

RELIABILITY OF TIME TO EXHAUSTION AFTER INTERVALS AT VO₂ MAX IN CYCLISTS

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by
REID KEVILLE BELONI

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REID KEVILLE BELONI
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Approved by:

Dave M. Morris, Ph.D.
Chairperson, Thesis Committee

Scott R. Collier, Ph.D.
Member, Thesis Committee

Alan C. Utter, Ph.D.
Member, Thesis Committee

N. Travis Triplett, Ph.D.
Chairperson, Department of Health and Exercise Science

Max C. Poole, Ph.D.
Dean, Cratis D. Williams Graduate School

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Abstract

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Reid Keville Beloni
B.S. Virginia Polytechnic Institute and State University
M.S. Appalachian State University

Chairperson: Dave Morris

Performance testing is one of the most important aspects of sport science and exercise physiology research. It is through the performance test that we understand the functional ways in which a particular intervention has affected the individual and the group. Many characteristics determine the efficacy of a performance test. The test must closely replicate the activity it is supposed to duplicate, it must minimize variation, and it must be able to detect small but important physiological changes. Of the available performance tests, each has strengths and weaknesses including technological limitations of some testing equipment. A traditional time to exhaustion test is usually done at a relatively low intensity, which takes a long time to complete and so incurs a large amount of variation. In short time to exhaustion tests the variations found in longer tests from boredom, monotony, and discomfort are reduced. Within certain testing equipment, technological variation from the testing equipment itself could be reduced by using a short time to exhaustion test. There are indications that higher intensity time to exhaustion tests, which would take substantially less time, could minimize sources of variation while also compensating for technological limitations. This study will investigate a particular performance protocol that involves repeated intervals followed by a time to exhaustion trial, all at relatively high intensities. The protocol involves a preliminary VO₂ max test upon which the intensities of the performance test are based. The performance test has four sets of intervals at peak VO₂ power output followed by a period of rest. Following the four intervals and rest is another interval at the same intensity, which is completed to exhaustion. The

time to exhaustion in the final interval is the performance variable. The time to exhaustion variable in this protocol will be evaluated to determine how reliable this protocol is compared to conventional performance tests. Therefore, the purpose of this study is to determine if a high-intensity time to exhaustion exercise test following high-intensity intervals is as reliable as conventional physiological tests. To evaluate this, ten well trained male and female cyclists were recruited and given an initial assessment of VO₂ max via incremental exercise test to exhaustion to determine power at VO₂ max (P_{MAX}). Participants performed three repeated trials of a warm-up and set of high-intensity intervals of four one-minute work (100% P_{MAX}) and rest (25% P_{MAX}) intervals followed by a final timed test to exhaustion (100% P_{MAX}). Mean times to exhaustion for the final effort were 134 ± 38 sec, 136 ± 42 sec, and 136 ± 43 sec for trials one, two, and three, respectively. No statistically significant differences between the trials were observed ($p=0.91$). These times revealed a maximum variation of 1.5% with a CV of 9.1%. These results suggest that this test to exhaustion is a reliable measure of exercise performance, as CV is within acceptable range and will allow investigators to detect small percent differences as a result of an intervention. This protocol is also useful for investigators who are interested in allowing for self-selected cadence, are restricted to test to exhaustion, or are interested in performance after a high intensity preload.

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Chapter 1

Introduction

In sport science and physiology, performance testing is often used to determine the efficacy of interventions on exercise performance. To do so, a performance test must be able to provide a reliable and consistent measurement of work production. Two common types of performance tests include work or distance based time trials and tests to exhaustion. A time trial test is one in which a set amount of work or distance is completed as fast as possible. This test has a quantifiable point of termination as the test ends once the work or distance is reached. Exercise tests to exhaustion are usually performed at predetermined work rates and terminate when the subject becomes exhausted. A test to exhaustion has a subjective termination point, as termination is determined by the subject's perception of fatigue. Of these two types, time trial tests are generally considered to have greater reliability when compared to tests to exhaustion (Jeukendrup, Saris, Brouns, & Kester, 1996). It is suggested that time trial tests typically exhibit a coefficient of variation below 5% while exercise tests to exhaustion are generally greater than 10% (Currell & Jeukendrup, 2008). However, reviews of time to exhaustion reliability generally focus on tests of low to moderate intensity which last in excess of one hour. Thus, there is a paucity of data on the reliability of short, high intensity exercise time to exhaustion tests.

Reliability within performance testing refers to variation of output of performance within a particular protocol as a result of biological, psychological or technical variation (Bagger, Petersen, & Pedersen, 2003). Reliability of tests to exhaustion is a key point of contention of their use in performance testing. In low to moderate intensity tests to exhaustion, the coefficient of variation is often greater than 10% (Currell & Jeukendrup, 2008). The relatively low intensity often used in tests

to exhaustion can result in exercise tests lasting in excess of three hours. In tests of such length, factors such as boredom, monotony, and discomfort may contribute substantially to the self-selected termination point. Thus, in these tests, factors other than physiological ability or experimental intervention may contribute to performance, which could lead to reductions in test reliability. Increasing the intensity and thus reducing the duration of a test to exhaustion will minimize the influence of these extraneous factors so that termination is determined by physiological exhaustion. In fact, reviews of tests to exhaustion have shown that reliability of these tests generally improves as exercise intensity increases and the duration of the test decreases (Currell & Jeukendrup, 2008). A limited number of investigations into test to exhaustion at or above VO₂ max have been done. Two of these short time to exhaustion tests at higher intensities, 125% and 150% of power at VO₂max, have seen lower coefficient of variation (CV), between 5.3% and 1.7% respectively (Coggan & Costill, 1984; Lindsay et al., 1996). While these two high-intensity time to exhaustion tests have had CV values closer to time trial tests, they both had limitations.

Despite the lower reliability of tests to exhaustion, these protocols are often used as performance tests because many electrically braked ergometers have a limited capacity for the performance of true time trial protocols. Accordingly, further exploration of the characteristics and reliability of tests to exhaustion at or above VO₂ max are warranted. It is the purpose of this investigation to determine if a short, high-intensity test to exhaustion protocol at or above VO₂ max provides a reliable test for evaluating exercise performance.

Statement of the Problem

While it is understood that time to exhaustion protocols utilizing exercise at relatively low exercise intensity are not reliable, the reliability of short, high-intensity tests to exhaustion is less clear. Therefore, the purpose of this study is to determine if a short, high-intensity test to exhaustion protocol at or above VO₂ max is a reliable method of assessing exercise performance and if there is a particular advantage to using this protocol with certain testing equipment.

Hypothesis

It is hypothesized that this short high-intensity time to exhaustion protocol will provide similar reliability to traditional time trial tests of similar length by way of minimizing biological and psychological variability.

Significance of the Study

This study has significance in providing insight into the design of fundamental physiological testing upon which the data of the field are based. This study will investigate a protocol in physiological testing which is not well researched—a high-intensity test to exhaustion following a set of high-intensity intervals—yet, shows promise as being a reliable and usable method of acquiring such data. This study is relevant for those who are attempting to accurately and precisely quantify physiological changes as a result of intervention.

Chapter 2

Review of Literature

The field of exercise science is based upon various physiological tests, the performance test being one of the most utilized. Principally, a performance test must be reliable. If a performance test is reliable, then there is confidence that the results of that test are meaningful. While various performance tests currently exist, aims of this investigation are to establish the reliability of a unique performance test so that it may be used to accurately assess the performance capacity of exercising subjects. This review of literature will explore characteristics of good performance tests as well as the utility for the proposed protocol.

Testing Equipment

The Lode Excalibur cycle ergometer is one of the most commonly used cycle ergometers, yet it has a number of limitations. Most models of this ergometer allow the user to apply work load in two different manners. One, called the hyperbolic mode, allows users to set a specific work rate and will automatically vary the pedaling resistance as users vary their cadence to maintain work rate. While using the hyperbolic mode, subjects can change their work rate by adjusting pedaling resistance using toggle switches on the ergometer control module, much in the same way pedaling resistance can be varied by switching gears on a free moving bicycle. This feature allows the user to attain optimal work rate while maintaining an optimal and comfortable pedaling rate. However; elapsed work is not displayed while in the hyperbolic mode, thus performing time trial tests while in the hyperbolic mode is not possible.

A second mode, called the linear mode, has users set a consistent resistance relationship which allows them to vary the work rate by varying the pedaling cadence. In the linear mode, elapsed work is displayed as exercise progresses. This feature allows the Lode to be used, in this mode, for traditional time trial protocols. During time trial tests subjects are encouraged to finish a predetermined amount of work as quickly as possible. Thus, it is imperative that each subject be allowed to adjust his or her work rate throughout the test so that he or she may achieve a maximal effort. A disadvantage of using the linear mode is that changing work rates can only be achieved with a change in cadence. This restriction can reduce the accuracy of a time trial test by forcing subjects to pedal at cadences that may be uncomfortable or unsustainable, and not optimal for work production (Brisswalter, Hausswirth, Smith, Vercruyssen, & Vallier, 2000; Vercruyssen & Brisswalter, 2010). There is a potential source of biological variability which stems from cadence restricted exercise testing, such as the Lode's linear mode, as the cadence required of the subject to produce a work rate may not be correlated with the subject's preferred cadence. Investigations have shown that pedaling cadence can significantly affect performance. A study by Brisswalter et al. (2000) found that there is an energetically optimal cadence which is close to the freely chosen cadence. These investigators found that the energetically optimal cadence shifted during exercise closer to the freely chosen cadence. Both the energetically optimal cadence and the freely chosen cadence vary between individuals (Brisswalter et al., 2000). Other studies have shown that optimal cadence can vary greatly between individuals depending on factors such as age, experience, and training status (Sacchetti, Lenti, Di Palumbo, & De Vito, 2010; Whitty, Murphy, Coutts, & Watsford, 2009). Finally, for shorter duration exercise in aerobically trained cyclists, a freely chosen cadence of 80-100 is preferred over the energetically optimal cadence of 70-85 because of prior familiarization to higher cadence, reduced crank forces, and reduced neuromuscular fatigue (Vercruyssen & Brisswalter, 2010). Given the various characteristics that can contribute to the individuality of an energetically optimal and a freely chosen cadence, a protocol which restricts cadence to a very narrow range limits the validity of

that protocol. The literature seems to support a freely selected cadence in the construct of a reliable test. Thus, using the linear mode for time trial tests is not an optimal method of testing the efficacy of treatment interventions, as possible gains from the intervention may be obscured by requiring the subject to pedal at less than optimal cadence.

Reliability

Reliability is defined as the degree of variation in repeated measurements. The variation of output of performance within a particular protocol can come as a result of biological, psychological or technical variation (Bagger et al., 2003). Though repeated measurements of the same phenomenon never precisely duplicate each other, they do tend to be consistent between measurements if a reliable method of measurement is used. The measure of test reliability is often coefficient of variation. It is through this measure that a test can be quantitatively compared to conventional tests. Understanding the characteristics of reliable test is important for the design of any protocol.

In determining the reliability of a protocol, the coefficient of variation is a commonly used statistic. It is the ratio of the standard deviation to the mean expressed as a percentage. Some advantages include comparison between data with widely different means and allowing for comparison between different protocols. A disadvantage is that as the mean approaches zero, the coefficient of variation becomes more sensitive to small changes in the mean.

Low Intensity Time to Exhaustion

The coefficient of variation is a commonly used measure of reliability as it provides a means of comparing the variation of different protocols. A highly reliable test, such as a conventional

incremental VO₂ max test, often has a coefficient of variation (CV) <1% for work rate (watts) at ventilatory threshold during an incremental exercise test (Weston & Gabbett, 2001). Time trial protocols often have a CV below 5% for time to completion (Currell & Jeukendrup, 2008). Conversely, time to exhaustion tests, which are typically done at 70%-80% of VO₂ max, generally have a CV above 10% and sometimes approach 25% for time to exhaustion (Currell & Jeukendrup, 2008). A reason time to exhaustion protocols may have a large variation could be due to the duration of the test. Many time to exhaustion protocols are at work rates 70-80% of VO₂max, which elicit finishing times ranges between 15 minutes to over 3 hours. These protocols have resulted in a CV of 5.6% to 26.6% which positively correlates to the duration of the test (Currell & Jeukendrup, 2008). It is far more likely that factors like boredom, monotony or discomfort from sitting on a bicycle seat are likely to occur in a long (>60 min.) exercise protocol than a shorter (<5 min.) one. These factors influence performance and would have a greater effect on reliability in a test which has a subjective termination point rather than an objective one and may contribute to premature termination such a test. For a test lasting one or more hours, it is possibly that there is a great deal of variability from the psychological demand of such a long test. Motivation to maintain power output in longer endurance exercise could also be more variable than in shorter tests (Hopkins, Schabert, & Hawley, 2001). Hopkins review of exercise duration also found that tests of around 1 second and longer than 1 hour were substantially less reliable than test lasting around 1 minute (Hopkins et al., 2001). Low-intensity, long duration, time to exhaustion protocols can be accepted as generally unreliable for many physiological and psychological reasons. Hopkins et al. (2001) indicated that tests with duration closer to one minute would be more reliable than longer tests.

High-Intensity Time to Exhaustion

A few short time to exhaustion tests have used higher intensities, 125% and 150% of power at VO₂max, and generally have seen lower CV, between 5.3% and 1.7% respectively (Coggan & Costill, 1984; Lindsay et al., 1996). Coggan and Costill (1984) investigated the sources of variability in different anaerobic performance tests. Subjects performed four timed rides to exhaustion at 125% of power at VO₂ max on an electrically braked Collins cycle ergometer. Subjects began the test pedaling at 80rpm and attempted to maintain this cadence and work rate as long as possible. Reliability of the performance measure was defined as the mean CV based on all four trials. Time to exhaustion was 98.0 ± 35.3 sec. with a CV of 5.3%. This investigation also looked at 30 and 60 second time trial protocols and found a CV of 5.4% in both cases. They determined that there was no difference in the reliability of both of fixed duration and exhaustive anaerobic power tests. As stated earlier, there are problems with fixed cadence performance tests, and it is not clear if this may have in any way affected the reliability of this study. This investigation also did not indicate any warm-up protocol for any of the performance tests. Warm-up protocols are common in performance tests and in competition, and both moderate and intense warm-ups are known to improve performance (Hajoglou et al., 2005). Neglecting to have a standardized warm-up could likely effect performance. The issues of fixed cadence and warm-up should be accounted for in further investigation.

In an investigation by Lindsay et al. (1996) into the effect of interval training on performance testing, three repeated baseline tests were performed. These repeated tests were done to determine baseline fitness and were evaluated for their reliability. An incremental exercise test to exhaustion and a time to exhaustion test at 150% of power at VO₂ max were done on one day, and a 40 km time trial test was done on another day, all being repeated three times. The two former tests were done on a Lode cycle ergometer in hyperbolic mode at self-selected cadence ranging from 60 and 120 rpm. The subjects initially performed the incremental exercise test to exhaustion followed by a rest period

of 150 second at 2 watts/kg. During the subsequent time to exhaustion tests the subjects exercised to exhaustion at 150% of the peak power achieved in the incremental exercise test to exhaustion. Time was recorded until self-selected cadence fell below 60rpm which was the criteria for termination. Results showed a CV for peak power of 1.14% and a CV of 1.7% for time to exhaustion (59.3 ± 1.1 sec.) with individual CV's ranging from 0.0% to 3.69%. Advantages of this protocol include the use of a hyperbolic mode which allowed for self-selected cadence in both the incremental test and in the time to exhaustion test. Additionally, unlike the Coggan and Costill (1984) study, there was a warm-up and preload in the incremental exercise test. This preload before the time to exhaustion test may have positively influenced the reliability of the time to exhaustion test.

A study by Laursen, Shing, & Jenkins (2003) of time to exhaustion at power eliciting VO₂ peak in highly trained cyclists indicated a low within subject coefficient of variation of 6%. This study indicates a reproducible and reliable test to exhaustion when exercising at VO₂ peak. The strong reliability of this study came despite a significant increase in time to exhaustion in the second of two trials. This investigation used a large subject pool, 43 subjects, but only tested them two times, with no familiarization trial. This could have contributed to the improvement in performance in the second trial. Multiple retests as well as a familiarization trial could reduce the variability between retests and improve reliability. Further, the findings of all three studies support the argument that higher intensity and shorter duration time to exhaustion test have greater reliability compared to longer time to exhaustion tests.

Preload

While it is understood that a warm up can increase exercise performance, there is little literature on the effect of a preload exercise before a time to exhaustion test. Particularly, there is

little on the effect of a high-intensity interval type of preload. It has been suggested that some biochemical markers such as lactate and pH increase to a greater degree after an interval session than a fixed rate exercise (Hermansen & Osnes, 1972). A preload before a physiological performance test more closely replicates actual performance such as a mass start race where the pace is variable before a final race finish effort.

While a number of high-intensity, time to exhaustion protocols have been investigated, high-intensity interval type protocols have not been tested. Typically, time to exhaustion protocols are an attempt to quantify either aerobic or anaerobic performance. Many performance tests also feature measurements of blood lactate and blood pH as well as exercise performance. Investigations of alkalinizing agents as ergogenic aid are explicitly interested in the observed changes in lactate or pH as a result of exercise. In investigating the ergogenic effect of alkalinizing agents such as sodium bicarbonate or calcium lactate, it is relevant to prescribe a protocol which elicits a great demand on the anaerobic energy systems and their associated buffers. It has been demonstrated that pH and lactate exhibit greater changes in response to interval work than a single exercise bout (Hermansen & Osnes, 1972). It has been suggested that an alkalinizing agent may have a greater ergogenic effect in repeated interval event (Matson & Tran, 1993). Further literature has shown that when high-intensity exercise to exhaustion is preceded by several high-intensity interval efforts, a greater ergogenic effect from alkalinizing agents is seen than in protocols that use a single high-intensity exercise bout (Matson & Tran, 1993). Thus, a repeated interval protocol may better elicit the demand of these systems for experimental quantification and improve the ability to detect changes in these performance markers. A repeated interval high-intensity protocol may be a better means of quantifying anaerobic performance because of increased demand on the bioenergetics systems of that exercise intensity. Additionally, a high-intensity preload before an exercise test to exhaustion is also a good representation of real world sport performance. It is common in cycling races for an individual to perform repeated high-intensity intervals such as attacking or chasing, followed by a

time to exhaustion test such as leading out a sprint finish. A series of high-intensity intervals followed by a time to exhaustion test is similar to the type of race experiences a trained subject is already familiar to from training and competition. This sort of protocol will also be useful in predicting the performance of an athlete as it closely replicates the race dynamic of a road cyclist particularly in the finish of a race which is more often characterized by repeated short high-intensity efforts rather than an effort at a fixed lower intensity. Despite this, no high-intensity interval time to exhaustion protocols have been evaluated for their reliability.

The literature shows time to exhaustion protocols may solve a technological limitation of certain testing equipment by allowing self-selected cadence at a set work rate. Evidence exists that high-intensity time to exhaustion protocols may be as reliable as time trial or incremental aerobic tests to exhaustion, which are both considered reliable. High-intensity interval preload may also be beneficial to certain experimental designs as a means of inducing an acidotic state. While a high-intensity interval preload before time to exhaustion has not been evaluated, a protocol of this nature could be very functional and just as reliable as conventional performance tests. Additionally, this test may better replicate certain types of actual performance.

Chapter 3

Methods and Results

Experimental Design Overview

The protocol for this study involved two main components: determination of VO₂ max and power output at VO₂ max (P_{MAX}), and three experimental trials. The initial visit was for determination of VO₂ max which was then used to calculate P_{MAX}. The value of P_{MAX} was then used as the prescribed workload in the subsequent three experimental trials. During the three experimental trials the subjects performed an interval performance test (IPT) consisted of a warm up period followed by four one-minute intervals at P_{MAX}, separated by a one minute rest period, followed by a time to exhaustion performance test at P_{MAX}. The performance times from the test to exhaustion were analyzed to determine the consistency between trials. Training programs leading up to intervention were reviewed to assess the training status of the subjects and their familiarity with exercise at high intensity and to exhaustion. This information was obtained to minimize the training and learning effect of the multiple applications of the IPT. This was ascertained via a questionnaire and interview to assess hours of training and training intensity.

Subjects

Ten subjects were initially recruited following from the local cycling population, including from the Appalachian State University Cycling Team. Exclusion criteria included cardio vascular

disease, metabolic disorders, known cardio vascular risk factors. Training status and history collected and training was standardized over the course of the study. Cycle ergometer positioned according to the subject's personal bike. One subject's data was later excluded resulting in a sample of nine regularly trained cyclists, including seven males, two females. Subjects were between 18 and 25 years of age with a VO₂ max: $57.3 \pm 6.4 \text{ mL} \cdot \text{Kg}^{-1} \cdot \text{min}^{-1}$, weight: $72.4 \pm 7.1 \text{ Kg}$, and VO₂ max Power: $359 \pm 54 \text{ watts}$. Complete subject characteristics are presented in Table 1.

Determination of VO₂ max and PMAX

All testing and training was performed in the Vascular Biology Laboratory at the Institute for Health and Human Services in Boone, NC. This investigation was performed after approval by Appalachian State University Institutional Review Board (see Appendix A). During the initial visit, subjects performed a progressive exercise test to exhaustion on a Lode Excalibur Sport cycle ergometer (Groningen, The Netherlands) to assess VO₂ max and power output at VO₂ max (PMAX). The Lode cycle ergometer adjusted according to the subjects' own bike and standardized for each trial. The graded exercise test (GET) was preceded by a warm up which started 100 Watts below the starting work rate for the graded exercise test and was increased by 10 Watts/min until work rate of 3 Watts/kg was achieved, followed by a five minute rest period. The graded test began at 3 Watts/kg and increased by 0.3 Watts/kg until volitional exhaustion was reached. The VO₂ max test followed the protocol used for similar exercise studies and has been found effective at reaching VO₂ max in trained individuals between 7 and 12 minutes. During the GET test, expired air was collected continually and analyzed for oxygen consumption and carbon dioxide production and respiratory exchange ratio using a Parvo Medics metabolic cart (Sandy, Utah). The Parvo Medics metabolic cart was calibrated according to the manufacturer's specifications. Heart rate during the test was monitored by Polar Electro (Kempele, Finland). Criteria for a successful test included a plateau in

oxygen consumption with an increase in work rate, a respiratory-exchange ratio greater than 1.15, and a maximal heart rate similar to the age-estimated maximal heart rate for the subject ($220 - \text{age}$). Pedaling cadence was maintained throughout the test at a self-selected cadence, generally between 75 and 110 rpm. Subjects must have completed 30 seconds of the final stage for that work rate to be used as their P_{MAX}; otherwise, the power output from the final completed stage was used for the P_{MAX}. Following the exercise test, the participants were given a 10 minute rest period before performing a practice trial of the interval performance test for familiarization. Data from this familiarization trial were not collected.

Description of Experimental Protocol

Three interval performance tests (IPT) were performed within two weeks of the initial VO₂ max test and were separated by at least 48 hours and not more than 96 hours. Testing time of day within participants was kept consistent and did not vary by more than 1 hour. Participants were instructed to consume a similar diet in the 24 hours prior to each visit and were three hours post prandial during each visit. Training volume and intensity was kept similar to the weeks before the investigation and remained similar throughout the duration of the investigation. Following the initial VO₂ max test a practice of the IPT was performed to familiarize the participant to the protocol.

The IPT followed a warm up period which started 50 Watts below the starting work rate for the graded exercise test and increased by 10 Watts/min for five minutes and then remained constant for five minutes, followed by a five minute rest period. The testing protocol consisted of four, one-minute work intervals separated by one minute of rest, followed by a final work interval to exhaustion. Work rates during the protocol were 100% P_{MAX} for the work intervals and 25% of P_{MAX} for the rest periods. All protocols used were entered into the automatic program feature of the

Lode ergometer. Thus, timing for the application and removal of workloads was automatically controlled by the ergometer's computer. Rate of perceived exertion on a Borg Scale (6-20) was collected at the end of each work interval. During these intervals, subjects maintained a cadence similar to what was self-selected during their VO₂ max test. Subjects received verbal encouragement from the investigators. During the last interval, time to exhaustion (TTE) was monitored by stop watches. Time of exhaustion was determined when cadence fell below 50 rpm for more than 10 consecutive seconds or at volitional exhaustion.

Statistical Analysis

Repeated measures ANOVAs were performed to detect differences in TTE resulting from each trial. A one way ANOVA was performed to detect differences between trials for TTE during the final interval of the IPT. Individual coefficients of variation (CV) were calculated for each subject and averaged to obtain an overall CV. Significance was determined by an alpha level ≤ 0.05 . Following a significant F-ratio, Bonferroni post hoc testing was performed. SPSS version 17 (Chicago, Illinois) was used for statistical analysis. The Cronbach's Alpha was calculated for the coefficient of reliability.

Results

The results of the three exercise tests to exhaustion are shown in Table 2. From those results some values were omitted from analysis. Subject two was omitted for failure to adhere to the protocol. Subject two performed the three trials over a longer test duration than the other subjects so the data was excluded. Subject three did not maintain a regular pedaling cadence and had the greatest

range in CV thought the data was retained. Subject seven had a single value omitted due to an absence, but when substitutions were required, the average was used.

A repeated measures ANOVA was performed to see if there were any within subject differences between the three trials. Mauchy's Test of Sphericity revealed that sphericity was violated with a significance value <0.05 . While sphericity was violated, a Greenhouse-Geisser correction showed that there was not a significant difference between the trials ($F=0.014$, $p=0.919$). Mean times to exhaustion for the final effort were 134 ± 38 sec., 136 ± 42 sec., and 136 ± 43 sec. for trials one, two, and three, respectively. These times revealed a maximum variation in finishing time of 1.5%. No statistically significant differences between the trials were observed ($p=0.91$). The coefficients of variation ranged from 33.6% to 1.12%, with a mean CV of 9.1%, and five of the nine resulting CVs were below 5%. Additionally, the Cronbach's Alpha value was 0.930.

Chapter 4

Conclusions and Suggestions for Further Research

Conclusions

Time trial protocols often have a CV below 5%, while time to exhaustion tests, which are typically done at 70%-80% of VO₂ max, generally have a CV of above 10% and sometimes approach 25% (Currell & Jeukendrup, 2008). A few short time to exhaustion tests have used higher intensities, at or above VO₂max and generally have seen lower CV, between 6% and 1.7% (Coggan & Costill, 1984; Laursen et al. 2003; Lindsay et al., 1996). There is no ubiquitously accepted CV value below which is said to be reliable; rather the lower the CV, the more reliable the test. In the present exercise protocol, the mean CV was 9.06%; however, there is some reason to believe that it might be lower if there had been better protocol adherence in certain participants. This is within the range of other exercise test CV values that have been deemed acceptable. With a small sample size, it is possible for a few outliers to have a substantial effect on the total mean CV.

The most notable limitation of the study is evident in subject three's performance. All of the subjects were allowed to use a freely selected cadence during the test to exhaustion, as the hyperbolic mode would maintain the same wattage regardless of pedaling cadence. It was incorrectly anticipated that each of the subject would choose a preferred cadence and use the same cadence for each trial. Subject three chose a very different cadence for each of the three tests. This was not criteria for exclusion as subjects were allowed to self-select cadence. It is suggested that future protocols state that a freely selected cadence is allowed, though the cadence must be kept close to freely selected cadence for each of the three trials.

Individual performance times in the present study varied from 60 to 221 seconds; however, mean time to exhaustion of trial one (134 ± 38 sec.), trial two (136 ± 42 sec.), and trial three (136 ± 43 sec.) were all within 1.5 %. The difference between trial 1 and trials 2 and 3 was 1.5%; trials 2 and 3 had the same mean time. Percent difference between mean performance time is not a commonly reported value, though it could be an easy and more practical way for an investigator to discern the expected differences in performance from intervention related differences.

A protocol which could be sensitive to such small differences in performance times may be useful in practical applications such as races, which are lost by very small differences in mean performance. The mean difference in performance times of a preloaded 15 minute time trial and an hour time trial—two protocols which had low CVs (3.5% and 3.4%), by Jenkendrup et al. (1996)—were 0.1% to 2.9% and 1.0% to 2.9% respectively. These exercise tests of slightly longer duration were decidedly reliable because of their low CV, but their mean difference in performance times was larger than in the present study, despite the present study having a slightly higher CV.

There is not a threshold below which a percent difference is reliable, but a test with a lower percent difference may be a more reliable protocol than a higher one. The present protocol yields a very low percent difference, especially between the second and third trial. Percent difference may be a more useful value than CV. Performance times in sports are often compared by percent difference, with elite athletes often having very marginal percent difference in performance. A protocol which could be sensitive to such small differences in performance times would be very useful for sports professionals and researchers looking to improve by very small margins. The present protocol yields a very low percent difference between trials, lower than some commonly accepted time trial protocols (Jeukendrup et al., 1996). An investigator using this protocol as a means of discerning the effect of an intervention should expect less than 1.5% difference in mean performance times between trials with no intervention. If an investigator found a percent difference greater than 1.5% in performance

times of any trial it may indicate an effect of the intervention. In exercise and sport physiology, distinguishing a 1.5% difference is difficult to do, yet could be expected with this protocol. By knowing the innate variation in performance that is expected in a performance test, the researcher can gain insight into the efficacy of the intervention.

Another reliability statistic which was used to analyze the data was Cronbach's Alpha, which is a coefficient of reliability. Cronbach's Alpha was used because it is a measure of internal consistency or reliability when comparing three or more repeated measures. Cronbach's Alpha values vary between 0 and 1, with a score closer to 1 being more reliable and a value over 0.8 being accepted as reliable. The resultant Cronbach's Alpha value from this study was 0.930.

These statistical treatments show that this protocol yielded results which were very consistently distributed. There was not a learning effect observed in the administration of this protocol. There was also no significant difference between any of the trials $p=.91$. The coefficient of variation varied from 1.12% to 33.36 %. The mean CV was 9.06%, though it may have been lower if there had been better protocol adherence in certain participants. With a small sample size, it is possible for few outliers to have a substantial effect on the total mean CV. Though CV might indicate a certain level of variability with the data, Cronbach's Alpha of 0.930 indicates that this protocol is highly reliable. Lastly, the percent difference between trials is small, $\leq 1.5\%$. A value which is equal to or lower than other protocols accepted as reliable. An investigator using this protocol would expect to be able to discern significance over small percent differences. Further investigations should focus on this type of high intensity time to exhaustion test following intervals using larger sample sizes with better subject adherence.

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Appendix A

IRB Documents

To: Reid Beloni
Health, Leisure and Exercise Science
CAMPUS MAIL

From: Dr. Stan Aeschleman, Institutional Review Board Chairperson

RE: Notice of IRB Approval by Full Board Review

Study #: 12-0124

Study Title: Reliability of Time to Exhaustion after Intervals at VO₂ max in Cyclists

Submission Type: Initial

Approval Date: 12/16/2011

Expiration Date of Approval: 12/11/2012

This submission has been approved by the above IRB for the period indicated above.

Investigator's Responsibilities:

Federal regulations require that all research be reviewed at least annually. It is the Principal Investigator's responsibility to submit for renewal and obtain approval before the expiration date. You may not continue any research activity beyond the expiration date without IRB approval. Failure to receive approval for continuation before the expiration date will result in automatic termination of the approval for this study on the expiration date.

You are required to obtain IRB approval for any changes to any aspect of this study before they can be implemented. Should any adverse event or unanticipated problem involving risks to subjects occur it must be reported immediately to the IRB.

Best wishes with your research!

CC:

David Morris, Health, Leisure And Exercise Sci

Consent to Participate in Research
Information to Consider About this Research

Reliability of Time to Exhaustion after Intervals at VO₂ max in Cyclists

Principal Investigator: Reid Beloni
Department: HLES
Contact Information:
ASU Box 06206
Boone, North Carolina 28608
belonirk@appstate.edu
704-577-3865

Faculty Advisor: Dr. Dave Morris
53 Holmes Convocation Center
Boone, North Carolina 28608
morrism@appstate.edu
828-262-7120

What is the purpose of this research?

The purpose of this research study is to determine if high intensity time to exhaustion exercise tests are as reliable as conventional time trial tests and if there is a particular advantage to using this protocol with certain equipment. While it is understood that time to exhaustion protocols utilizing exercise at relatively low exercise intensity are not reliable, it is not fully understood how reliable higher intensity time to exhaustion test are. It is hypothesized that this repeated high intensity time to exhaustion protocol will provide similar reliability to traditional time trial tests of similar length by way of minimizing biological and psychological variability and have a distinct advantage in certain laboratory settings where available cycle ergometer equipment lends itself to time to exhaustion tests.

Why am I being invited to take part in this research?

You are being invited to take part in this research because you are a well trained competitive cyclist or triathlete 18-45 years of age who is accustomed to performing high-intensity exercise.

Are there reasons I should not take part in this research?

If you will be unable to maintain a consistent training schedule, are pregnant or think you might be pregnant, you do not conform to the above listed requirements, or if you have any known cardiovascular, respiratory, or metabolic diseases, you should not participate in this study. If you volunteer to take part in this study, you will be one of about 15 people to do so.

What will I be asked to do?

The research procedures will be conducted at the Vascular Biology Lab at the Institute for Health and Human Services or the Human Performance Lab within Holmes Convocation Center, Boone, NC. Parking at the Institute for Health and Human Services is available free of charge in a visitor/participant area of that building's parking lot. Parking at Holmes Convocation center is available only to those with the appropriate parking pass. This study will not compensate for any parking costs or fines. You will need to come here 4 times during the study. Your initial visit as well as your final 3 visits will each require about 1 hour of your time. The total amount of time you will be asked to volunteer for this study is about 4 hours over the next 10 – 21 days.

During your initial visit, you will be asked to perform a progressive, maximal exercise test to exhaustion so that we can determine your VO₂ max and the work rate that elicits your VO₂ max. This test will be performed on a stationary bicycle ergometer that is similar to your bicycle. The intensity for the test will start at a low to moderate level and will be increased by a small amount until you are exhausted. This test generally takes about 8-10 minutes to complete. During this test, a snorkel-like mouthpiece will be placed in your mouth and your nose will be plugged with a nose clip. This will allow us to collect your expired air and analyze it to determine your oxygen consumption level. Once you have become exhausted, the mouthpiece will be removed and you will be allowed to rest for 10 – 15 minutes. Following this rest, you will complete an interval test (ITE) on the bicycle ergometer. This workout will consist of 4, 1-minute work intervals followed by 1-min rest intervals. The intensity for the work intervals will be 100% of the maximum work rate that you achieved on your VO₂ max test. The intensity of your rest intervals will be 25% of the maximum work rate that you achieved on your VO₂ max test. Immediately following your final rest interval, you will perform a final effort at 100% of the maximum work rate that you achieved on your VO₂ max test. This final effort will be performed to exhaustion. This will complete your requirements for your first visit.

You will be asked to return to the lab on 3 occasions to perform the ITE test. You will begin a 10 minute warm-up on the bicycle ergometer before performing your intervals test. Following the completion of your interval test, you will be allowed to cool-down.

What are possible harms or discomforts that I might experience during the research?

To the best of our knowledge, the risk of harm for participating in this research study is no more than you would experience in everyday life as a competitive athlete. We know about the following risks or discomforts that you may experience if you choose to volunteer for this study: The risk of performing intense exercise in the laboratory will be no more than those experienced while training or racing. No other risks are expected. Risk is expected to be minimal.

Are there any reasons you might take me out of the research?

During the study, information about this research may become available that would be important to you. This includes information that, once learned, might cause you to change your mind about wanting to be in the study. We will tell you as soon as we can.

There may be reasons we will need to remove you from the study, even if you want to stay in. We may find out that it is not safe for you to stay in the study. If we find that the research might harm you or that it is not providing enough of a benefit to justify the risks you are taking, we will terminate

your involvement in the study. We may also find that you are not or cannot come for your study visits as scheduled. If those things are found to be true, we will need to take you out of the study.

What are possible benefits of this research?

You will be given access to your personal data collected from the study, including results of your VO2 Max performance test. Other than that there is no expected direct benefit. This research should help us learn more about whether the experimental protocol will help improve researchers understanding of the reliability of certain exercise tests. The information gained by doing this research may help others in the future.

Will I be paid for taking part in the research?

We will not pay you for the time you volunteer while being in this study

What will it cost me to take part in this research?

It will not cost you any money to be part of this study.

How will you keep my private information confidential?

Your information will be combined with information from other people taking part in the study. We intend to publish the results of this study so that it may be shared with other researchers. This publication will only contain the combined information from you and the others who participated in the study. You will not be personally identified in any published or presented materials.

All personal information obtained during the course of your participation will be accessible only to Reid Beloni and Dr. Morris. You will be identified by code to preserve your confidentiality and your file will be kept in a locked cabinet in Dr. Morris's office. We will make every effort to prevent anyone who is not part of the research team from knowing that you gave us information or the content of that information. However, there are some circumstances in which we may have to show your information to other people. For instance, we may be required to show information that identifies you to people who need to be sure that we have done the research correctly, such as Appalachian's Institutional Review Board.

Data from this research will be kept indefinitely, however, codes linking you to your data will be destroyed three years following the completion of the data collection.

What if I get sick or hurt while participating in this research study?

If you need emergency care while you are at the research site, it will be provided to you. If you believe you have been hurt or if you get sick because of something that is done during the study, you should call your doctor or, if it is an emergency, call 911 for help. In this case, tell the doctors, the hospital or emergency room staff that you are taking part in a research study and the name of the Principal Investigator. If possible, take a copy of this consent form with you when you go. Call the Principal Investigator, Reid Beloni, at 704-577-3865 as soon as you can. He needs to know that you are hurt or ill.

There are procedures in place to help attend to your injuries or provide care for you. Costs associated with this care will be billed in the ordinary manner to you or your insurance company. However, some insurance companies will not pay bills that are related to research costs. You should check with your insurance company about this. Appalachian Student Health Services (262-3100) provides General Health Services, including an Injury Clinic, for Appalachian students who have paid the health fee. You should talk to the Principal Investigator about this, if you have concerns.

Who can I contact if I have a question?

The people conducting this study will be available to answer any questions concerning this research, now or in the future. You may contact the Principal Investigator at 704-577-3865. If you have questions about your rights as someone taking part in research, contact the Appalachian Institutional Review Board Administrator at 828-262-2130 (days), through email at irb@appstate.edu or at Appalachian State University, Office of Research and Sponsored Programs, IRB Administrator, Boone, NC 28608.

Do I have to participate? What else should I know?

Your participation in this research is completely voluntary. If you choose not to volunteer, there will be no penalty and you will not lose any benefits or rights you would normally have. If you decide to take part in the study you still have the right to decide at any time that you no longer want to continue. There will be no penalty and no loss of benefits or rights if you decide at any time to stop participating in the study.

This research project has been approved by the Institutional Review Board (IRB) at Appalachian State University. This study was approved on 12/16/2011. This approval will expire on 12/11/2012 unless the IRB renews the approval of this research.

I have decided I want to take part in this research. What should I do now?

The person obtaining informed consent will ask you to read the following and if you agree, you should sign this form:

- I have read (or had read to me) all of the above information.
- I have had an opportunity to ask questions about things in this research I did not understand and have received satisfactory answers.
- I understand that I can stop taking part in this study at any time.
- By signing this informed consent form, I am not giving up any of my rights.
- I have been given a copy of this consent document, and it is mine to keep.

Participant's Name (PRINT)

Signature

Date

Appendix B

Health History Questionnaire

The purpose of the following questionnaire is to assess your medical risk factors and determining your suitability to serve as a subject in a research study. Should you be retained as a subject, all information from this form will be kept in strict confidence and will be made available only to members of the research team. This form will remain in your personal file in a locked file cabinet for the duration of the research study. Should you not be retained as a subject, the form will be promptly destroyed.

ID # _____ Date: _____

Age: _____ Gender: _____

Height: _____ Weight: _____ BP: _____

Physical Injuries or Limitations: _____

Are you currently taking any medications (prescription or over the counter), vitamins, or dietary supplements? Y / N

If you are currently taking any medications, vitamins, or supplements, are you aware of any that could change the rate or rhythm of your heart? Y / N

Do you now, or have you ever used tobacco? Y / N If yes, what type: _____

How long? _____ Amount _____/Day Years since quitting? _____

How often do you drink the following?

Caffeinated coffee, tea or soda _____ oz/day Hard Liquor? _____ oz/week

Wine _____ oz/week Beer? _____ oz/week

Do you currently practice regular physical exercise? Y / N

If yes, what type : _____

Frequency of exercise : _____ times/week

Volume per week : _____ hrs/week

Exercise Intensity: _____

What is your current emotional stress level? High Moderate Low

Appendix C

Maximal Oxygen Consumption Test Data Sheet

Subject ID: _____

Date: _____

Mass (Kg): _____

Height (cm): _____

Starting Work Rate (Watts) **Mass (Kg) * 3** = _____

Work Rate Increments (Watts) **Mass (Kg) * 0.3** = _____

Time (minutes)	Watts	Time of stage@ exhaustion	VO2 max
0-1			
1-2			
2-3			
3-4			
4-5			
5-6			
6-7			
7-8			
8-9			
9-10			
10-11			
11-12			
12-13			
13-14			
14-15			

Tested by: _____

Bike Geometry

Saddle Height _____(cm)

Saddle Setback _____(cm)

Handlebar Reach _____(cm)

Appendix D
Borg RPE Scale

6	Very, Very Light
7	
8	
9	Very Light
10	
11	Light
12	
13	Somewhat Hard
14	
15	Hard
16	
17	Very Hard
18	
19	Extremely Hard
20	Maximal Exertion

Appendix E

Time to Exhaustion Test Data Sheet

Subject ID: _____

Date: _____

Protocol Number: _____

Visit Number: _____

VO₂ Max Work Rate (Watts) **From Max Test** = _____

Rest Work Rate (Watts) **VO₂max (Watts) *0.25** = _____

Warm up Work Rate (Watts)

0-1 min _____

1-2 min _____

2-3 min _____

3-4 min _____

4-5 min _____

5-10 min _____

Interval Protocol RPE

Int. 1 _____

Int. 2 _____

Int. 3 _____

Int. 4 _____

Time to Exhaustion: _____

Tested by: _____

Table 1. Individual Subject Characteristics

SUB	Gender	VO2 max	VO2 max power	Rest power	Weight
		mL/Kg/min	watts	watts	Kg
1	F	54.5	327	82	61.1
3	M	61.3	375	94	73.7
4	F	43.0	266	66	69.8
5	M	56.5	365	91	75.9
6	M	61.6	357	89	65.7
7	M	63.6	340	85	71.4
8	M	62.3	404	101	71.8
9	M	53.9	336	84	75.5
10	M	59.4	460	115	86.4
	Mean	57.3	359	90	72.4
	SD	6.4	53	13	7.1

Table 2. Individual Time to Exhaustion at Power of VO2 max Reported in Seconds

SUB	trial 1	trial 2	trial 3	mean	SD	cv
	Sec.	Sec.	Sec.	Sec.	Sec.	%
1	135	137	138	136.7	1.5	1.1%
3	168	103	93	121.3	40.7	33.6%
4	178	214	221	204.3	23.1	11.3%
5	123	116	116	118.3	4	3.4%
6	60	69	79	69.3	9.5	13.7%
7	132	129	136	132.2	3.3	2.5%
8	177	181	181	179.7	2.3	1.3%
9	134	145	137	138.7	5.7	4.1%
10	103	127	120	116.7	12.3	10.6%
mean	134	136	136			
SD	38	42	43			

Vita

Reid Keville Beloni was born in Charlotte, North Carolina. He attended elementary schools in that city, and graduated from Myers Park High School in Charlotte in May 2005. The following autumn, he entered Virginia Tech to study Human Nutrition, Foods, and Exercise. He was awarded the Bachelor of Science degree in May 2010. In the fall of 2010, he accepted a graduate research assistantship in Exercise Science at Appalachian State University and completed his Masters of Science in 2014. He is the son of Chief of Radiology Dr. Andrew John Beloni and the artist Mrs. Christine Keville Beloni of Charlotte, North Carolina, and sibling to the entrepreneur Evan Beloni.