EVENT ORDER IN THE BIATHLON DOES NOT HAVE AN EFFECT ON METABOLIC RESPONSE.

THESIS

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The purpose of this study was to examine the effects of event order on a cycling(C)/running(R) or R/C biathlon. Eight experienced male biathlete/triathletes with a mean age of 24.9 ± 4.6 yr formed the sample of the study. Results show no significant interaction effects on oxygen consumption peak, oxygen consumption during steady-state, ventilation, and heart rate when C/R or R/C are performed at 70% oxygen consumption peak for subsequent R and C respectively. These results seem to indicate that the biathlete/triathlete is efficient in both C and R to the extent that event order does not significantly interact with metabolic response in submaximal cycling and running.

TABLE OF CONTENTS

TABLE OF CONTENTS -- Continued

LIST OF FIGURES AND TABLE

CHAPTER 1

INTRODUCTION

The sport of triathlon has enjoyed rapid growth and increasing popularity in the 1980's (Murphy, 1989). The sport began in 1978 and will make it's first appearance in the Olympics as an experimental sport in 1992, at Barcelona, Spain. The triathlon is a three-stage sport that involves swimming, cycling and running in succession. The three-sport nature of the triathlon, in which all three sports involve specific cardiovascular adaptations from aerobic training, promote it as a high-level fitness activity (Town, 1985). Those individuals who are unfamiliar with the sport tend to associate the triathlon with the grueling ultra-distance Ironman Triathlon held in Kona, Hawaii each October; when actually the triathlon is a sport that often may consist of shorter events, making it possible for an athlete to compete several times each month. Though triathlons have numerous distances and also have various event orders, they can be placed primarily into three different categories: the ultra-distance course, consisting of a 3.9 km swim, a 180.2 km bike segment, and a 42.2 km run; the long course, consisting of a 3.1 km swim, a 120 km bike segment, and a 32 km run; and the Olympic distance course, consisting of a 1.5 km swim, a 40 km bike segment, and a 10k run. The majority of triathlon events are of the Olympic type, and frequently the bike/run order is reversed. Previous studies (Holly, Barnard, Rosenthal, Applegate, and Pritikin, 1986; Kohrt, Morgan Bales, and Skinner, 1987; O'toole, Hiller, Crosby, and Douglas, 1987) provided useful information that has been used to describe the physical and physiological characteristics of the triathlete. These investigations demonstrated that male triathletes have oxygen uptake values comparable to those of well-trained athletes who compete in each of the three individual events. O'toole et al., (1987) compared the physique of the triathlete to that of the elite cyclist. A majority of the studies completed on triathletes have examined the physiological stress or damage occurring during a triathlon. Farber, Hill, Hill, Arbetter, Grimaldi, and Shaefer (1985), Smith, Otto, Southard, and Weathermax (1985), van Rensburg, Kielblock, and van der Linde (1986) concluded that triathlon competition significantly elevated serum enzyme levels, and in some cases, caused muscle tissue damage. Also, from studying the steroid hormone, cortisol, Rogers, Goodman, Mitchell, and Hattingh (1986), Urhausen and Kindermann (1987) demonstrated that the prolonged duration of a triathlon caused the triathlete considerable physiological strain and possibly some muscular damage.

Wells, Stern, Kohrt, and Cambell (1987) studied the effects of sequential bike to run and run to bike performances. These investigators reported a significant decrease in the vascular volume, resulting in hemoconcentration for both males and females. Also, moderate dehydration, in the face of ad libitum fluid replacement, was observed to occur. The investigators, however, did not make conclusions as to what extent the initial mode of exercise affected the subsequent mode. No data exists at this time in the current literature reporting the effects that sequential running and cycling have on metabolic measures, such as maximal oxygen uptake, heart rate, and workload at time of exhaustion. Such a study would enhance the base of knowledge concerning the effects that one mode of exercise has on the other, in terms of metabolic response.

Statement of the Problem

What effects do initial cycling and running have on subsequent cycling and running, in terms of $\dot{V}O2$ peak, $\dot{V}O2$, ventilation, and heart rate. There will be a relationship between event order in the Biathlon.

Hypothesis

There will be a relationship between the order of performance, cycling/running or running/cycling, and oxygen consumption, ventilation, and heart rate.

Limitations

This study was limited by the following factors:

1. Small sample size;
2. The study was conducted in a laboratory setting which may limit the specificity of running and cycling.
3. The metabolic cart had a 2000 breath storage capacity, making it difficult to collect data continuously during long term exercise bouts.
4. CO_2 measurements were not accurate, causing an invalid measurement of RQ.

Delimitations

The study was delimited by the following factors:

1. Only males between the ages of 17 and 35 were tested;
2. Only competitive triathletes/biathletes were chosen for the study.

Definitions

Triathlon--A multi-sport that most commonly includes swimming, cycling, and running.

Biathlon--A multi-sport that most commonly includes cycling and running in either order.

$\dot{V}O_2$ Peak--The greatest rate of oxygen consumption attained during exercise at sea level, usually expressed in liter per minute (l.min-1) or milliliters per kilogram body weight per minute (ml.kg.min-1).

Cardiovascular drift--The cardiovascular adjustment to prolonged exercise in which heart rate increases and stroke volume decreases in order to maintain cardiac output during constant load exercise.

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CHAPTER II

REVIEW OF LITERATURE

The Physiological Characteristics of the Triathlete/Biathlete

The successful triathlete is a very unique athlete who must be highly conditioned and skilled in three sporting events in order to be competitive in the triathlon. Swimming, cycling and running are the sports that the triathlete must become efficient at in order to be successful. Training for optimal performance in triathlon competition requires the athlete to use specific principles of conditioning for each sport. When examining the physical structure of the triathlete, the $\bar{x}$ body fat of the male is approximately 9.0% and the female is approximately 13.7% (O'Toole, Hiller, Crosby, and Douglas, 1987; Holly, Barnard, Rosenthal, Applegate, and Pritikin, 1986). The male triathletes exhibit more body fat than that of the elite runner, but have less than that of the elite swimmer. After comparing the height, weight, and percent body fat of triathletes to elite athletes in the three respective sports, the triathlete's physique was determined to be most similar to that of the elite cyclist's (O'Toole et al.,1987). For the female triathlete, weight was less than that of elite swimmer's and cyclist's, but greater than that of the elite runner. The average percent body fat of the female triathlete in two previous studies was 13.7% (O'Toole et al., 1987; Holly et at., 1986). Like the male, the female body type was characteristic of elite female cyclists (O'Toole et al.,1987).

The $\dot{V}O2_{max}$ (maximal oxygen consumption) values for male triathletes suggest that these athletes are at the well-trained level in each of the three sports (Kohrt, Morgan, Bates, and Skinner, 1987; O'Toole et al.,1987). Four males who finished in the top fifteen in the Ironman Triathlon World Championship in Hawaii had a mean $\dot{V}O2_{max}$ 72.0 ml/kg/min measured while running on a treadmill (O'Toole et al.,1987). Those four athletes were all of elite status. However, no measurements were taken during cycle ergometry or swimming performance. Therefore, it is difficult to determine whether these four males were elite swimmers and cyclists as well as runners, or just elite runners who were well-trained in swimming and cycling. When excluding these four males, the remaining male triathletes who were competitive in nature (professional as well as amateur) demonstrated $\dot{V}O2_{max}$ values that were equally high in all three sports, but not of the elite caliber in any single sport as compared to that of elite athletes in the three single sports. Furthermore, when comparing the mean percentage of $\dot{V}O2_{max}$

during cycling and swimming to running $\dot{V}O2_{max}$, these percentages were significantly higher in triathletes than those of recreational athletes involved in swimming and cycling (O'Toole et al., 1987; Kohrt et al., 1987). The female triathlete also compared favorably to athletes in each of the three sports (Holly, Barnard, Rosenthal, Applegate, and Pritikin,1986; O'Toole et al., 1987). One female triathlete has recorded $\dot{V}O2_{max}$ values of 80 ml/kg/min running, 74.8 ml/kg/min cycling, and 59.6 ml/kg/min arm ergometer (O'Toole et al., 1987).

Because a triathlete must train for three different sports, it seems that the mileage for all three sports must be reduced from that compared to the elite athlete who trains solely in one sport. However, the training load for each of the three sports can still be adequate for a competitive triathlete to maintain a well-trained status in all three sports (O'Toole et al., 1987; Holly et al., 1986). The literature is still inconclusive as to whether cross-training effects occur when training for swimming, cycling, and running in preparation for a triathlon. Cross- training refers to training for a particular aerobic activity which will enhance another aerobic activity. Otto, Smith, Weathermax, Southard, and Wygand, 1986, compared the metabolic capacities of novice triathletes to their performances in a triathlon and demonstrated a significant correlation ($p<.05$) between running $\dot{V}O2_{max}$ and run time. A poor correlation existed, however, between the $\dot{V}O2_{max}$ and performance times of the swim and cycle events. It might be postulated that a factor such as efficiency in swimming and cycling could improve performance beyond that which would be expected from the measured $\dot{V}O2_{max}$ exclusively (Kohrt et al., 1987; Otto et al., 1986). When determining success in the triathlon, the $\dot{V}O2_{max}$ is less significant than economy (Dangle, Flynn, Costill, Kirwan, Beltz, Neufer, 1986).

Training practices of triathletes may give researchers more insight as to the proper training regimen that can be incorporated for optimal triathlon performance. An empirical investigation of triathlon performance and training practices showed that the training practices reported by participants were related to final times in a triathlon as well as times in each of the three legs of the event (Zinkgraf, Jones, Warren, and Krebs, 1986). These investigators demonstrated that average weekly distances, longest single workouts, training frequencies, and performance times in mile, 5 km and 10 km runs, and mile swims were related to performance. However, interval-type training or long/slow distance training as compared to intense steady-state training was not mentioned in the study. Subsequently, it is clear that training specificity for each sport is the limiting factor for triathlon success (Zinkgraf et al., 1986).

Another characteristic examined by researchers was that of the dietary intake of the triathlete. Holly, Barnard, Rosenthal, Applegate, and Pritikin,(1983), concluded that a low fat, high complex-carbohydrate diet is a safe and effective diet for prolonged endurance competition. The average daily intake of the triathletes examined was 59% carbohydrate, 21% fat, and 20% protein measured by dietary recall. Twenty-seven triathletes that participated in the 1988 Hawaii Ironman Triathlon were used to characterize the race-day dietary intakes of the triathlete (Applegate, O'Toole, and Hiller, (1989). The data showed that the athletes in this study used good fluid and food replacement strategies, and that caffeine and anti-inflammatory agents are common ergogenic aids used by these triathletes (Applegate et. al., 1989).

Researchers have attempted to measure the anaerobic characteristics of the triathlete and compare the results to athletes that compete in sprint, middle-distance, and distance events. Skinner, Kohrt, Bates, and Morgan (1985), measured the anaerobic capacity of eleven triathletes using arm and leg ergometer tests. The triathletes' anaerobic power and anaerobic capacities were lower than those of the sprinters, and higher than those of the endurance athletes. The triathletes' compared equivalently with those who compete in middle-distance events in terms of anaerobic power and capacity. However, when ratios of anaerobic power/$\dot{V}O2_{max}$ and anaerobic capacity/$\dot{V}O2_{max}$ were calculated, the triathlete was most similar to the endurance athlete and lower than the sprinter and middle-distance athletes. The high $\dot{V}O2_{max}$ of the triathlete associated with endurance training, and the low ratio of anaerobic power/$\dot{V}O2_{max}$ and anaerobic capacity/$\dot{V}O2_{max}$ seem to suggest a low percentage of fast-twitch muscle fibers present in the triathlete (Skinner et al., 1985).

The Acute Physiological Effects of Triathlon Competition

The sport of triathlon attracts over 1.5 million participants annually (O'Toole and Douglas, (1989) . Many athletes interested in the triathlon have come to realize that, if trained for properly, the triathlon is an event which an athlete can compete in several times monthly. This does not include the ultra-distance events which may take months of preparation as well as adequate time for recovery. Most individuals associated the early triathlons with ultra-distance events and the studies initiated examined the potential catabolic effects which might affect or even endanger the athletes of the triathlon.

Tharp (1975) studied the role of cortisol in relation to long-term exercise and concluded that this hormone increases in magnitude during the ultra-type endurance events. Rogers, Goodman, Mitchell, and Hattingh (1986), and Van Rensburg, Kielblock, and van der Linde (1986), showed significant elevations in the stress-induced hormone during ultra-distance triathlon competitions. van Rensburg et al. (1986), stated that the duration of such an event in which increased fatty acid release takes place is a primary reason for the elevated cortisol levels. Rogers et al. (1986), stated that the duration of such an event, added to the physiological and psychological stress during the race, may have constituted the cortisol elevation in post-race blood samples. Urhauser and Kindermann (1987), examined another hormone, testosterone, using subjects who competed in an event approximately one-quarter the length of an ultra-event. Their findings show testosterone elevation for several days after the race, which suggest a possibility of pronounced catabolic activity. These results, based on only a one-quarter ultra-distance triathlon, show the possibility for severe catabolic activity in an ultra-distance race is quite likely.

Serum enzymes such as serum lactate dehydrogenase (LDH), serum glutamate pyruvate transaminase (SGPT), serum glutamate oxalo-acetate transaminase (SGOT), and creatine phosphokinase (CPK) are all serum enzyme components that have been associated with muscle tissue damage. Apple and

McGue (1983), reported resting enzyme levels elevated beyond normal levels in marathon runners during training. Other investigators have shown significant elevations in serum enzyme levels following exhaustive exercise (Block, van Rijemont, Badjou, Von Melsen, and Vogeleck, 1971). Several groups of investigators have shown serum enzymes to be extremely elevated above the normal ranges following triathlon competition (van Rensburg et al., 1986; Smith, Otto, Southard, and Weathermax, 1985; Holly et al., 1986; Farber, Hill, Hill, Arbetter, Grimaldi, and Schaefer, 1985). The majority of triathletes measured exhibited resting enzyme levels elevated above normal. However, after triathlon competition, LDH, SGOT, and SGPT levels were elevated 88%, 41%, and 116%, respectively (Farber et al.,1985), and remained elevated for up to five days post-competition (Holly et al., 1985; Holly et al., 1986). This finding suggests significant muscle tissue damage (Holly et al., 1986; Farber et al.,1985). In another study, SGOT, SGPT, and LDH were shown to increase 700%, 262%, and 222% respectively in the Ironman Triathlon competition. The duration and intensity as well as large muscle mass used in this three-sport event, help support the evidence of such extremely high serum tissue enzyme levels (Holly et al., 1986). Other investigators (Rensburg et al., 1986) attempted to produce correlations between relative intensity, expressed as a percentage of $\dot{V}O2_{max}$, and the potential elevation of serum enzymes. The duration of the event was also postulated to have an effect on serum enzyme levels, and therefore an attempt was made to correlate these two factors together. In conclusion, neither exercise intensity nor duration showed direct correlations to the elevation of serum enzymes exhibited after an ultra-distance triathlon. Other factors, such as the muscle mass utilized, combined with the psychological stress placed on an athlete during an event, influence serum enzyme levels during the ultra-distance triathlon (Rensburg et al., 1986). Smith et al., (1985) took the enzymes LDH and CPK and examined the sub-components LDH 1-5, CPK-MB and CPK-MM. LDH 1 and CPK-MB elevations are suggestive of myocardial tissue stress and LDH 5 and CPK-MM are often associated with skeletal muscle catabolism or stress. The objective of the study was to determine whether or not any myocardial tissue damage occurred during a triathlon along with the damage done to the skeletal muscle tissue. The results revealed no significant elevations of LDH 1 or CPK-MB. However, the serum enzyme LDH 5 and CPK-MM were significantly elevated ($p < .001$) demonstrating damage done to skeletal muscle tissue without any myocardial damage occurring. All of these studies conclude that during ultra-distance and even in short-distance triathlons, some muscle tissue catabolism occurred. While this finding is not an entirely surprising phenomena, more studies need to be conducted that will monitor triathletes during normal training to ensure the athletes train in such a specific manner as not to cause long term skeletal muscle damage.

Plasma triglycerides were examined in one triathlon of the ultra-distance type and these were found to have been decreased in order that adequate glucose homeostasis be maintained (Farber et al., 1985). Free-fatty acid increases were shown in a one-half ultra-distance triathlon and heart-rate and $\dot{V}O2_{max}$ decreased causing blood lactate levels to also decrease (Woodard and Town, 1983). In another ultra-distance length triathlon, nonesterified fatty acids had increased by 191% (Holly et al., 1985). This increase shows the predominance of free-fatty acid use during the race, thus maintaining glucose homeostasis. Furthermore, in another study using a triathlon that substituted 28 km of canoeing for the swim portion of the event, followed by a 96km bike ride, followed by a 12 km mile run, an enhanced free-fatty acid oxidation rate led these investigators to believe that glycogen stores were spared, thus prolonging the state of exhaustion (Rensburg et al., 1986).

In order to obtain more complete knowledge of hematological changes that occur during a triathlon competition, investigators conducted a twelve parameter blood cell profile on subjects before and after each phase of a triathlon (Davidson, Robertson, and Maughan, 1986). The order of events and the mileage of this triathlon was 18km cycling, 7.5 km running, and finally 11.5 km canoeing. Post-cycling values included an increase in hemoglobin, plasma cell volume, leukocytes, and platelet count. A mean decrease of plasma volume occurred most significantly after the cycling stage. Post-running values for mean hemoglobin and plasma cell volume were no longer significantly increased and, in fact, had decreased in comparison to those of the post-cycling values. After canoeing, the mean values for hemoglobin and plasma cell volume remained unchanged. Also, total white cell count as well as platelet count had not been altered significantly after canoeing. It should be mentioned that body weight of the subjects was maintained through ad libitum water replacement. In summary, the investigators failed to demonstrate any significant differences in blood changes while examining three different forms of athletic activity, despite variations in duration, posture, and muscle recruitment patterns. It was postulated that the failure to show any significant differences was due to the continuing pattern of exercise throughout the event (Davidson et al., 1986). Another study attempted to investigate the relationship of triathlon race distance and hemolysis

(O'Toole, Hiller, Roalstad, and Douglas, 1988). An Olympic distance triathlon (1.5 km swim, 40 km bicycle ride, and 10 km run) and an ultra-distance triathlon (3.9 km swim, 180 km bicycle ride, and a 42.2 km run) had significant differences in red blood cell breakdown. The shorter distance triathlon had a 20% reduction compared to a 32% decrease in the ultra event. It was deduced that all triathletes experience some reduction in red blood cells during a triathlon, and the longer the event, the greater in magnitude the hemolysis (O'Toole et al., 1988).

The Physiological Effects of Sequential Running and Cycling on the Triathlete/Biathlete

Wells, Stern, Kohrt, and Campbell (1987), compared performance measures of triathletes when running 10 km runs followed by cycling 40 km, then reversing the order and cycling 40 km followed by a 10 km run. In addition, emphasis in this particular study was placed on examining changes in plasma blood, and red cell volumes. When comparing performance results of seven men and five women, total time for the males differed by only .53 of a minute. The females' total times differed by only .62 of a minute. From the analysis of fluid shifts during sequential running and cycling, it was concluded that no significant differences occur between men and women. Other conclusions from this study include significant hemoconcentration, moderate dehydration despite fluid replacement ad libitum, and no significant differences in fluid shifts between 10 km running and 40 km cycling performance when each was the initial exercise (Wells et al. 1987). No oxygen consumption, heart-rate, ventilation, or any other measure of cardiovascular function were taken during the trials.

In two studies using well-trained triathletes, the effects of initial cycling exercise upon subsequent running were examined (Mayers, Holland, Rich, Vincent, and Heng, 1986; O'Toole, Hiller, Douglas, Pisarello, and Mullen, 1985). Cycling at anaerobic threshold followed by maximal running compared to maximal running alone showed no differences in running $\dot{V}O2_{max}$ for either trial (Mayers et al., 1986). However, Total treadmill time after cycling was reduced when compared to treadmill running without initial cycling by almost 1.5 min. (Mayers et al., 1986). This explains the decrement in running performance at the end of a triathlon without a reduction of $\dot{V}O2_{max}$ (Mayers et al., 1986). In another study using trained triathletes, 5h of cycling followed by 3h of running at 50% $\dot{V}O2_{max}$ showed no significant changes in $\dot{V}O2_{max}$, heart rate, stroke index, or cardiac index (O'Toole et al., 1985). It was postulated that highly conditioned triathletes could perform at 50%

$\dot{V}O2_{max}$ for more than 8h without any adjustment of the cardiovascular system (O'Toole et al., 1985).

In summary, the triathlon is an endurance event that can induce muscle catabolism, sometimes severe in nature (Tharp et al., 1985; Rogers et al., 1986; Van Rensburg et al. 1986; Urhauser et al., 1987; Smith et al. 1985; Holly et al., 1986; Farbert et al., 1986). This tissue catabolism takes place without any damage to myocardial tissue (Smith et al., 1986). The destruction of red blood cells is prevalent during any distance triathlon (Davidson et al., 1986; O'Toole et al., 1988). However, the longer in distance the triathlon, the more pronounced the hemolysis (O'Toole et al., 1988). When examining fluid shifts, as an athlete makes the transition from one event to another there is a consistent initial shift followed by only minor changes in the latter event (Kohrt et al., 1987). In bike to run studies, the running $\dot{V}O2_{max}$ is not effected by an initial bike at anaerobic threshold (Mayers et al., 1986). Also, when cycling 5h and then running 3h at 50% $\dot{V}O2_{max}$ no cardiovascular adjustments were made when using trained triathletes (O'Toole et al., 1985). No data has been collected at present that examines the metabolic response of bike to run and the reverse, run to bike using trained triathlete/biathletes. Therefore, in lieu of the need for data in this particular area of this complex and intriguing sport, this investigation will be conducted.

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Chapter III

METHODS

This chapter presents the methods and procedures that were used in the investigation. Specifically, experimental protocol design, subject selection, and methods of measurement are to be presented. Each subject performed a maximal treadmill test, as well as a maximal bicycle ergometer test, to determine peak $\dot{V}O2_{max}$ during the two modes of exercise. The two tests were separated by a 48h recovery period. Following maximal testing, subjects performed running (40min) and cycling (60min) at 70% $\dot{V}O2$ peak. A $\dot{V}O2$ peak test immediately followed both steady-state exercise bouts. Lastly, cycling (60min)/running (40min) and running (40min)/cycling (60min) tests were performed and both were followed by peak $\dot{V}O2$ tests. The final two tests were designed to simulate a competitive situation for cycling and running in a triathlon or biathlon. These subsequent tests were initiated by a steady-state bout of exercise at 70% of $\dot{V}O2$ peak, consisting of both cycling and running. The initial exercise bout lasted 40 minutes for running and 60 minutes for cycling. The first 5 minute period of both tests was used to achieve a steady-state at 70% $\dot{V}O2$ peak.

Upon completion of the steady-state exercise, the subject was given a two-minute transition period to prepare for the next exercise bout. Following the initial steady-state exercise test, the mode of exercise not yet used was then performed. The duration of each of these preloaded tests was 60 minutes for cycling and 40 minutes for running. The workrate ($\dot{w}$) for each of the preloaded tests was predetermined by calculating the $\overline{x}$ $\dot{w}$ from the two initial steady-state tests. At the end of the pre-loaded exercise tests the subjects then performed a maximal test. During maximal, steady-state, and pre-loaded exercise bouts, $\dot{V}O2$ peak, heart rate, and ventilation ($\dot{V}E$) were measured. The values measured during pre-loaded exercise were compared directly to the same time points measured during steady-state exercise. Measurements taken at $\dot{V}O2$ peak were also compared for each mode in all three tests. Performance similarities and differences of values obtained during maximal, steady-state, and pre-loaded testing are presented in this paper.

Subjects

Eight experienced male triathletes/biathletes ranging from the ages of 17 to 35 were recruited from the Dallas/Ft. Worth metroplex. Each subject was informed of the purpose of the study and required to sign a consent form prior to testing. Before each testing session, height, weight, and percent fat were measured.

Procedures

Maximal Testing

$\dot{V}O_2$ peak was measured for all subjects on a motor-driven treadmill, as well as on the bicycle ergometer. The bicycle ergometer was equipped with cycling handle bars, clipless pedals, and racing saddle. $\dot{V}O_2$ peak measurements on both treadmill and bicycle ergometer were made using stress test protocols designed for elite athletes as described by Macdougal, Wenger, and Green (1982). The tests were altered somewhat for this study. The running treadmill protocol is a continuous progressive loading test characterized by increasing elevation with velocity kept constant. The treadmill speed was subjectively determined before each $\dot{V}O_2$ peak test. With treadmill speed remaining constant, each stage was one minute in length starting with 0% grade for minute one and a 2% grade increase up to minute five, followed by a 1% increase each minute until $\dot{V}O_2$ peak was achieved. This protocol was designed for high-level runners so that running speed would not affect running skill, and excessive increases in elevation would not alter running mechanics (Macdougal et al. 1982). The bicycle ergometer $\dot{V}O_2$ peak protocol is characterized by 1 minute stages. For each minute up to the fourth minute the $\dot{w}$ increases .5 kp (kilipond) starting at 1.0 kp. Beginning at minute five the $\dot{w}$ then increases by .3 kp every minute until exhaustion. A constant pedaling rate of 80 rpm was maintained by the athlete throughout the entire cycle ergometer test.

During each maximal test, oxygen uptake ($\dot{V}O2$) was measured using a Sensor Medics 4400 MMC automated system (Sensor Medics Inc., Anaheim CA). Data for $\dot{V}O2$ peak, heart rate, $\dot{V}E$, and $\dot{V}O2$ peak, were recorded at 15 second intervals. An electrocardiogram (ECG) using a three-lead, V5 hookup was used to provide continuous monitoring of cardiac rhythms during the $\dot{V}O2$ peak test and during the recovery period (Blair, Gibbons, Painter, Pate, Taylor, Will, 1986). The heart rate was constantly monitored and measured every 15 sec., at $\dot{V}O2$ peak, and during a five-minute recovery period. The subject had the option to end a test at any time.

Steady-state Testing

After completion of the maximal $\dot{V}O2$ peak tests and a 48h recovery period, the subjects returned to the laboratory for cycling and running steady-state tests. The two steady-state tests were completed using 70% $\dot{V}O2$ peak as determined during cycling and running $\dot{V}O2$ peak max testing. The cycling test length was set at 60m so that the test approximated a well-trained triathletes time in a 40 km cycling event during a triathlon. The running test length was set at 40m so that the run test was approximately that of a well-trained triathlete during the 10 km run of a biathlon or triathlon. During both cycling and running steady-state tests the $\dot{w}$ was manipulated so that the athletes could maintain exactly 70% $\dot{V}O2$ peak. The cycling test $\dot{w}$ was manipulated by either increasing or decreasing the bicycle resistance at a constant 80 rpm. Treadmill speed was either increased or decreased at a constant 1% grade to elicit a 70% $\dot{V}O2_{max}$ peak steady-state. The first 5m period of each steady-state test was used to slowly "ramp" the subject to the desired 70% $\dot{V}O2$ peak $\dot{w}$. Throughout each steady-state test, $\dot{V}O2$, $\dot{V}E$, heart rate, and $\dot{w}$ were monitored and recorded every 30s. Running data was recorded at minute 10, 30, and 40. Cycling data was recorded at minute 10, 30, 40, and 60. Water was available ad Libitum for each subject at 15m and 25m of each test. At the completion of each steady-state exercise bout a progressive $\dot{V}O2$ peak test immediately followed and ended upon complete exhaustion or at the request of the subject. The $\dot{V}O2$ peak tests were administered in the same manner as the initial $\dot{V}O2$ peak tests. The $\bar{x}$ $\dot{w}$ of the cycling and running tests were calculated for use during subsequent exercise bouts during pre-loaded exercise testing.

Pre-loaded Testing

The pre-loaded testing bouts were run-to-bike and bike-to-run tests similar in length to those events in a triathlon or biathlon. The initial exercise bout was manipulated in order for $\dot{V}O2$ to stay at exactly 70% $\dot{V}O2$ peak. During the initial steady-state bout, $\dot{V}O2$, $\dot{V}E$, heart rate and $\dot{w}$ were monitored and recorded every 30s. Data was recorded at minute 10, 30, and 40 for running and 10, 30, 40, and 60 for cycling. Water was available for ad Libitum replacement at 15m and 25m during each test. At the end of each initial test the subjects were given a two minute transition period in which to prepare for the pre-loaded exercise bout to follow. A two minute period was given each subject at the beginning of pre-loaded exercise to become accustomed to a progressive $\dot{w}$. At minute two the $\dot{w}$ was then set at exactly the $\bar{x}$ $\dot{w}$ for that mode of exercise during the steady-state testing. During the pre-loaded exercise bouts, $\dot{V}O2$, $\dot{V}E$, and heart rate were monitored every 30s. Data was again recorded at minute 10, 30, and 40 for running and 10, 30, 40, and 60 for cycling. Water was available at 15m and 25m during each pre-loaded exercise bout. At the end of each of the subsequent exercise tests a progressive continuous test to complete exhaustion immediately followed. The subject was instructed to exercise to complete exhaustion or to end the test at any time. $\dot{V}O2$, $\dot{V}E$, and heart rate were monitored and recorded at 15s intervals and at exhaustion for the maximal tests. Following completion of the maximal test, the subject was required to complete at least a five-minute cool-down period.

Research Design and Analysis

Design I

Bike Run

Peak VO2
(T-Test)

Design II

	Max	SS	PL
B			
R			

Peak VO 2
2 x 3

Design III (Run)

	10	30	40
SS			
PL			

HR
VO2 2 x 3
VE

Design IV (Bike)

	10	30	40	60
SS				
PL				

HR
VO2 2 x 4
VE

Design V (Run and Bike)

	10	30	40
SS			
PL			

RUN

2 x 2 x 3

SS			
PL			

BIKE

Independent Variables

Type - SS (steady-state) or PL (pre-loaded)

Mode - Bike or Run

Time - minute 10,30,40,and 60

Dependent Variables

$\dot{V}O_2$ peak, $\dot{V}O_2$, heart rate, $\dot{V}E$, $\dot{W}$

The statistical analysis used was the repeated measures analysis of variance to compare bike and run peak tests, steady-state tests, and pre-loaded tests. The subjects' failure to complete all tests reduced the power of the statistical analysis. An alpha level of .01 was established.

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CHAPTER IV

RESULTS

In this section the subject groups will be described with respect to age, height, weight, percent body fat, and experience in triathlons/biathlons. Maximal testing results and comparisons of different maximal values for cycling and running are presented. Analysis of steady-state measurements when subjects performed independent cycling and running at 70% $\dot{V}O2$ peak are presented. Finally, event-order testing results are provided with preloaded events being compared to that of the steady-state bouts performed previously. Two subjects were either unable to perform all tests, or for some reason failed to complete all testing procedures. The results were analyzed using mode (running and cycling), type (steady-state and pre-loaded), and time as variables.

SUBJECTS

The physical description and physiological data are presented in Tables I. The subjects age ranged from 20 to 35 years with a mean age of 24.88 $\pm$ 4.55. Percent body fat was 9.25 $\pm$ 3.27% and ranged from 5.1 to 14.2%. Percent body fat agreed with previous studies that estimated male triathlete percent body fat at 9.0% (O'Toole, Hiller, Crosby, and Douglas, 1987; Holly, Barnard, Rosenthal, Applegate, and Pritikin, 1986).

Table 1. Physical Description and Physiological Data

Physical Description		$\bar{x}$	SD
	Age (yr)	24.88	4.55
	Weight (kg)	71.18	8.13
	Height (cm)	178.56	7.59
	Percent Body Fat	9.25	3.27
Training			
	Experience (yrs)	3.06	1.52
	No. of biathlons or triathlons	17.63	12.36
	Run (mi/wk)	30.75	7.26
	Cycle (mi/wk)	158.75	62.89
Competition Times			
	Run (open 10k)	36.14	2.53
	Cycle (open 40k)	64.50	5.90
	Run (tri 10k)	40.50	4.68
	Cycle (tri 40k)	69.63	8.38
	Triathlon (Olympic distance)	137.38	10.14

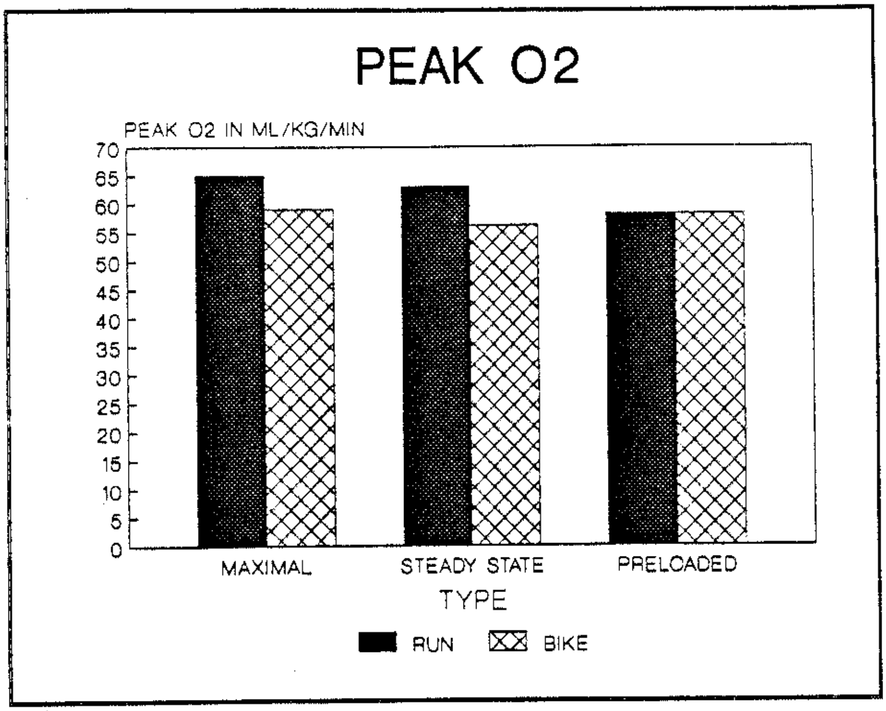

Figure I

Maximal Testing

Mean peak O2 consumption values for treadmill running were 65.28 ± 6.7 ml/kg/min and ranged from 55.9 to 79.5 ml/kg/min. Cycle ergometer mean peak O2 consumption values were 58.84 ± 8.74 ml/kg/min and ranged from 48.0 to 75.9 ml/kg/min (Figure I). Running and cycling peak O2 consumption values were significantly ($p<.01$) different. The peak O2 consumption was further analyzed with a 2 (mode) by 3 (type) ANOVA with repeated measures. There were no significant effects ($p>.01$). While running $\dot{V}O_2$ peak did drop across the types of exercise, cycling remained constant.

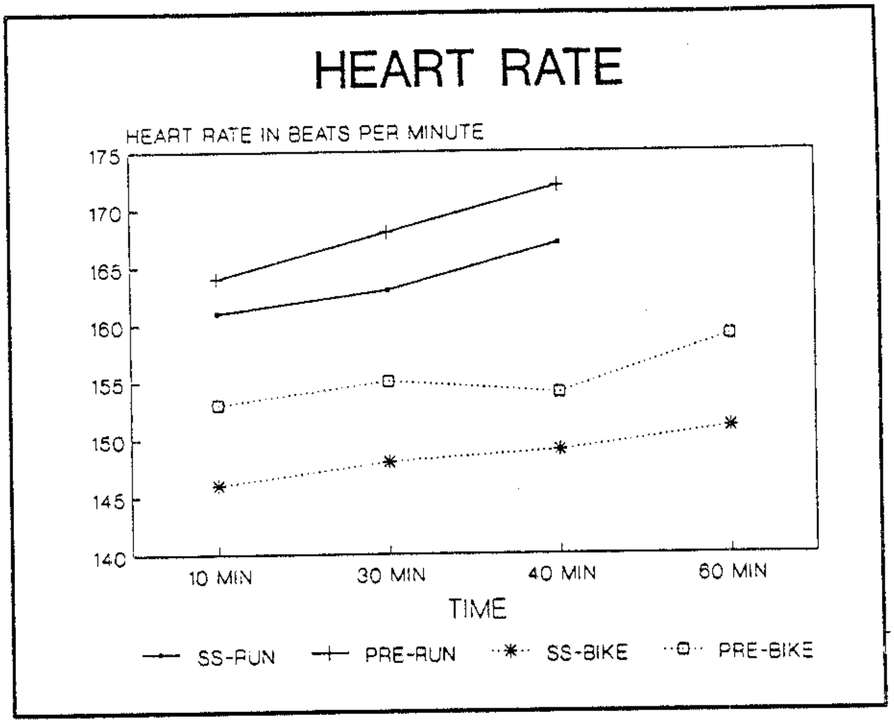

Figure II

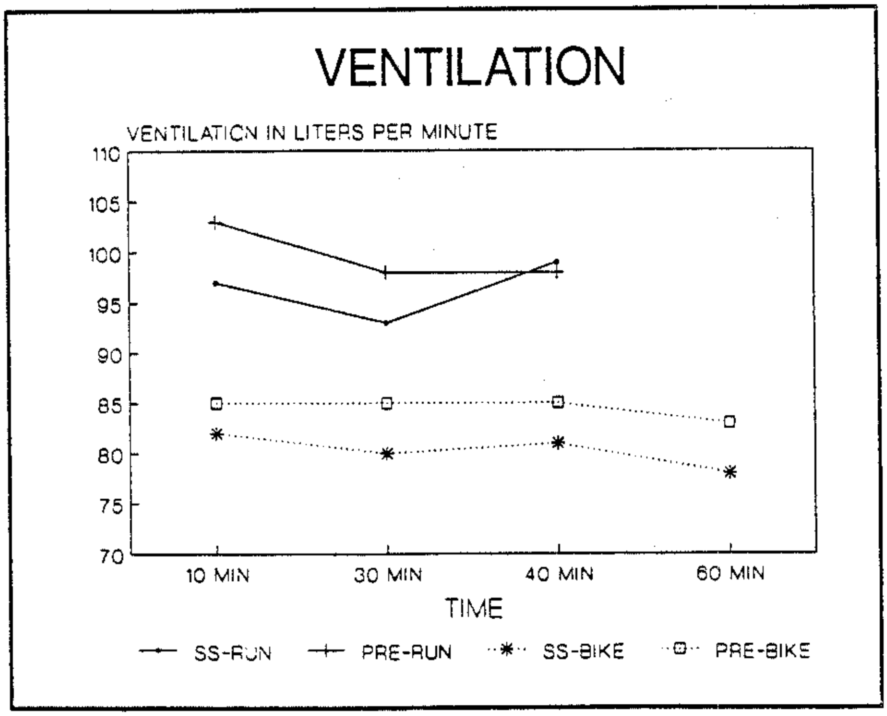

Figure III

However, the interaction was not significant (Figure I). Only six of eight subjects completed the maximal O_2 testing procedures. This decrease in sample size from 8 to 6 may account for the non-significant effects in running when comparing steady-state to pre-loaded peak O_2 consumption even though a decrement of approximately 4.53 ml/kg/min was seen from steady-state to pre-loaded running.

Type by Time Analysis of Running

The type (steady-state and pre-loaded running) by time (10,30,40, minutes) analysis was done using a two by three repeated measures ANOVA. Steady-state running mean heart rates were 161 $\pm$ 7.17 Bpm, 163 $\pm$ 9.8 Bpm, and 166.63 $\pm$ 7.46 Bpm for 20, 30, and 40 min respectively. Pre-loaded running mean heart rates were 164 $\pm$ 10.09 Bpm, 168 $\pm$ 10.36 Bpm, and 172 $\pm$ 10.45 Bpm (Figure II). A significant effect ($p<.01$) occurred when the steady-state and pre-loaded heart rates were compared over time. This significant heart rate over time effect demonstrated that the cardiovascular drift was consistent over time for steady-state and pre-loaded running (Figure II). There was a significant ($p<.01$) type effect for minute ventilation (Figure III) in which pre-loaded exercise had higher $\dot{V}E$ than steady-state exercise. No effects ($p>.01$) occurred for $\dot{V}O_2$ peak over time during steady-state and pre-loaded running. The subjects' were able to maintain their $\overline{x}$ pace during pre-loaded running compared to the $\bar{x}$ of steady-state running. The $\bar{x}$ treadmill running speed was 8.5 mph.

Type by Time Analysis of Cycling

The type (steady-state and preloaded cycling) by time (10,30,40,60, minutes) analysis was done using a two by three repeated measures ANOVA. Mean values for heart rate during cycling steady-state were 145.87 $\pm$ 9.54 Bpm, 148.25 $\pm$ 9.74 Bpm, 148.63 $\pm$ 11.78 Bpm, and 151.13 $\pm$ 10.43 Bpm for 10, 30, 40, and 60 min. Pre-loaded heart rates for cycling were 152.88 $\pm$ 12.15 Bpm, 155 $\pm$ 11.59 Bpm, 154.25 $\pm$ 11.76 Bpm, and 159.25 $\pm$ 11.49 Bpm (Figure II). There were significant ($p<.01$) type and time effects for steady-state and pre-loaded cycling, again demonstrating the effects of cardiovascular drift. No significant ($p>.01$) effects occurred for $\dot{V}E$ or $\dot{V}O2$ (Figures III and IV). The $\bar{x}$ $\dot{w}$ from the steady-state cycling bouts was maintained during the pre-loaded tests. The $\bar{x}$ cycling $\dot{w}$ was 2.9 kgm.min.

Mode by Type by Time Analysis

The mode by type by time analysis was done using a three-way repeated measures ANOVA. For heart rate there was a significant ($p<.01$) mode effect because running heart rates were higher than cycling (Figure II). A type effect occurred ($p<.01$) showing the pre-loaded tests heart rate greater than the independent steady-state performances (Figure II). A significant effect ($p<.01$) also occurred when looking at the heart rate increase over time (Figure II). No significant effects ($p>.01$) occurred when $\dot{V}E$ and $\dot{V}O2$ were analyzed (Figures III and IV).

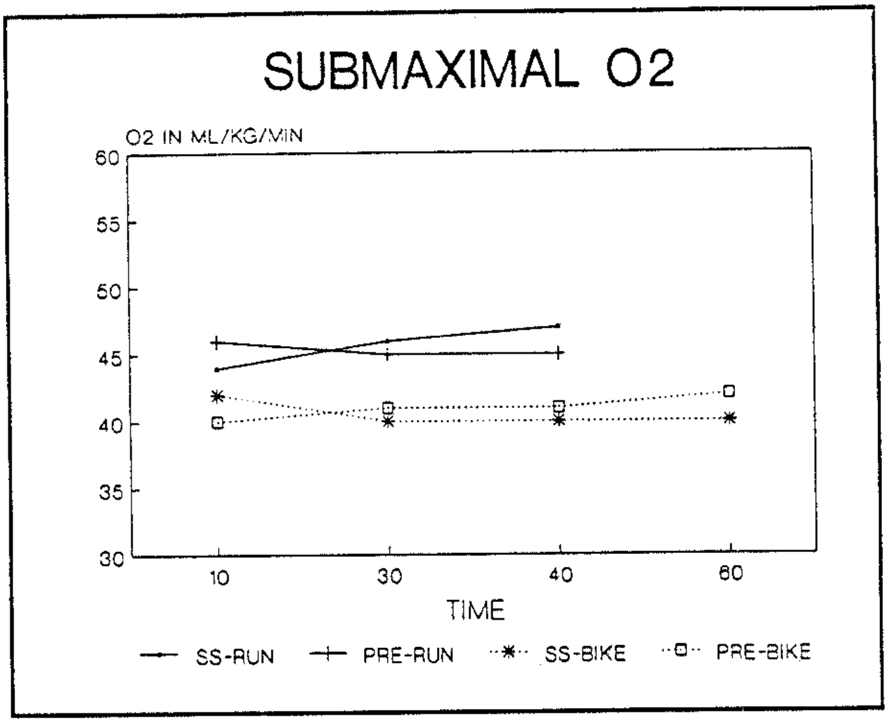

Figure IV

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CHAPTER V

DISCUSSION

Multi-sport events such as the triathlon and biathlon have demonstrated exponential growth in the 1980's. The sport had attracted an estimated 800,000 competitors in 1984 (O'toole, Hiller, Crosby, and Douglas, 1987) with an increase to 1.5 million in 1988 (O'toole, Douglas, 1989). Athletes who compete in either the triathlon or biathlon or both, train specifically for running and cycling. In competition cycling and running are performed in succession and the order of the two events is often reversed. The athlete who is well-trained in running and cycling and competes in both gives exercise physiologists an opportunity to study these athletes and the effects of multi-event competition as well as the adaptations from cross-training. The majority of the studies in the literature that deal with running and cycling are characterized by those that use athletes trained for only one of the two sports. The triathlon, and to a greater extent the biathlon, are such new sports that only a limited amount of data has been collected regarding the applied physiology of these unique athletes. Few studies have examined the effects of previous exercise upon subsequent exercise using trained triathletes/biathletes (Kohrt, O'Conner, Skinner, 1987; Dengel, Flynn, Costill, Kirwan, Beltz, and Neufer, 1987; O'toole, Hiller, Douglas, Pisarello, and Mullen, 1985; Mayers, Holland, Rich, Vincent, and Heng, 1986). Furthermore, studies comparing running and cycling in different orders seem to be nonexistent.

This study was conducted on the premise that running, pre-loaded with cycling, and cycling, pre-loaded with running, might demonstrate a metabolic response that was significantly associated with event order. Also, it was hypothesized that pre-loaded steady-state running and cycling might have a significantly different metabolic response from those steady-state bouts of running and cycling done alone. Results showed no significant event order interaction for the dependent variables heart rate, $\dot{V}E$, and $\dot{V}O2$. The results did show consistency in cardiovascular drift. Furthermore, the fact that event order did not demonstrate a significant interaction would lead one to assume that other physiological factors could lead to the decrement in performance usually seen when the triathlete/biathlete competes in running/cycling or cycling/running events.

Peak O2 consumption values during the initial maximal testing phase of the study were 65.28 $\pm$ 6.70 ml/kg/min for running and 58.84 $\pm$ 8.74 ml/kg/min for cycling. These values characterize these athletes as well-trained for athletes that compete in running and cycling, but not at the elite level (Astrand, Rodahl, 1970). The percent difference between peak running and cycling measures was 10%. O'toole et al. (1987) and Kohrt et al. (1987) have demonstrated percent differences between maximal running and cycling to 3% and 4% respectively. The former study used triathletes that were elite and the latter study had well-trained athletes. It is evident in the literature that untrained individuals maximally tested with cycling have values that are approximately 90% of their maximal running value, or percent decrement of 8-12% (Faulkner, Roberts, Elk, and Conway, 1971; McCardle, Magel, 1970; Miyamura, Kitamura, Yamada, and Matsui, 1978; Pechar, McCardle, Katch, Magel, and Deluca, 1974). This would lead one to assume that the athletes in this particular study were closer to those that are at the untrained level because of the agreement in percent decrement between peak running and cycling values. However, the peak O2 consumption values are not low enough to warrant consideration of untrained status. A factor to be considered when looking at this particular group of athletes is the fact that the data collection took place during pre to early season when training conditions were not conducive for optimal cycling and therefore more run training had taken place. The higher peak O2 values achieved during running as compared to cycling in this study agreed with past literature findings (Astrand et al., 1970; Mccardle, Katch, and Katch, 1981). Also, the subjects in this study, for the most part, came from competitive running backgrounds, whereas trained cyclists can often equal or exceed their running $\dot{V}O2$ peak when tested on cycle ergometer (Miyamura et al., 1978).

Comparisons of Results to the Literature

O'toole et al., (1985) conducted a study that began with 5 hours of cycling, followed by 3 hours of running both at 50% $\dot{V}O2_{max}$. Another study simulated a triathlon consisting of 30 min swimming, 60 min of cycling, and 45 min of running (Albrecht, Foster, Dickinson, and Debever, 1986). The intensity was self-adjusted at, or just below, lactate or ventilatory threshold. The intensities of cycling and running were 79% $\dot{V}O2_{max}$. No significant increase in $\dot{V}O2_{max}$ or heart rate occurred from the point of initiating cycling to the end of the running bout (Albrecht, Foster, Dickinson, and Debever, 1986). In the present study there was no significant change in O2 consumption when comparing cycling and running, pre-loaded and non-preloaded, for mode, type, and time. There was, however, a significant increase in heart rate over time when comparing cycling and running.

This cardiovascular drift effect, whereas during long-term exercise heart rate steadily increases over time, while stroke volume decreased allowing the $\dot{V}O2$ to remain unchanged, has been shown repeatedly in the literature (Bechner and Winsor, 1954; Ekelund, 1966; Ekelund, 1964; Rowell, 1974; Rowell, 1983; Rowell, 1986; Saltin and Stenberg, 1964). Also, in studies done by Astrand and Rodahl (1970) and O'toole, Hiller, Crosby and Douglas (1987) it was concluded that during prolonged exercise at a constant intensity below anaerobic threshold, $\dot{V}O2$ is expected to stay at the same level as that attained at approximately 5 min into the exercise as long as there is adequate supply of oxygen and substrates.

The hypothesis for this study stated that a significant effect would occur when pre-loaded cycling were compared to pre-loaded running at submaximal (70% $\dot{V}O2$ peak) levels. Studies on cycling would lead one to believe that cycling before running would cause a metabolic effect that was more significant than running before cycling. Faulkner, Roberts, Elk, and Conway (1978) state that the intensity and duration of muscular contraction are greater in cycling than in running, thus limiting muscle blood flow, venous return, and thus $\dot{V}O2_{max}$. It has also been hypothesized that cycling produces a more specific training response than running because there is a localized muscular stress (Faulkner, Roberts, Elk, and Conway, 1971; Miyamura, Kitamura, Yamata, and Matsui, 1978; Pechar, Mccardle, Katch, Magel, and Deluca, 1974; Roberts and Alpaugh, 1972). The running literature is inconsistent on whether running promotes a general training effect (Pechar, McArdle, Katch, Magel, and Deluca, 1978; Roberts and Alspaugh, 1972) or evokes specific training adaptations (McArdle, Magel, Delio, Toner, and Chase, 1978; Pannier, Vrigens, and Van Cauter, 1980). Magel, McArdle, Toner and Delio (1978) state that exercise using large muscle groups (i.e., running) stresses the oxygen transport mechanisms. These studies seem to indicate that running is not as tissue specific an exercise as cycling. It would seem that fatigue is muscle-specific during cycling and would lead to a more erratic metabolic response than in running. A study by Kreider, Boone, Thompson, Burkes, and Cortes (1988) simulated a triathlon in laboratory using the swim-bike-run order of events. When comparing the swim- bike-run events performed in the triathlon to control swimming, cycling, and running performed independently, the triathlon events suffered a decrement in performance throughout the duration of the triathlon. The decrement in performance for running after cycling might cause significant changes metabolically not seen in control running at the same percent of $\dot{V}O2_{max}$. However, in this study the event order had no interactive effect on exercise metabolism.

Summary

The following represents the findings of the present study:

1. Maximal treadmill running produced significantly higher peak O_2 consumption than maximal cycling. This finding is consistent with past literature.
2. The event order, running/cycling and cycling/running, produced no significant interaction for submaximal (70% $\dot{V}O_2$ peak) metabolic response.
3. There was a consistent increase in heart rate across time during submaximal exercise which is consistent with the literature.

Conclusion

Running/cycling or Cycling/running event orders in triathlon/biathlon competitions produced no meaningful interactive metabolic effects for participants.

Recommendation for Future Study

The following studies are recommended:

1. Conduct a similar study to the present investigation but proceed cycling and running events with a swimming performance.
2. Conduct a field-based study that examines heart rate and $\dot{V}O_2$ response in actual triathlons with different event orders.

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APPENDIX

Lay Summary and Consent Form

One maximal running and cycling test are to be conducted on two separate days with 48 hours rest time in between tests. After these preliminary tests are completed, I will in the next two weeks perform four more tests. The first two tests are steady-state tests performed at 70% $\dot{V}O_2$ peak for cycle and run. The two tests that follow are competition simulation transition tests. One test will include a run steady-state at 70% $\dot{V}O_2$ peak followed by a steady-state cycle at 70 % $\dot{V}O_2$ peak. The other test is a cycle steady-state at 70% $\dot{V}O_2$ peak followed by a run steady-state at 70% $\dot{V}O_2$ peak. Every test performed in the study will conclude with a peak $\dot{V}O_2$ test at the conclusion of the final steady-state performed for that particular trial.

The initial individual maximal bicycle and running tests are used to obtain baseline data which will be used to compare with the second event maximal tests. Parameters examined include: $\dot{V}O_2$ peak, heart rate, and minute ventilation recorded every 15 seconds during the tests, and at the time of exhaustion.

The subject will undergo stress tests on both the running treadmill and bicycle ergometer that will lead to complete exhaustion. This type of testing can be extremely uncomfortable toward the latter stages. I will confront extreme physiological fatigue and cardiovascular stress. Research has shown that exhaustive physical exercise increases the chances of cardiovascular incidents of life-threatening dimensions; however, my activity and health history indicate that the only discomforts that I will probably encounter are those of fatigue. I understand that I will be completely free to stop my participation in this study at any time. My participation is completely voluntary, and if I decide not to continue, I will be allowed to do so without any prejudice from the investigative team.

From the data collected form the above-mentioned tests, I will have the knowledge of what my maximal oxygen consumption and maximal heart rate are. Also, I will discover how the initial mode of exercise can affect the second exercise, after a two-minute transitional period. This data can be of great use in formulating a training program.

I have read the explanation of procedures and I understand them. By signing this form, I voluntarily consent to the procedure designated in the paragraphs above.

Date: ______________________

Witness: ____________________ Signed: ____________________

Signed: ____________________

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