

RUNNING ECONOMY DURING THE LAST LEG OF INTERNATIONAL TRIATHLON  
UNION DUATHLON RACE SIMULATION IN A LABORATORY SETTING

Isaac Zebadiah Lee

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Approved By:

Bonita L. Marks

Claudio L. Battaglini

Edgar W. Shields

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## ABSTRACT

Isaac Lee: Running Economy During the Last Leg of a ITU Duathlon Race Simulation in a Laboratory Setting (Under the direction of Bonita Marks)

This retrospective study examined running economy (RE) as measured by oxygen uptake ( $\text{VO}_2$ ) for 7 highly trained male multi-sport athletes during a laboratory duathlon simulation (running + cycling). Methods: Trial 1 = speed-only single-bout run  $\text{VO}_{2\text{max}}$  test; Trial 3 = 10 km run + 30 km cycling at 95-98% of ventilatory threshold followed by a speed-only single-bout run  $\text{VO}_{2\text{max}}$  test. RE was represented by  $\text{VO}_2$  obtained at 5, 7, and 10 mph during the  $\text{VO}_{2\text{max}}$  tests during Trials 1 and 3. Results: A significant interaction effect ( $p = 0.047$ ) occurred for Trial \* Intensity (3 x 2 repeated measures ANOVA; Factor 1 = exercise intensities [speeds 5, 7, 10 mph]; Factor 2 =  $\text{VO}_{2\text{max}}$  for Trials 1 and 3). Post hoc paired samples t-tests approached significance for 7 and 10 mph ( $p = 0.054$ ;  $p = 0.064$ , respectively). Conclusion: RE is affected in a laboratory duathlon simulation during moderate intensity running.

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## DEFINITION OF TERMS AND ABBREVIATIONS

- **Euhydration:** Normal daily body water content, measured by urine specific gravity (USg). Normal USg values range from 1.010 to 1.030.
- **International Triathlon Union (ITU) Duathlon:** A 10 km run, 40 km cycling time trial and 5 km run performed in immediate and successive order.
- **Maximal Oxygen Uptake ( $VO_{2max}$ ):** The maximal amount of oxygen that can be utilized during exercise, measured in milliliters of oxygen consumed per minute per kilogram of body weight (ml/kg/min).
- **Submaximal Oxygen Uptake ( $VO_{2submax}$ ):** An estimation of  $VO_{2max}$  during submaximal exercise testing.
- **Maximal Treadmill Protocol Test:** An exercise test which provides incremental increases in intensity up to maximum capacity for aerobic exercise. In this study we used a cycle ergometer and treadmill protocol for the test, which was done in the lab.
- **Running Economy (RE):** A measure of the energy demand of running at a set submaximal speed. Runners with good RE use less energy and less oxygen than runners with poor RE, which is reflected in a lower level of oxygen uptake at any given speed.
- **Speed-Only  $VO_{2max}$  (SO $VO_{2max}$ ):** a protocol for measuring  $VO_{2max}$  using incremental increases in speed while maintaining a constant grade of 0%.
- **Ventilatory Threshold ( $V_T$ ):** The point at which pulmonary ventilation increases relative to oxygen consumption during aerobic exertion. This usually occurs at  $\geq 50\% VO_{2max}$ , and is dependent on the subject's aerobic conditioning status.

## **CHAPTER I**

### **INTRODUCTION**

The duathlon, a run-bike-run competition, is a time honored multi-sport event dating back to the early 1970s. At that time duathlons, initially termed biathlons, were popular as informal local competitions which in subsequent decades led to more formalized and structured competitions sponsored by large corporations (ITU, 2012). In the 1980s duathlons experienced a surge in popularity, but this resurgence was later overshadowed by the sport of triathlon, which included swimming along with running and biking and attracted larger numbers of competitors (ITU, 2012). Today the duathlon remains a popular sport although it is still not officially recognized by the International Olympic Committee.

In the United States, the recognized governing body for the duathlon is USA Triathlon, whose duties include certifying duathlons and setting rules for competition. International duathlon events are governed by the International Triathlon Union (ITU), which also certifies races and set rules for competition on a global level (ITU, 2012). Duathlons typically consist of run-bike-run competitions of various lengths, but the ITU established length of a duathlon consists of a 10 kilometer (km) running event followed by a 40 km cycling event and ending with a 5 km run (ITU, 2012). There are typically periods, referred to as transitions, between each running and cycling phase in which athletes exchange running shoes for bikes and helmets, and vice-versa. Transitions have energy costs of their own and have been shown to affect overall race performance and race time (Millet and Vleck, 2000). An athlete's ability to successfully perform in these events is dependent on a wide array of factors, which include physiological factors (age, gender, diet, general state of health

and previous conditioning), psychological factors, geographic factors (altitude, weather conditions during the event) and the physical characteristics of the race route itself (Saunders et al., 2004).

As in any sports event, athletes and coaches involved in duathlons everywhere are concerned with the age-old question of how to maximize an athlete's performance to confer an advantage over that of the competition. To that end, various physiological measures and performance tests have been adapted in an effort to develop and perfect training methodologies. One of the most important of these metrics includes testing for maximal oxygen uptake ( $VO_{2max}$ ), which represents the maximal capacity to utilize oxygen during exercise, and is typically done on a treadmill. The results of the  $VO_{2max}$  test reflect an athlete's level of cardiopulmonary fitness and can be used not only to design exercise training programs and to prescribe the level of training intensity, but also to monitor training load, so as not to overly stress an athlete beyond his or her capabilities (Balady et al. 2010).

Running economy (RE), which can be thought of as one measure of optimal running performance, is a metric which has been defined in many different terms. The simplest definition of RE is the most descriptive: RE is the oxygen uptake ( $VO_2$ ) at submaximal intensities. Runners with good running economy are those who have lower oxygen uptake at any given speed (Davies et al., 1997). In other words, they are able to utilize oxygen more efficiently during sustained long distance running. Running economy has been demonstrated to be a better metric than  $VO_{2max}$  for predicting performance in elite long distance runners who have comparable capacities for oxygen uptake (Saunders et al. 2004). In spite of this, RE has been less well studied than other factors in the field of running performance (Foster and Lucia, 2007).

To date, there have been relatively few studies investigating the compounding effects of a multi-sport competition on running performance. One of these, a master's thesis by

Vanhooy (2012), examined the effects of two different graded treadmill protocols on  $VO_{2max}$  in highly trained distance runners. Results showed that training specificity has no effect on performance during treadmill protocols of various grades. De Vito et al. (1995) examined the effects of the swim and cycling bouts on running performance using an Olympic distance triathlon simulation and in 2003. Vallier et al. investigated the compounding effects of the run-cycle-run transitions on the final run performance of a duathlon. The field therefore remains wide open for further research into the area of duathlon competition and running performance and the factors which affect it.

### **Statement of Purpose**

The purpose of this study was to examine the effects of a 10 km run followed by a 30 km cycling bout on the running economy of the last 5 km of an ITU duathlon simulation race performed in a laboratory setting.

### **Research Question**

Research Question: Is the running economy of an elite athlete's performance in a 10-30-5 duathlon affected by the compounding physiological effects of the two run- and cycle-legs of the race which precede the final 5 km run?

### **Hypothesis**

Hypothesis 1: There will be no difference in running economy between Trial 1 and Trial 3 at 5 mph.

Hypothesis 2: There will be no significance difference in running economy between Trial 1 and Trial 3 at 7 mph.

Hypothesis 3: There will be no significance difference in running economy between Trial 1 and Trial 3 at 10 mph.

## **Limitations**

This was a retrospective study and as such was bound by the previous study's limitations, (Berry, 2012), including:

- The study did not control for the training phase each subject was undergoing at the time of the study; subjects were not synced with regard to their training phases during the course of the study, which may have affected the results.
- Although the cycle ergometer was set up and adjusted for each subject, the bike positioning on the ergometer may have produced limitations on the riding mechanics of each athlete.
- Levels of fatigue and dietary status were monitored prior to each testing trial using self-report questionnaires. There is always a level of uncertainty introduced when using questionnaires for assessment of parameters in any clinical trial (Bowling A. 2005).

## **Delimitations**

This was a retrospective study and as such was bound by the previous study's delimitations, (Berry, 2012), including:

- All participants in this study were highly trained multi-sport athletes.
- Each subject's hydration status was monitored utilizing urine specific gravity tests before the start of each trial.
- Subjects were provided pre-testing information and completed a questionnaire before each trial to assess whether dietary patterns were consistent with normal daily intake.
- Start times for all trials were consistent for each subject – trials were scheduled for each subject to start at the same time each day – in order to control for normal daily

hormonal fluctuations.

- In the laboratory setting, a 40 km ride at an intensity of between 95-98% of ventilatory threshold takes an average of 35-45 minutes longer than cycling the same distance outdoors at a variable pace. Therefore, for this study, the 40 km cycling distance prescribed by the ITU was shortened to 30 km in order to more closely replicate the total time of an actual duathlon.

### **Assumptions**

- Subjects in this trial self-reported abstinence from all alcohol, drugs, or any other substances that otherwise might have affected the results of the study for 48 hours to 7 days prior to testing (see General Procedures section below).
- Subjects avoided making changes in their standard dietary regimens between trials and consumed the same foods and liquids and in approximately the same amounts that they would normally consume prior to a competition.
- Subjects answered the training history questionnaire and pre-trial questionnaires to the best of their knowledge and as accurately as possible (Berry, 2013).

### **Significance**

The physiological changes that occur with the fatigue and depletion experienced by most competitors at the last leg of a duathlon race are significant and can affect race outcomes. Running economy has been shown to be an important and useful measure of the efficiency of an athlete's running performance during competition and can be used as a parameter that can be used to guide racing strategies aimed to improve performance outcome. The results of this study may help shed further light on factors involved in the development of potential new training strategies to maximize duathlon racing performance.

## CHAPTER II

### REVIEW OF LITERATURE

This literature review covers three main topics pertinent to this retrospective study: maximal oxygen consumption, running economy (RE) and a discussion of performance interventions used to improve overall running economy.

#### **Maximal Oxygen Consumption ( $VO_{2max}$ )**

Past studies have demonstrated that  $VO_{2max}$  is one of the best measures of cardiopulmonary endurance and aerobic fitness when it comes to endurance sports like long distance running (Abe et al. 1998, Blomstrand et al. 1997). Oxygen consumption is the rate at which the body can uptake and metabolize oxygen, which is a complex physiological process and is dependent on many factors. A complete discussion of these processes is beyond the scope of this current study but thorough reviews can be found in exercise physiology textbooks such as Brooks et al. (2005).

Previous research has shown that testing for  $VO_{2max}$  can provide precise knowledge of an athlete's strengths and weaknesses (Saunders et al. 2004, Foster and Lucia, 2007).  $VO_{2max}$  testing also defines baseline physiological measurements from which not only exercise prescriptions and training programs can be developed but also can be used to provide feedback for evaluation of the effectiveness of existing training programs (MacDougall and Wenger, 1982). Since  $VO_{2max}$  is an important indicator of endurance potential and aerobic fitness, it has been a useful and widely used test for athletes, especially when used for determining the maximum performance capability during prolonged endurance exercise

(Brooks et al., 2005). Expected values for  $\text{VO}_{2\text{max}}$  in highly trained multisport athletes of various disciplines range from the high fifties to nearly 70 ml/kg/min ( $57.9 \pm 5.7$  to  $68.9 \pm 7.4$ ) (Millet et al., 2011).

Various studies have shown that highly trained single-sport athletes demonstrate a higher  $\text{VO}_{2\text{max}}$  than highly trained multi-sport athletes when tested in their specific discipline (Bouckaert et al. 1990, Millet et al. 2009). However, while highly-trained multi-sport athletes have high  $\text{VO}_{2\text{max}}$  values, these values are lower than that of highly-trained athletes who specializes in one event (Sleivert and Rowlands, 1996). So, single event athletes are more efficient in utilizing oxygen during competition than their multi-sport event counterparts, and therefore may have a competitive advantage in this respect.

An athlete's  $\text{VO}_{2\text{max}}$  is usually determined based on attainment of at least three of the four following objective criteria (Brooks et al., 2005). 1) a plateau in  $\text{VO}_2$ , or no increase in  $\text{VO}_2$  with an increase in workload (i.e., approximately three consecutive 15-second  $\text{VO}_2$  measurements within  $\pm 2$  ml/kg/min of each other); 2) a respiratory exchange ratio (RER) greater than 1.15; 3) elevated levels of blood lactic acid greater than 8 millimoles per liter (mmol/L); 4) Rated Perceived Exertion (RPE)  $\geq 17$ ; and/or 5) achievement of an age-predicted maximal heart rate ( $\pm 10$  bpm).

Past research has examined possible ways to improve the accuracy of  $\text{VO}_{2\text{max}}$  testing. For example, Kasch et al., (1982) showed that there can be as much as a  $\pm 5.6\%$  biological variability between subjects. Noakes (1998) reported that  $\text{VO}_{2\text{max}}$  measurements will change with differences in use of selected muscle groups, altitude and exercise duration. Lastly, Bassett and Howley (1997) reported that sport-specific  $\text{VO}_{2\text{max}}$  testing showed cyclists displayed a more representative  $\text{VO}_{2\text{max}}$  during cycling compared to running, whereas runners displayed a more representative  $\text{VO}_{2\text{max}}$  during running compared to cycling.



During competition, multiple factors contribute to the performance of athletes including: the psychological profile of the athlete, the percentage of  $VO_{2max}$  at which the athlete can perform and the duration of time the athlete can sustain maximal performance (Saunders et al., 2004). According to Bosquet et al. (2002),  $VO_{2max}$  alone is not sufficient to precisely predict the performance in athletic competition, but it is nevertheless considered a strong predictor of successful endurance running. In summary, measurement of  $VO_{2max}$  can provide an indication of an athlete's true ability and potential, especially with respect to endurance. Measurement of  $VO_{2max}$  can be used in the calculation of RE and thus provide a more precise determination of an athlete's cardiopulmonary fitness performance potential.

### **Running Economy (RE)**

Running economy (RE) is a measurement of an athlete's efficiency of oxygen utilization while running at a given pace. It is a metric widely used in the field of long distance running performance and has been defined as a measure of the energy required during submaximal running at a given velocity on a treadmill (Saunders et al., 2004). Running economy can also be defined as oxygen uptake ( $VO_2$ ) at submaximal intensities and has been shown to be a good predictor of running performance. In distance running, such as in a triathlon or duathlon, athletes can potentially improve their running performance by noting trends in measured RE during training and altering training strategies accordingly. Running economy can be a better predictor than  $VO_{2max}$  of running performance, especially for high level endurance runners (Saunders et al., 2004).

In the past four decades there have been few studies focused on RE and performance. Recently many exercise physiologists, trainers, and athletes have turned their attention to this topic; however, there is still a dearth of studies on this important subject.

## **Measurement of Running Economy**

Previous research studies have compared the energy costs of running over ground with running on a treadmill in a laboratory setting (Hauswirth et al. 1997; Kubukeli et al. 2002). Measurement of metabolic parameters in the field has the potential to introduce environmental variables into the data, such as air and wind resistance, which can negatively impact the results. These variables can be controlled for when done in a simulated laboratory setting on a treadmill, which was the method used in this study. For example, Pugh (1970) studied 5000 meter track runs and found that 8% of the total energy cost was expended overcoming air resistance. A telemetric system was used in another study to measure RE over ground in the field (Hauswirth et al., 1997). However, the system did not include the capability of measuring energy expenditure during either sub-maximal or maximal exercise.

Measuring RE while running on a treadmill has been shown to be highly correlated to outdoor ground running RE (Saunders et al., 2004). In the RE test, an individual is monitored while running under standardized thermo neutral laboratory conditions. While treadmill running is not identical to outdoor ground running, it is still a useful indicator of RE (Saunders, Pyne, Telford, & Hawley, 2004). Shifts in measured RE can be traced to quantifiable factors which can be used to modify training regimens with the ultimate goal of improving performance.

Establishment of a high degree of standardization in testing is necessary to measure changes in RE through repeated testing. Running economy changes over time, and is influenced by a variety of factors, including training (Saunders, et al., 2004).

## **Calculation of Running Economy**

Calculation of RE can be done using various methods. In some studies, RE was calculated by dividing the oxygen consumption corresponding to a submaximal velocity by that velocity, expressed as milliliters of O<sub>2</sub> consumed per kg per minute (ml/kg/min). Davis et al. (1997) calculated RE as the ratio of an individual's VO<sub>2</sub> in liters per minute (L/min) divided by body mass (BM) in kilograms. However, this measurement has the potential to introduce error in comparisons between subjects because oxygen consumption does not proportionally increase with increases in body mass (Bergh et al., 1991). Because there are so many variations in RE determination, this current study, decided to use VO<sub>2max</sub> at various running intensities to represent RE.

## **Running Economy: Performance and Endurance**

Runners who have good RE expend less energy and use less oxygen than runners who have poor running economy at the same velocity. Running economy is strongly associated with distance running performance and is a greater predictor of performance than VO<sub>2max</sub> among elite runners with similar levels of VO<sub>2max</sub> (Saunders, et al., 2004). VO<sub>2max</sub> is thereby a valuable measure of the upper limit of endurance performance in athletes.

The primary limiting factor for VO<sub>2max</sub> in humans is oxygen delivery to the tissues, including skeletal muscle tissue. Endurance training results in metabolic adaptations in skeletal muscle tissue through alterations in mitochondrial enzymes, among other mechanisms. In response to prolonged endurance training, mitochondria in skeletal muscle tissue increase in both number and size along with increases in myoglobin and oxidative enzymes (Zamora, A. J., et al. 1995; Wilmore, et al. 2008).

A combination of factors influence running performance. The degree to which an athlete can take up and utilize oxygen is a limiting factor for performance, but training can improve an athlete's level of performance overall. In other words, while  $VO_{2max}$  may be a limiting factor of endurance performance, the use of appropriate training raises this level. Training produces an increase in  $VO_{2max}$  through an increase in maximal cardiac output (Bassett & Howley, 2000).

Conditioning is an important factor in running performance. The training typically undertaken by each runner has been found to have significant positive effects on RE and can contribute to increases in running endurance (Saunders, et al., 2004). Various elements of training have been found to impact RE. Stretching prior to an endurance event, for example, has been found to lower endurance performance while at the same time raising the energy cost of running (Wilson et. al., 2010). Therefore, it is important to factor in conditioning when designing a program to improve RE.

### **Performance Interventions**

Specific training programs designed to improve RE vary widely. The general goal is to improve an athlete's  $VO_{2max}$ . Improvements in endurance and muscular conditioning are also important. Paavolainen et al. (1999) studied the impact of concurrent endurance training and explosive-strength training on physical performance characteristics. Results showed that the simultaneous application of these two training options resulted in an increase in maximal anaerobic ability and greater RE, which was attributed to improved neuromuscular conditioning that resulted from the training. In 2010, Ferrauti et al. found similar results, with concurrent strength and endurance training producing a positive result in the levels of running performance and RE in recreational marathon runners.

## CHAPTER III

### METHODOLOGY

This study was a retrospective analyses of data obtained from a clinical study by Nathaniel T. Berry (2012) in the UNC exercise physiology laboratory under the direction of Dr. Claudio L. Battaglini (Thesis Title: *The effects of a 10 km run and 30 km cycling time-trial on ventilatory threshold during the final running leg of an ITU Duathlon in highly-trained multi-sport athletes*. IRB #12-0199). This retrospective study was designed to extend the analyses of existing data to include measurement of running economy (RE) during the final leg of a 10-30- 5 km duathlon. Only methods information directly relevant to this current study is presented in detail. For a more complete description of the original study, please refer to the published master thesis of Berry (2012).

#### **Subjects**

Six highly-trained multi-sport male athletes, ranging in age from 18-45 years, were recruited to participate in the original study conducted by Berry (2012). An additional subject was added to the study at a later date, so data from a total of seven subjects were used for analysis in this current study. Prior to enrollment in the study, all subjects had been training a minimum of 15 hours per week for a minimum of six months. Before any evaluation or form completion, subjects signed informed consent which was approved by the University's Office of Human Research Ethics Institutional Review Board.

Each subject was given a physical examination, administered a medical history questionnaire, and completed a Par-Q (physical activity readiness questionnaire) prior to

being accepted for admission in the study. Samples of these forms are contained in Berry's

Appendices section (2012). All subjects were found to be healthy – defined as low risk individuals for participation in maximal exercise testing based on the guidelines set forth by the American College of Sports Medicine (2010), and had no prior orthopedic injuries. Subjects were required to have an organized dietary and nutritional plan during the study, with consistency in number of meals and caloric intake each day.

### **Instrumentation**

Height and weight were recorded using a stature meter (Perspective MO, USA) and Detecto 2381 balance beam scale (Detecto, Webb City, MO, USA). Urine specific gravity (USg) was assessed with a refractometer (TS Meter, American Optical Corp, Keene, NH, USA).

Oxygen consumption ( $\text{VO}_2$ ), expired carbon dioxide ( $\text{VCO}_2$ ), ventilation ( $\text{V}_E$ ), ventilatory threshold  $\text{V}_T$  and respiratory exchange ratio (RER) were assessed using a Parvo Medics TrueMax® 2300 Metabolic gas analyses system (Parvo Medics, Salt Lake City, UT, USA). A Lactate Plus lactate analyzer (Sports Resource Group, Hawthorne, NY) was used to determine blood lactate values. The Borg 6-20 scale (Borg, 1970) was used to quantify rating of perceived exertion (RPE) throughout each of the three trials. Heart rate (HR) was monitored with a Pacer model of polar heart rate monitor to measure heart rate during each trial (Polar, Lake Success, NY, USA)

### **General Procedures Relevant for the Current Study**

The *original study* (Berry, 2012) consisted of three testing trials, all performed in a human performance exercise lab in a large research university located in the Southeastern region of the United States. Testing sessions were done on three different days and all were

completed within 21 days of the first trial.

In the laboratory setting, a 40 km ride at an intensity of between 95-98% of  $V_T$  takes an average of 35-45 minutes longer than cycling the same distance outdoors at a variable pace. Therefore, for this study, the 40 km cycling distance prescribed by the ITU was shortened to 30 km in order to more closely replicate the total time of an actual duathlon. Prior to testing, subjects were given pre-trial testing guidelines listed below:

1. No eating 4 hours prior to testing.
2. Void completely before testing
3. Maintain proper hydration prior to testing.
4. Please wear appropriate clothing/shoes for testing (running shorts/shirt/shoes)
5. No exercise 12 hours prior to testing.
6. No alcohol consumption 48 hours prior to testing.
7. No diuretic medications 7 days prior to testing.
8. To control for circadian rhythm and any variation that could affect the results of this study, each additional session was scheduled at a similar time of day ( $\pm 2$  hours).

**Trial 1.** Each subject performed a speed-only  $VO_{2max}$  (SO $VO_{2max}$ ) treadmill testing protocol. Although only  $VO_2$  was used to determine RE, other metabolic factors such as  $VCO_2$ ,  $V_E$ , HR, and the RER were measured every 15 seconds throughout the testing session to corroborate the physiological intensity.

Trial 1 protocol included screening of subjects for eligibility for participation in the study. The screening consisted of a physical examination conducted by medically trained personnel, self-completion of the PAR-Q (a questionnaire designed to assess physical activity readiness), a training history questionnaire, and a questionnaire designed to subjectively quantify pre-exercise levels fatigue, sleep and dietary habits. All questionnaires can be found

in Berry's thesis publication (2012). Each subject was then weighed and submitted a urine sample for assessment of hydration status using a refractometer. Subjects were required to have a urine specific gravity (USg) reading between 1.010 to 1.030 to confirm a euhydrated state (i.e., not dehydrated). After all screenings were completed, subjects received more detailed information regarding the study protocol and requirements.

Testing consisted of an incremental treadmill test to assess  $VO_{2max}$ . Measurement of  $VO_{2max}$  was performed using a speed-only protocol (SO $VO_{2max}$ ) consisting of one minute stages, beginning at 5mph and increased by 1mph each minute until a speed of 11mph was reached. At that point, speed was increased by 0.5mph per minute. The measured physiological variables included  $VO_2$ ,  $VCO_2$ ,  $V_E$  and RER every 15 seconds throughout the testing session. The rating of perceived exertion (RPE) was taken at the conclusion of each stage and at the conclusion of the testing protocol. Heart rate (HR) was monitored and a blood sample for lactate levels was taken by finger stick three minutes after the end of the final stage. Results from Trial 1 were used to compare  $VO_{2max}$  and  $V_T$  observed during a single bout of maximal exercise to those values obtained during Trial 3.

**Trial 3.** Trial 3 consisted of a 10 km run and a 30 km cycling time-trial followed by Vanhoy's (2012) treadmill SO $VO_{2max}$  testing protocol. Subjects completed the 10 km run and 30 km cycling time trial on a treadmill and cycle ergometer; each of these exercise bouts were performed at  $VO_{2max}$ . Subjects were taken on and off the metabolic cart throughout various times of the exercise bouts in order to assess and monitor exercise intensity. Criteria used for determining  $VO_{2max}$  was the same in all trials.

Per standard  $VO_{2max}$  determination criteria (Brooks et al., 2005), subjects were required to achieve a minimum of three of the following five criteria for the trial to be considered a true, viable and maximal effort:



- 1)  $RER \geq 1.15$
- 2)  $RPE \geq 17$
- 3) HR within 10 beats of maximum predicted for age
- 4)  $VO_2$  plateau within  $\pm 2\text{ml/kg/min}$  or decline of  $VO_2$  with increased workload
- 5) Blood lactate  $\geq 8\text{mmol/L}$

Trial 3 simulated an ITU Duathlon. Similar to Trial 1, each subject completed pre-trial questionnaire and submitted a urine sample to assure proper hydration status before  $VO_{2\text{max}}$  testing. This third trial consisted of a 10 km run, a 30 km cycling time-trial and the same treadmill  $SOVO_{2\text{max}}$  protocol described earlier. These were performed in immediate and successive order. The initial 10 km run and succeeding 30 km cycling time trial were performed at an intensity equal to 95-98 of  $V_T$ . During the 10 km run, this intensity was equated to a specific running speed while exercise intensity on the cycle ergometer was equated to a specific workload measured in Watts (W). During both the 10 km run and 30 km cycling time trial, the same physiologic data as Trial 1 were collected at the same specified intervals in order to assess and monitor exercise intensity. Upon completion of these two exercise bouts, the subjects transitioned back onto the treadmill to complete the  $SOVO_{2\text{max}}$  protocol. Oxygen uptake and  $V_E$  were measured every 15 seconds throughout the trial while simultaneously monitoring HR. RPE was recorded at the end of each stage. A blood lactate sample obtained via fingerstick was obtained three minutes after the completion of the  $SOVO_{2\text{max}}$  protocol.

### **Research Design Statistical Analyses**

Retrospective analysis consisted of comparing RE for each intensity level (speed) for Trial 1 vs. Trial 3 conducted in Berry's study 2012. Running economy was calculated as follows:

$RE = VO_{2submax}$  (ml/kg/min): The recorded submaximal  $O_2$  uptake (ml/kg)-at a given speed-(in minutes) (Davis et al., 1997).

The independent variables for this current study were running intensity (low @ 5 mph, medium @ 7 mph and high @ 10 mph) and trial (Trial 1 vs. Trial 3). The dependent variable was RE ( $VO_2$ ) at any given intensity (speed). Descriptive data was reported as means  $\pm$ SD. Statistical significance was set a priori at an alpha level of 0.05 for all analyses. The data were analyzed using the SPSS (v. 19.0) Statistical Software Package (IBM Solutions, Durham, North Carolina). RE data were analyzed using a 3 X 2 repeated measures of ANOVA with two factors. (Factor 1= 3 different exercise intensities (5mph, 7mph, and 10mph); Factor 2=  $VO_{2max}$  trial 1 and  $VO_{2max}$  trial 3). If an interaction effect of the ANOVA model was found to be significant, post hoc analyses using dependent samples t-tests were used to compare RE between trials 1 and 3 at 5, 7, and 10 mph.

## CHAPTER IV

### RESULTS

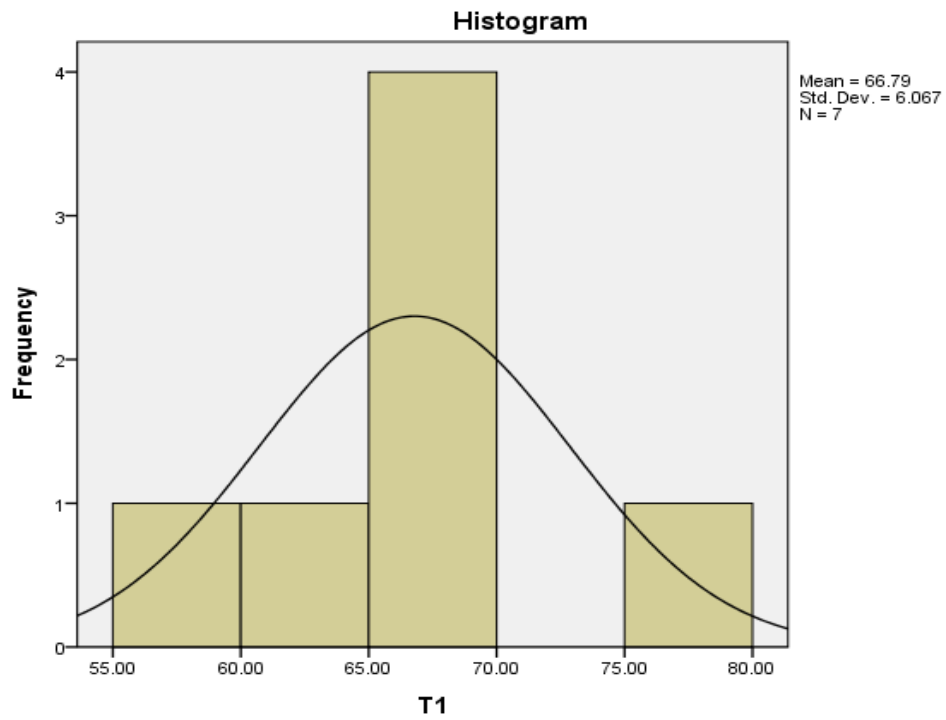
The purpose of this retrospective study was to examine the effects of a 10 km run followed by a 30 km cycling bout on RE during the last 5 km of an ITU duathlon simulation race performed on a laboratory setting, as measured by the change in  $VO_2$ .

#### Descriptive Information

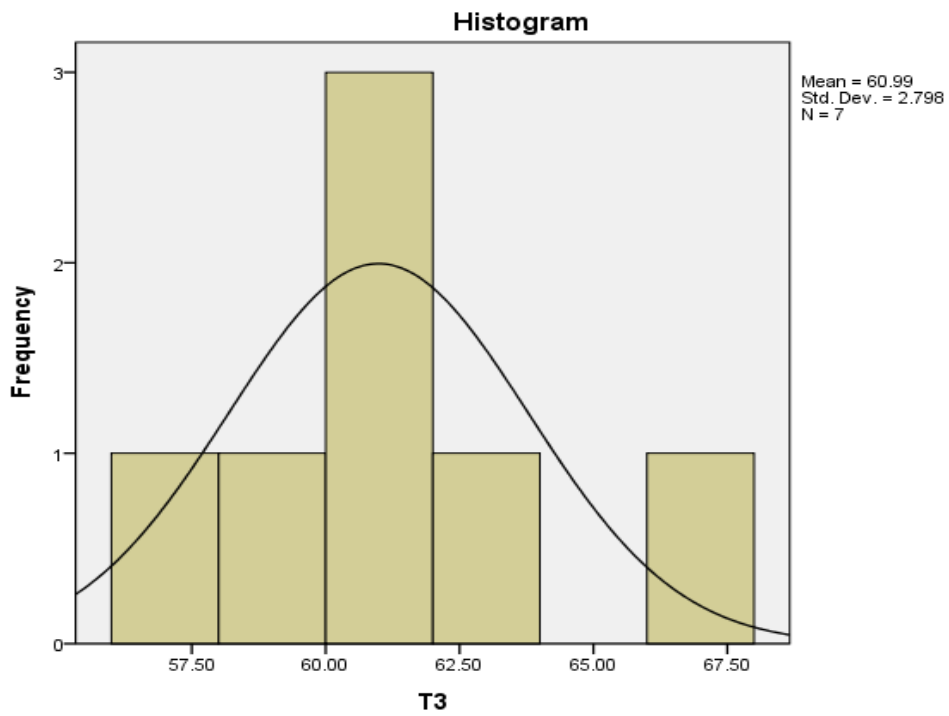
Seven highly-trained male multi-sport athletes participated in this study. Their mean descriptive information was as follows: age 34 ( $\pm 9$  years), height 177.7 ( $\pm 3.7$  cm), and weight 74.2 ( $\pm 2.6$  kg). To determine if the subjects' maximum aerobic capacities were normally distributed within each trial, the data were plotted on histograms and visually examined for possible influential outliers. As seen in the histogram plots of Trial 1 and Trial 3 (Figures 1 & 2) the individual aerobic maximum capacities attained from the  $VO_{2max}$  tests were similar within each trial. A complete set of data is available in the thesis of Nathaniel Berry (2012).

On the histogram frequency data output (Figures 1 and 2 below), the mean and median  $VO_{2max}$  scores were similar (Trial 1 Mean, Median = 66.79, 66.4, respectively; Trial 3 Mean, Median = 60.99, 60.1, respectively), the standard deviations were low (Trial 1  $\pm 5.62$ ; Trial 3  $\pm 2.59$ ), and there was a relatively normal distribution curve for the values as seen on each of the histograms. Although Trial 3 data appears skewed to the left, this slight deviation is still within normal limits, as suggested by the standard deviation (which is relatively low) and by the mean and median. Therefore, these results focus on the collective group without any case excluded, and so parametric tests were used.

**Figure 1. Mean Distribution (n = 7) VO<sub>2</sub> max (ml/kg/min) for Trial 1**



**Figure 2. Mean distribution (n = 7) VO<sub>2</sub> max (ml/kg/min) for Trial 3**



## Repeated Measures ANOVA Analysis

The hypothesis for this retrospective thesis stated, “*There will be a significant decrease in running economy (RE) at three different levels of running intensity (low = 5mph, moderate = 7mph and high = 10mph) at final VO<sub>2max</sub> (Trial 3) when compared to same intensities of the VO<sub>2max</sub> test performed in Trial 1.*” The hypothesis was tested using a 3 x 2 repeated measures ANOVA with two factors. Factor 1 was the independent variable named exercise intensity (3 intensity speeds: low (5mph), moderate (7mph), and high (10mph). Factor 2 was the trial (2 trials). The dependent variable was running economy (RE) for each of the 2 trials, and was represented by the measured VO<sub>2max</sub> (ml/kg/min) value. Table 1 shows the results of the analyses of the 3 x 2 repeated measures ANOVA model. Tables 1 through 4 and Figure 3 show the 95% confidence intervals for intensity, trial, and interaction (respectively).

**Table 1. ANOVA Analysis**

Source	Df	MS	Critical F Value	Significance (p value)
Intensity	2	3803.255	187.683	0.000
Trial	1	6.800	0.479	0.515
Intensity * Trial	2	21.537	3.988	0.047

**Table 2. Confidence intervals for Intensity Estimates**

Intensity	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	20.479	2.108	15.320	25.638
2	36.957	0.981	34.557	39.357
3	53.443	0.936	51.154	55.732

**Table 3. Confidence intervals for Trial**

Trial	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
1	36.557	0.918	34.310	38.804
2	37.362	1.446	33.824	40.900

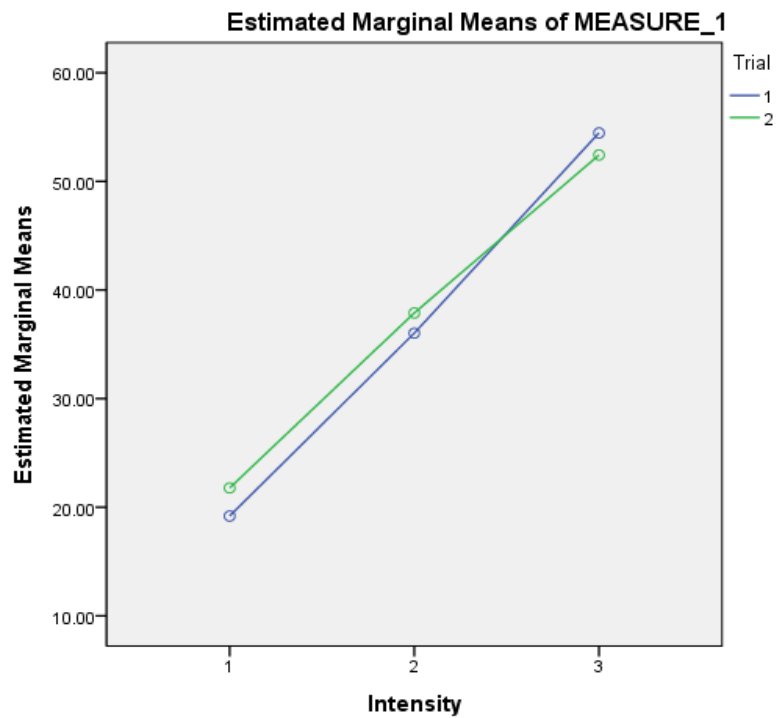
**Table 4. Confidence intervals for interaction (Intensity \* Trial)**

Intensity	Trial	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
1	1	19.186	1.405	15.748	22.624
	2	21.771	3.128	14.118	29.425
2	1	36.029	1.072	33.406	38.651
	2	37.886	1.037	35.349	40.423
3	1	54.457	0.884	52.293	56.621
	2	52.429	1.170	49.565	55.292

**Table 5. Paired Sample T-Test**

		t	Df	Significance (p value)
Pair 1	LI_T1 - LI_T3	-1.080	6	0.322
Pair 2	MI_T1 - MI_T3	-2.397	6	0.054
Pair 3	HI_T1 - HI_T3	2.263	6	0.064

**Figure 3. The plot of the marginal means for intensity by trial**



As shown in the data analysis tables and Figure 3 above, the overall repeated measures ANOVA test, showed there was a significant main effect for intensity ( $p < 0.0001$ ) as well as a significant main effect for trial or trial\*intensity ( $p = 0.047$ ). Descriptive statistics for the analysis of the hypothesis 1 is presented in Table 6.

**Table 6. Descriptive statistics for the 3x2 repeated measures ANOVA (N=7)**

<b>Trials</b>	<b>Running Economy = <math>VO_{2max}</math> (ml/kg/min) (Mean <math>\pm</math> SD)</b>
Trial 1 (Low intensity, 5mph)	18.6 $\pm$ 4.9
Trial 3 (Low intensity, 5mph)	21.7 $\pm$ 8.2
Trial 1 (Moderate intensity, 7mph)	36.2 $\pm$ 2.8
Trial 3 (Moderate intensity, 7mph)	37.8 $\pm$ 2.7
Trial 1 (High intensity, 10mph)	54.4 $\pm$ 2.3
Trial 3 (High intensity, 10mph)	52.4 $\pm$ 3.0

The results of the post hoc analyses showed no significant difference in RE between Trial 1 and Trial 3 for RE calculated at 5mph ( $p = 0.32$ ). However, at moderate (7mph) and high (10mph) intensities the results of the analyses approached significance (Moderate Intensity,  $p = 0.054$  and High Intensity,  $p = 0.064$ , respectively).



## CHAPTER V

### DISCUSSION

The purpose of this retrospective study was to examine the effects of a 10 km run followed by a 30 km cycling bout on the RE of the last 5 km of an ITU duathlon simulation race on seven highly-trained male multi-sport athletes.

It was hypothesized that there would be a significant decrease in RE, which can be thought of as the rate at which the volume of oxygen ( $\text{VO}_2$ ) is used at a specific speed during the final leg of a simulated duathlon. This result would be due mainly to the compounding physiological effects of the two run and cycle legs of the race which precede the final 5 km run. In this study, RE was quantified using  $\text{VO}_{2\text{max}}$  (ml/kg/min) at three different levels of running intensity (low = 5mph, moderate = 7mph and high = 10mph).

As expected, this retrospective study showed there was a statistically significant difference ( $p < 0.0001$ ) for the main effect of intensity. As noted in the results Table 1, there was also a significant trial \* intensity interaction effect ( $p = 0.047$ ). The results of the planned paired sample t-test approached significance (nearing  $p < 0.05$ ) for both the moderate (7mph) and high intensities (10mph). The  $\text{VO}_{2\text{max}}$  was higher in Trial 3 (versus Trial 1) at both the low and moderate intensities. Conversely,  $\text{VO}_{2\text{max}}$  was *decreased* by 2 ml/kg/min at the high intensity level in Trial 3. However, this slight decrease is well within the measurement error and so may not be important from a practical perspective. Therefore, these results should be viewed with caution.

Running economy, as stated earlier, can be defined as submaximal oxygen uptake ( $\text{VO}_{2\text{submax}}$ ) for a given speed. This current study utilized  $\text{VO}_2$  values attained at different running speeds. Runners with good running economy were those who had a lower level of oxygen uptake at any given speed (Davies et al., 1997). In other words, they were able to utilize oxygen more efficiently during sustained long distance running.

To date, there have been only two studies investigating the compounding effects of a multi-sport competition on running performance. De Vito et al. (1995) examined the effects of the swim and cycling bouts on running performance of six male triathletes using an Olympic distance triathlon simulation, and found an impairment in endurance performance which was attributed to the physiologic effects on athletes of the first two segments of the race. In contrast, Vallier et al. (2003) investigated the compounding effects of the run-cycle-run transitions on the final run performance of a duathlon and found no significant difference in the energy cost of running between the first and final leg of the simulated duathlon.

What are the possible cumulative physiological effects on runners of the first two legs in this study which might have contributed to a decrease in running economy during the final 5 km of the simulated race? Level of fatigue, and the energy costs of transitioning from the bike-to-run phase are three of the salient factors that come into play. Millet and Vleck published a review of studies in 2000 documenting the physiological effects of the bike-run transition, which showed that the energy costs of running during the cycle to run transition is higher than the energy costs of routine running at the same speed. In an outdoor study of running economy, Guezennec and colleagues (1996) published a study of 11 trained male subjects designed to examine the increase in energy cost of running of an Olympic distance triathlon, measuring  $\text{O}_2$  uptake, heart rate and ventilation, and found a decrease in running efficiency at the end of the triathlon. In 1997, a study of 7 well trained athletes in three experimental trials, Hausmann et al. examined the increased energy cost of running at the end

of a triathlon and a marathon. His research team found a decrease in running efficiency which they attributed not only to kinematic parameters, but also to “global alterations of many different parameters.” Published results like those of Hausmann et al. (1997) appear to support the hypothesis presented here: that there will be a significant decrease in running economy during the final 5km run of a 10-30-5 km simulated duathlon when compared to the running economy of the initial 10 km run tested in a laboratory setting.

### **Study Limitations**

Certain limitations of this study may have factored into the results of this current retrospective analyses, most notably, the small sample size. A larger sample may have yield more power to detect clearly significant differences rather than “trends” toward significance for the planned comparisons. Furthermore, although all subjects had been training a minimum of 15 hours per week for a minimum of six months prior to enrollment, the design of the study did not control for the training phase each subject was undergoing at the time of the study, so subjects were not synced with regard to their training phases. Additionally, even though the cycle ergometer was set up and adjusted for each subject, the bike positioning on the ergometer may have produced limitations on the riding mechanics of each athlete.

Subjects in this study also self-reported abstinence from all alcohol, drugs, or any other substances that otherwise might have affected the results of the study for 48 hours to 7 days prior to testing. Again, the utilization of self-reporting is sometimes unreliable. Diet, both the type and amount of food consumed, has been shown to play a significant role in sport performance, which was not controlled for in this study. To minimize these known self-reporting issues, subjects reported avoiding making any changes in their standard dietary regimens between trials and reported consuming the same foods and liquids and in approximately the same amounts that they would normally consume prior to a competition.

## CHAPTER VI

### CONCLUSION

#### Summary

One of many ways of optimizing an athlete's performance is to increase his or her running economy, the efficiency with which an athlete uptakes and utilizes oxygen during activity. This study examined the effects of a 10 km run and 30 km cycling on the running economy in the last 5 km of a simulated duathlon executed by seven experienced male athletes. After measuring the final maximal oxygen consumption following a 5, 7, and 10 mph running phase, the researchers drew conclusions about the multiple athletes' running economy. The results of the overall 3 x 2 ANOVA showed a significant main effect for intensity ( $p < 0.0001$ ) plus a significant interaction effect between trials \* intensity ( $p = 0.047$ ). The planned comparisons using dependent t-tests produced near-significant differences that warrant the drawing of conclusions about the running economy, even in this small sample size. Specifically, dependent tests approached significance (nearing  $p < 0.05$ ) for both the moderate (7mph) and high intensities (10mph). This suggests a possible statistical trend toward support for the hypothesis, had a larger sample of subjects been used in this study.

#### Conclusions

The results of this study showed that RE appears to suffer the compounding effects of running and cycling prior to the last running leg of duathlon event only when the athlete reached moderate and high intensities during the last run; represented in this study by speeds

of 7mph and 10mph. However, due the relatively small more research is warranted to confirm and results the results of this study.

### **Practical Application**

This research is important for assisting coaches and multi-sport athletes to design training plans aimed to minimize as much as possible the apparent decline in RE during the last leg of a duathlon race demonstrated by this study. With the results of this study, coaches may be able to not only design training plans aimed to maximize running performance during a duathlon race, but also determine racing strategies that allow the athlete to maximize performance by avoiding the possibility of running beyond what they should and attain better racing results.

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