concept of the heart rate deflection point. *Sport Med*, 30(1): 31-46, 2000.
5. Borg, G., *Borg's Perceived Exertion and Pain Scales*. Champaign, IL: Human Kinetics, Inc, 1998.
6. Bourgois, J., Coorevits, P., Danneels, L., Witvrouw, E., Cambier, D., and Vrijens, J., Validity of the heart rate deflection point as a predictor of lactate threshold concepts during cycling. *J Strength Cond Res*, 18(3): 498-503, 2004.
7. Burke, E., *Serious Cycling*. 2002, Champaign, IL: Human Kinetics, Inc
8. Cannon, D.T., Kolkhorst, F.W., and Buono, M.J., On the Determination of Ventilatory Threshold and Respiratory Compensation Point via Respiratory Frequency. *Int J Sport Med*, 30(3): 157-162, 2009.
9. Carey, D., Assessment of the accuracy of the Conconi Test in determining gas analysis anaerobic threshold. *J Strength Cond Res*, 16(4): 641-644, 2002.
10. Chaffin, M.E., Berg, K., Zuniga, J., and Hanumanthu, V.S., Pacing Pattern In a 30-Minute Maximal Cycling Test. *J Strength Cond Res*, 22(6): 2011-2017, 2008.
11. Conconi, F., Ferrari, M., Ziglio, P.G., Droghetti, P., and Codeca, L., Determination of the anaerobic threshold by a noninvasive field test in runners. *J Appl Physiol*, 52(4): 869-73, 1982.
12. Conconi, F., Grazi, G., Casoni, I., Guglielmini, C., Borsetto, C., Ballarin, E., Mazzoni, G.,

## FRIEL ANAEROBIC THRESHOLD TEST

- Patracchini, M., and Manfredini, F., The Conconi test: Methodology after 12 years of application. *Int J Sport Med*, 17(7): 509-519, 1996.
13. Coutts, A.J., Slattery, K.M., and Wallace, L.K., Practical tests for monitoring performance, fatigue and recovery in triathletes. *J Sci Med Sport*, 10(6): 372-381, 2007.
14. Dorel, S., Couturier, A., and Hug, F., Influence of different racing positions on mechanical and electromyographic patterns during pedalling. *Scand J Med Sci Sport*, 19(1): 44-54, 2009.
15. Earnest, C.P., Wharton, R.P., Church, T.S., and Lucia, A., Reliability of the lode excalibur sport ergometer and applicability to computrainer electromagnetically braked cycling training device. *J Strength Cond Res*, 19(2): 344-348, 2005.
16. Egan, D. and Head, T., Energy substrate metabolism during dual work rate exercise: Effects of order. *J Sport Sci*, 17(11): 889-894, 1999.
17. Eschbach, L., Validity and reliability of the Computrainer cycle simulator. 2002.
18. Figueira, T.R., Caputo, F., Pelarigo, J.G., and Denadai, B.S., Influence of exercise mode and maximal lactate-steady-state concentration on the validity of OBLA to predict maximal lactate-steady-state in active individuals. *J Sci Med Sport*, 11(3): 280-286, 2008.
19. Friel, J., *The Triathlete's Training Bible: A Complete Training Guide for the Competitive Multisport Athlete*. Boulder, CO: Velo Press, 1998.
20. Friel, J., *The Cyclist's Training Bible*. Boulder, CO: VeloPress, 2003.
21. Friel, J., *Computrainer Workout Manual*. Seattle, Washington: Racermate, Inc., 2004.
22. Friel, J., *The Cyclist's Training Bible*. Boulder, CO: VeloPress, 2009.
23. Friel, J., *The Triathlete's Training Bible*. Boulder, CO: VeloPress, 2009.
24. Grappe, F., Candau, R., Busso, T., and Rouillon, J.D., Effect of cycling position on ventilatory and metabolic variables. *Int J Sport Med*, 19(5): 336-341, 1998.
25. Grazi, G., Casoni, I., Mazzoni, G., Uliari, S., and Conconi, F., Protocol for the Conconi test and determination of the heart rate deflection point. *Physiol Res*, 54(4): 473-475, 2005.
26. Grazi, G., Mazzoni, G., Casoni, I., Uliari, S., Collini, G., Heide, L., and Conconi, F., Identification of a Vo<sub>2</sub> deflection point coinciding with the heart rate deflection point and ventilatory threshold in cycling. *J Strength Cond Res / National Strength & Conditioning Association*, 22(4): 1116-23, 2008.
27. Guiraud, T., Leger, L., Long, A., Thebault, N., Tremblay, J., and Passelergue, P., Vo<sub>2</sub> requirement at different displayed power outputs on five cycle ergometer models: a preliminary study. *Br J Sports Med*, 44(6): 449-54, 2010.
28. Harnish, C., King, D., and Swensen, T., Effect of cycling position on oxygen uptake and preferred cadence in trained cyclists during hill climbing at various power outputs. *Eur J Appl Physiol*, 99(4): 387-391, 2007.
29. Kubukeli, Z.N., Noakes, T.D., and Dennis, S.C., Training techniques to improve endurance exercise performances. *Sports Med*, 32(8): 489-509, 2002.
30. Laursen, P.B. and Jenkins, D.G., The scientific basis for high-intensity interval training - Optimising training programmes and maximising performance in highly trained endurance athletes. *Sports Med*, 32(1): 53-73, 2002.
31. Macpherson, R.E., Hazell, T.J., Olver, T.D., Paterson, D.H., and Lemon, P.W., Run Sprint Interval Training Improves Aerobic Performance but Not Max Cardiac Output. *Med Sci Sports Exerc*, 2010: epub date 05/2010.
32. Magill, R., *Motor Learning and Control: Concepts and Applications*. Boston: McGraw-Hill, 2007.
33. Nikooie, R., Gharakhanlo, R., Rajabi, H., Bahraminegad, M., and Ghafari, A., Noninvasive Determination Of Anaerobic Threshold By Monitoring The %SpO<sub>2</sub> Changes and Respiratory Gas Exchange *J Strength Cond Res*, 23(7): 2107-2113, 2009.

## FRIEL ANAEROBIC THRESHOLD TEST

34. Origenes, M.M., Blank, S.E., and Schoene, R.B., Exercise Ventilatory Response To Upright and Aero-Posture Cycling. *Med Sci Sports Exerc*, 25(5): 608-612, 1993.
35. Passelergue, P., Cormery, B, Lac, G, and Léger, L.A., Utility of the Conconi's heart rate deflection to monitor the intensity of aerobic training. 2006.
36. Plowman, S., *Exercise physiology for health, fitness, and performance*. San Francisco, CA: Lippincott Williams & Wilkins, 2003.
37. Sentija, D., Vucetic, V., and Markovic, G., Validity of the modified Conconi running test. *Int J Sport Med*, 28(12): 1006-1011, 2007.
38. Sleamaker, R., *Serious training for endurance athletes*. Champaign, IL: Human Kinetics Inc., 1996.
39. Svedahl, K. and MacIntosh, B.R., Anaerobic threshold: the concept and methods of measurement. *Can J Appl Physiol = Revue canadienne de physiologie appliquee*, 28(2): 299-323, 2003.
40. Tokmakidis, S.P. and Leger, L.A., Comparison of mathematically determined blood lactate and heart rate "threshold" points and relationship with performance. *Eur J Appl Physiol Occupat Physiol*, 64(4): 309-17, 1992.
41. Vachon, J.A., Bassett, D.R., Jr., and Clarke, S., Validity of the heart rate deflection point as a predictor of lactate threshold during running. *J Appl Physiol*, 87(1): 452-9, 1999.
42. Van Sickle, J.R. and Hull, M.L., Is economy of competitive cyclists affected by the anterior-posterior foot position on the pedal? *J Biomech*, 40(6): 1262-1267, 2007.
43. Vetter, R.E. and Symonds, M.L., Correlations Between Injury, Training Intensity, and Physical and Mental Exhaustion Among College Athletes. *J Strength Cond Res*, 24(3): 587-596, 2010.
44. Yamamoto, L.M., Klau, J.F., Casa, D.J., Kraemer, W.J., Armstrong, L.E., and Maresh, C.M., The Effects Of Resistance Training On Road cycling Performance Among Highly Trained Cyclists: A Systematic Review *J Strength Cond Res*, 24(2): 560-566, 2010.