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Cardiovascular, Thermoregulatory, Metabolic and Performance Responses to Repeated Ultraendurance Cycling

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by

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ABSTRACT

CARDIOVASCULAR, THERMOREGULATORY, METABOLIC AND PERFORMANCE RESPONSES TO REPEATED ULTRAENDURANCE CYCLING

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The purpose of this study was to describe physiological and performance responses in six highly trained cyclists during four days of repeated ultraendurance cycling. Each subject raced in four consecutive 100 mile per day time trials using their own bicycles mounted to a computerized ergometer. The race course profile consisted of rolling terrain with simulated gradients of minus five to ten percent. Body weight was measured prior to each time trial. Total performance time and fluid intake for each time trial were recorded. All other data were measured at ten mile intervals during each 100 mile time trial. Means for days one through four were obtained by averaging respective time trial means for all subjects combined. Data were analyzed for differences among days one through four using repeated measures ANOVA. Heart rate and rate pressure product were significantly higher on day one than days two through four. These changes may have been related to competitive effort and unfamiliarity with the race course on day one. Alternatively, significant differences may have been related to a type one error. When alpha levels were adjusted using the Bonferroni technique, heart rate and rate pressure product were no longer significantly different. Blood pressure, mean arterial pressure, peak aortic velocity, peak aortic acceleration, stroke distance, rectal temperature, fluid intake, oxygen uptake, body weight, power output and performance time were not significantly different among days one through four. Highly trained cyclists are able to maintain cardiovascular, thermoregulatory and metabolic function from day to day during four days of repeated ultraendurance cycling without detrimental changes in physiological function or performance.

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CHAPTER 1

Introduction

The ultraendurance event is any aerobic activity lasting several hours to several days in length. Types of ultraendurance events include marathons, triathlons, swimming, and cycling. These events may consist of a series of consecutive bouts spanning several days. One example is the "Tour De France". This is an event in which cyclists race approximately 100 miles per day for 21 to 28 days.

Because ultraendurance exercise lasts approximately four hours or more, greater physiological and performance demands are realized than during exercise of shorter duration. Medical complications have been reported during prolonged exercise lasting more than one hour and during ultraendurance exercise. Case reports of sudden cardiac death and myocardial infarction have been associated with marathons (Noakes et al., 1977; Zoltic et al., 1987). Structural and functional cardiac changes including myocardial dysfunction have been associated with exercise lasting greater than one hour (Ekelund et al., 1967; Ekelund and Holmgren, 1964; Saltin and Stenberg, 1964; Seals et al., 1988) and with ultraendurance exercise, (Douglas, 1989; Douglas et al., 1987; Niemela et al., 1984). Niemela et al. (1984) suggested the need for medically based selection criteria for ultraendurance events. Dehydration, exhaustion, heat injury and muscle cramping have also been associated with ultraendurance exercise (Laird, 1987; Murphy, 1986). However, some investigators have concluded that the cardiovascular and thermoregulatory systems are not limiting factors during ultraendurance exercise (Davies and Thompson, 1986; O'Toole et al., 1987).

Physiological and performance responses to ultraendurance exercise and especially repeated ultraendurance exercise are not understood. A few investigations have reported the food and fluid intake and ergogenic demands of repeated ultraendurance cycling (Brouns et al., 1989; Saris et al., 1989; White et al., 1984;). Other studies which have examined cardiovascular, metabolic and performance responses to repeated ultraendurance cycling have been case studies (Bruce et al., 1974; Cahalin et al., 1990; Cahalin and Ice, 1994). Further research is needed to describe the physiological and performance demands of repeated ultraendurance exercise. The following study examines several measures of cardiovascular, thermoregulatory, metabolic and performance responses during four days of repeated ultraendurance cycling. The cardiovascular variables measured and calculated during this investigation included heart rate, systolic, diastolic, and mean arterial pressure and rate pressure product. Continuous-wave Doppler ultrasound variables measured included peak velocity, peak acceleration and stroke distance of ascending aortic blood flow. Thermoregulatory measurements included rectal temperature and fluid intake. The metabolic variables measured included oxygen uptake and body weight. Performance measures included performance time and power output.

The race course workload used during this investigation was programmed into the computerized ergometer in gradient percentages (table 1.) and consisted of rolling terrain with grades from minus five to ten percent. The ergometer simulated gradients via resistance provided by an electrically braked roller which was in contact with the rear bicycle tire. However, the subjects were able to individually regulate power output from moment to moment based on their exertional effort. All subjects were competing for cash prizes as they would be in a normal competition.

Several physiological responses varied with workload changes during each daily time trial. However, the focus of this investigation was on the physiological and performance response from day to day. The primary research question was whether or not these responses would significantly change from day to day.

Statement of Purpose

The purpose of this investigation was to describe cardiovascular, thermoregulatory, metabolic and performance responses of highly trained cyclists to repeated ultraendurance cycling.

Hypotheses

Four null hypotheses were chosen for this investigation:

1. There will be no statistically significant differences in heart rate, systolic blood pressure, diastolic blood pressure, mean arterial pressure, rate pressure product, peak aortic velocity, peak aortic acceleration or stroke distance among days one through four.
2. There will be no statistically significant differences in rectal temperature or fluid intake among days one through four.
3. There will be no statistically significant differences in oxygen uptake or body weight among days one through four.
4. There will be no statistically significant differences in power output or performance time among days one through four.

Delimitations

This investigation was conducted within the following parameters:

1. Subjects were competitive male cyclists with training volumes of 200 - 400 miles per week and were recruited from the Mid-Atlantic region.
2. Subjects performed four 100 mile per day time trials using their own bicycles attached to a computerized ergometer.
3. All data which were measured during each time trial were sampled at each ten mile interval during each daily time trial.

Limitations

1. Characteristics of the subject population may limit application of conclusions to populations other than elite athletes.

Assumptions

1. The subjects performed as they would during normal race conditions.

Operational Definitions

1. Body weight. Body weight was measured in kilograms prior to each daily time trial. Mean body weight for each day was obtained by averaging respective time trial body weights for all subjects combined.

2. Diastolic Blood Pressure (DBP). Diastolic pressure was measured as the fifth Kortokoff sound determined using a standing mercurial sphygmomanometer and stethoscope. All blood pressures were measured from the left brachium. For each time trial, ten mile interval measurements were averaged. Mean diastolic blood pressure for each day was obtained by averaging respective time trial means for all subjects combined.

3. Fluid Intake. The amount of fluid consumed during each time trial was measured to the nearest milliliter by graduated flask and cylinder. Subjects consumed fluid ad libitum. The fluid provided was a brand name product called Exceed® which was mixed with water. The subjects also drank plain water. Proportions of each fluid were not recorded. Total fluid intake for each time trial was measured. Mean fluid intake for each day was obtained by averaging respective time trial means for all subjects combined.

4. Heart Rate (HR). Heart rate was measured by 12 lead ECG. At each ten mile interval heart rate was averaged from a six second rhythm strip. For each time trial, ten mile interval measurements were averaged. Mean heart rate for each day was obtained by averaging respective time trial means for all subjects combined.

5. Mean Arterial Pressure (MAP). Mean arterial pressure was calculated as 1/3 of the difference between systolic blood pressure and diastolic blood pressure plus diastolic blood pressure. For each time trial, ten mile interval measurements were averaged. Mean mean arterial pressure for

each day was obtained by averaging respective time trial means for all subjects combined.

6. Oxygen Uptake (VO2) The difference between the inspired and expired oxygen as determined by a Beckman OM11 and LB2 oxygen and carbon dioxide analyzers (Sensormedics Corp., Yorba Linda, CA.) and Screenmate pneumotach using S&M software (S&M Instruments, Doyleston,PA.) VO2 max was defined by at least two of three criteria during pre race maximal testing: 1. Heart rate within 10 percent of predicted maximal heart rate. 2. A plateau in VO2 with increasing workload. 3. Respiratory exchange ratio greater than or equal to 1.1. For each time trial, ten mile interval measurements were averaged. Mean oxygen uptake for each day was obtained by averaging respective time trial means for all subjects combined.

7. Peak Acceleration (PKA). The greatest change in velocity of ascending aortic blood flow during left ventricular ejection per unit time; measured at the sternal notch using the Quinton Exerdop® ultrasound instrument (Quinton Instruments, Seattle WA.). For each time trial, ten mile interval measurements were averaged. Mean peak acceleration for each day was obtained by averaging respective time trial means for all subjects combined.

8. Peak Velocity (PKV). The greatest change in distance of ascending aortic blood flow during left ventricular ejection per second; measured at the sternal notch using the Quinton Exerdop® continuous-wave Doppler ultrasound instrument(Quinton Instruments, Seattle, WA.). For each time trial, ten mile interval measurements were averaged. Mean peak velocity for each day was obtained by averaging respective time trial means for all subjects combined.

9. Performance Time. Total time for cyclists to complete one time trial was measured. Mean performance time for each day was obtained by averaging respective time trial performance times for all subjects combined.

10. Power Output. Power output, measured in watts, was determined by the Schwinn Velodyne® computerized cycle ergometer via an electrically braked roller which was in contact with the rear wheel of the bicycle. All workloads were programmed into the computerized ergometer by percent

grade and were simulated by rolling resistance. For each time trial, ten mile interval measurements were averaged. Mean power output for each day was obtained by averaging respective time trial means for all subjects combined.

11. Rate Pressure Product (RPP). Rate pressure product was calculated as the product of systolic blood pressure times heart rate times .01. For each time trial, ten mile interval measurements were averaged. Mean rate pressure product for each day was obtained by averaging respective time trial means for all subjects combined.

12. Rectal temperature (Tr). The internal core temperature was measured by a Yellow Springs Instruments (YSI) 2100 thermometer and YSI 401 rectal thermister (YSI, Yellow Springs Ohio). For each time trial, ten mile interval measurements were averaged. Mean rectal temperature for each day was obtained by averaging respective time trial means for all subjects combined.

13. Stroke distance of aortic blood flow (SD). The systolic velocity/ time integral representing the distance of ascending aortic blood flow during left ventricular ejection; measured at the sternal notch using the Quinton Exerdop® continuous-wave Doppler ultrasound instrument (Quinton Instruments, Seattle, WA.). For each time trial, ten mile interval measurements were averaged. Mean stroke distance for each day was obtained by averaging time trial means for all subjects combined.

14. Systolic Blood Pressure (SBP). Systolic blood pressure was measured as the first Korotokoff sound determined using a standing mercurial sphygmomanometer and stethoscope. All blood pressures were measured from the left brachium. For each time trial, ten mile interval measurements were averaged. Mean systolic blood pressure for each day was obtained by averaging time trial means for all subjects combined.

15. Time Trial. A single 100 mile exercise bout. Subjects participated in four consecutive time trials over four days.

16. Ultraendurance Exercise. Any aerobic activity lasting approximately four hours or more.

CHAPTER 2

Literature Review

Introduction

This chapter will present a review of the literature concerning the cardiovascular, thermoregulatory, metabolic, and performance responses to prolonged and ultraendurance exercise. Literature concerning continuous-wave Doppler ultrasound assessment of left ventricular function will be presented as well. Because few investigations of repeated ultraendurance exercise have been published, the literature review will include studies of prolonged exercise and ultraendurance exercise lasting one day or less.

Cardiovascular Responses

Heart Rate

Three investigations of ultraendurance cycling reported a decline in heart rate over time or over several days. During a 24 hour open road cycling event White et al. (1984) measured heart rate in one cyclist. Heart rate declined from 88 percent to 74 percent of maximal heart rate within the first six hours of the event and to 63 percent of maximal heart rate by the end of the event. A gradual decline in speed was also reported. Cahalin et al. (1990) studied two cyclists participating in the Race Across America ultraendurance cycling event. There was a 24 percent decrease in heart rate after day two of the nine day race. The variance in speed was between zero and four miles per hour. Post-race maximal heart rates were decreased by 11.5 percent compared to pre-race maximal heart rates. Cahalin and Ice (1994) measured heart rate in two ultraendurance cyclists who rode a tandem bicycle across the United States in less than eight days. Heart rate highs on days one through three were 130-170 beats per minute (mean 150) and declined to highs of 88-112 beats per minute (mean 100) thereafter. Subjects slept approximately two hours per night. The decline in heart rate was suggested to be related to sleep loss which may increase parasympathetic influence on the heart.

Bruce et al. (1974) studied cardiovascular responses in a single subject before and after a two and one half month run across the United States. Maximal testing three days after the run revealed a significant increase in heart rate and a decrease in stroke volume and cardiac output at all workloads from rest to maximum. Resting heart rate was unchanged. Oxygen uptake was not significantly different from pre-event values and was maintained by an increase in heart rate and arterial oxygen content. The authors concluded that there was cardiac limitation to maximal oxygen transport. Because these responses were seen three days after exercise, they represent a more chronic adaptation to repeated ultraendurance exercise.

Other investigators have reported an increase in heart rate over time during four to eight hours of running and or cycling and have concluded that the cardiovascular system is not a limiting factor in ultraendurance exercise (Davies and Thompson, 1986; O'Toole et al., 1987). The increase in heart rate during these investigations was defined as cardiovascular drift.

A gradual decrease in stroke volume and increase in heart rate as well as a reduction in arterial pressures in the presence of a constant workload are the primary responses characterized as cardiovascular drift (Rowell, 1974). Raven and Stevens (1988) have reviewed cardiovascular drift as a response to prolonged exercise and have suggested its cause may be partially related to competition for blood flow. Translocation of blood for thermoregulatory purposes is thought cause cardiac compensation to meet the demands of metabolically active muscles. A number of studies have reported some or all of these findings (Ekelund, 1966; Ekelund and Holmgren, Davies and Thompson, 1986; O'Toole et al., 1987; Saltin and Stenberg, 1964). However, Hamilton et al. (1991) found fluid replacement and glucose infusion to prevent cardiovascular drift during prolonged cycling.

In summary, heart rate response to repeated ultraendurance cycling has been reported to decline over several days of exercise and was suggested to be related to sleep loss. An increase in post-event maximal heart rate was reported by Bruce et al. (1974) three days after repeated ultraendurance running. This may represent a chronic adaptation to repeated ultraendurance exercise. Continuous increases in heart rate in the presence of a constant workload during a single bout of prolonged exercise appears to be related in part to thermoregulatory and metabolic demand for blood flow. The relationship between heart rate, physiological function and performance during repeated ultraendurance exercise remains unclear.

Blood Pressure

Systemic arterial pressure responses during prolonged exercise of one to three hours duration have been reported to significantly decrease throughout exercise (Ekelund, 1966; Ekelund and Holmgren, 1964; Saltin and Stenberg, 1964; Seals et al., 1988). Saltin and Stenberg (1964) found a drop in arterial pressure during prolonged exercise which was suggested to be related to the need for increased cutaneous blood flow serving thermoregulatory requirements. Normal arterial pressures were seen in a subsequent maximal test. Cahalin and Ice (1994) found no significant changes in resting blood pressures during seven days of repeated ultraendurance cycling. Blood pressure was not measured during exercise. Bruce et al. (1974) studied responses in a single subject after running across the United States and reported a decrease in arterial blood pressure at all levels of exercise during a maximal exercise test. Performance capacity and maximal oxygen uptake were unimpaired compared to pre-event measurements.

Blood pressure responses during repeated ultraendurance exercise have not been reported and therefore it is not known whether significant changes occur from day to day.

Rate Pressure Product

The product of systolic blood pressure and heart rate is highly correlated with coronary blood flow and myocardial oxygen consumption (Kitamura et al., 1972). Bruce et al. (1974) have suggested that lower systemic arterial pressure and rate pressure product, despite increased heart rate, during exercise may enhance cardiac efficiency.

Peak Aortic Velocity, Acceleration and Stroke Distance

There have been no investigations which have reported peak acceleration, peak velocity and stroke distance of ascending aortic blood flow during repeated ultraendurance exercise. Mehta et al. (1988) found the reproducibility of Doppler variables during exercise to be high with less than ten percent coefficient of variation. Salmasi et al. (1987) found the coefficient of variation of stroke distance to be less than six percent at maximal workloads during supine cycling exercise to exhaustion. Chandraratna et al. (1984) found very good correlations for inter and intraobserver variability in continuous-wave Doppler measurements (r=.98 and .97 respectively). Percent change in peak aortic velocity has been found to correlate with percent change in ejection fraction during exercise in normals (r=.64), and in patients with coronary artery disease (r=.84) (Mehidrad et al., 1987). The literature also suggests that the integral of velocity over time, stroke distance, and the first derivative of velocity, peak acceleration, are clinically useful indicators of left ventricular function.

The left ventricle has been described as an impulse generator whose initial impulse is defined as the product of force (mass x acceleration) and time (Rushmer, 1964). The peak acceleration of blood flow ,which occurs in early systole, is thought to represent the initial ventricular impulse (Rushmer, 1964). This dynamic characteristic of ventricular ejection can be greatly changed by autonomic control and simulated disease states in dogs. Rushmer (1964) reviewed several investigations which demonstrated increases in the left ventricular initial impulse, measured as aortic blood flow acceleration, with sympathetic stimulation. Decreases in the same measurements were reported with induced premature ventricular contractions, acute coronary occlusion and exanguination hypotension. Although peak aortic acceleration of blood flow was reported to be sensitive to cardiac performance, there were no diagnostic differences between the simulated disease states. Other investigators have concluded that peak aortic acceleration of blood flow is representative of the maximum force exerted by the left ventricle in early systole and left ventricular power (Noble et al., 1966; Stein and Sabbah, 1976). Peak acceleration has been reported to be a sensitive indicator of left ventricular inotropic state in dogs (Noble et al., 1966) and in man (Bennett et al., 1984). Bennett et al. (1984) found peak acceleration to be insensitive to left ventricular loading conditions induced by lower body positive pressure which created a 33 percent change in stroke volume. In the same experiment Bennett et al. reported a 29 percent increase in peak acceleration with dobutamine infusion. Noble et al. (1966) found similar results in dogs after stimulating left ventricular myocardium with calcium gluconate and isoproplynorepinephrine. Peak acceleration increased more so than peak flow and left ventricular rate of pressure rise measured by catheter. Noble et al. (1966) also found peak acceleration to be sensitive to induced regional myocardial ischemia in dogs.

Stroke volume has been calculated using stroke distance and an independent measure of aortic root diameter determined echocardiographically. This measurement has been highly correlated with stroke volume and cardiac output when compared to thermodilution technique at rest and during exercise (Chandraratna et al, 1984; Colocousis et al., 1977; Shaw et al, 1985). Stroke volume determined by the same method was found to be a reliable indicator of the Starling response induced by lower body positive pressure (Bennett et al., 1984).

The application of continuous-wave ultrasound in the study of exercise in athletes has not been evaluated. Several investigators have reported reliability and validity with comparison to existing measures. Peak aortic acceleration and stroke distance appear to have qualitative value in their representation of left ventricular performance however they do not appear to have specific diagnostic application.

Although there have been no investigational reports of continuous-wave Doppler ultrasound during repeated ultraendurance exercise, several authors have reported post-event echocardiographic changes. Depressed contractile state, changes in heart volume, and valvular dysfunction have been reported after ultraendurance exercise and identified as indicators of myocardial dysfunction. Niemela et al. (1984) studied echocardiographic changes in runners prior to and after a 24 hour uninterrupted run. Despite a seven percent decrease in end diastolic dimension, end systolic dimension increased with a subsequent significant decline in stroke dimension and fractional shortening. Circumferential fiber shortening also significantly declined nine percent from pre-race values even though afterload was decreased. No electrocardiographic evidence of myocardial injury was found and the decreased contractile state was reversed after two to three days of recovery. The authors suggested that selection criteria may be advised prior to ultramarathon competition in view of the possibility of cardiac fatigue. Douglas et al. (1987) conducted an investigation during the Hawaii Ironman triathlon and found post-race increases in left ventricular systolic cavity size and decreased fractional shortening despite decreased left ventricular diastolic size. These changes were reversed within one day of recovery. The authors concluded their findings were suggestive of cardiac fatigue. Niemela et al. (1987) studied left ventricular diastolic function in runners before and after a competitive uninterrupted 24 hour run. Subjects who ran 200km or more had decreased diastolic dimension increase in early diastole, delayed mitral valve opening and prolonged filling time. These alterations were reversed two to three days after the race. It was suggested that abnormal resting diastolic function combined with impaired resting systolic function may be more deleterious to cardiac output during exercise due to a shorter diastole at elevated heart rates. Although these echocardiographic changes were not measured during exercise, they may be similar to the findings of Bruce et al. (1974) who reported decreases in stroke volume and cardiac output at all levels of exercise from rest to maximum following repeated ultraendurance exercise.

Micrographic evidence of myocardial damage was reported by King and Gollnick, 1970 who studied the effects of exhaustive exercise on the ultrastructure of trained rat hearts and found evidence of extensive mitochondrial damage including swelling, disruption and degeneration in which some mitochondria were devoid of cristae. Whether or not myocardial damage occurs in man during ultraendurance exercise is questionable. Some authors have concluded that myocardial damage does not occur during ultraendurance exercise based on isoenzyme profiles and electrocardiographic changes during stress tests following exercise (Kaman et al., 1977; Kielblock et al., 1979). It has also been suggested that the cardiovascular and thermoregulatory systems are not limiting factors during ultraendurance exercise (Davies and Thompson, 1986; O'Toole et al.,1987).

Thermoregulatory Responses

The ultraendurance athlete is faced with the problems of maintaining thermal and fluid balance during exercise. The prolonged nature of the ultraendurance event may pose a greater challenge in terms of avoiding progressive fluid loss which influences cardiovascular and thermal responses during exercise (Kreider, 1991). Fluid balance appears to play a key role in the underlying mechanisms related to cardiovascular and thermoregulatory changes seen during prolonged exercise. Loss of blood volume through dehydration and sweating exacerbates competition for blood flow between working muscles and the cutaneous vasculature which can cause changes in cardiovascular and thermoregulatory response to ultraendurance exercise (Kreider, 199; Nadel, 1988; Raven and Stevens 1988).

Rectal Temperature

Davies and Thompson (1986) studied ultramarathoners and reported rectal temperature increases of 0.63 Celsius (38.4 to 39.0 degrees Celsius) between the first and fourth hour during four hours of treadmill running at their highest sustainable intensity which was between 67 and 76 percent of VO_2 max. O'Toole et al. (1987) studied subjects performing prolonged cycling and running a total of eight hours at intensities ranging from 45 to 64 percent of VO_2 max. They reported rectal temperature increases of 0.2 degrees Celsius (37.7 to 37.9 degrees Celsius) during five hours of cycling and 0.7 degrees Celsius (37.9 to 38.6 degrees Celsius) during three hours of running which immediately followed the cycling. These temperatures were within the normal physiological range for exercise (Davies et al., 1976).

Fluid Intake

Fluid intake and body weight loss have been measured during repeated ultraendurance cycling both during competition and in the laboratory. Saris et al. (1989) studied cyclists during the 22 day Tour de France. Daily fluid intake was 6.7 liters with extremes up to 11.8 liters. The relatively high intake of carbohydrate-rich fluid was suggested to have been integral to the maintenance of performance capacity. Brouns et al. (1989) studied cyclists performing 280 minutes of exercise at intensities of 50 to 80 percent of VO_2 max on two consecutive days. Reported fluid intakes were 3.18 liters and 3.17 liters for days one and two of exercise respectively. Final event body weight was significantly less than initial body weight.

Dehydration has been reported to be the most common medical complication during ultraendurance events (Laird, 1987; Hiller, 1989). Ultraendurance athletes have been identified as having chronic dehydration prior to competition (Hiller, 1989; Laird, 1987) and it has been suggested that the ultraendurance athlete is predisposed to develop chronic dehydration due to the prolonged nature of ultraendurance events (Hiller, 1989; Kreider, 1991). Body water loss may be detrimental to performance when exceeding three percent of body weight (Costill and Miller, 1980). In view of the importance of hydration during exercise it has been recommended that athletes consume one to two liters of fluid per hour (Brouns et al., 1989; Kreider, 1991).

Metabolic Responses

Oxygen Uptake

Davies and Thompson (1986) reported a nine percent increase in relative oxygen uptake over a period of three hours during four hours of running which was suggested to be related to "metabolic drift" caused by muscle fatigue and increased muscle fiber recruitment. During a 24 hour cycling event, White et al. (1984) reported decreases in oxygen uptake, which was derived from heart rate, from 75 percent VO_2 max at six hours to 55 percent VO_2 max by the end of the race. O'Toole et al. (1987) found no significant changes in oxygen uptake in males during eight hours of cycling and running with an exercise intensity of 45 to 64 percent of VO_2 max. Bruce et al. (1974) studied cardiovascular responses in one individual prior to and after running across the United States. The subject ran an average of 42 miles per day six days a week. There were no significant changes between pre-event and post event maximal oxygen uptake. However, post-event stroke volume and cardiac output significantly declined and was compensated for by an increase in arterial oxygen content. Although oxygen uptake has been studied during single-day ultraendurance exercise, responses occurring from day to day during repeated ultraendurance exercise are still unclear.

Body Weight

Saris et al. (1989) studied four cyclists during the 22 day Tour de France. Pre-race body weight and post-race body weight were not significantly different. Maintenance of body weight was partially attributed to hydration practices. White et al. (1984) reported a 1.19 kg body weight loss in a single cyclist participating in a 24 hour cycling event. Brouns et al. (1989) studied cyclists performing 280 minutes of exercise at intensities of 50 to 80 percent of VO_2 max on two consecutive days. Body weight significantly decreased during both exercise days. Final event body weight was significantly less than initial body weight.

Performance Responses

Power Output

Davies and Thompson (1986) reported that maximal voluntary contraction of the quadriceps was reduced by 25 percent following ultraendurance running. They also observed an increase in relative oxygen uptake with a constant cardiac output which was suggested to be related to muscle fatigue and increased fiber recruitment. Cahalin et al. (1990) studied cardiovascular changes in an ultraendurance cyclist before and after the Race Across America and found a 24 percent decrease in post-event maximal workload. Both of these studies reported power output changes subsequent to ultraendurance exercise. Power output changes from day to day during repeated ultraendurance exercise are unclear.

Performance Time

Foster et al. (1993) compared physiological responses during competitive conditions and simulated laboratory conditions and found that competitive responses can be significantly greater. Measurements in the laboratory more closely approximated competitive measurements under conditions in which subjects were able to control moment to moment power output rather than when work output was dictated by protocol. Davies and Thompson (1979) studied ultramarathon runners and reported that performance times were increasingly related to fractional utilization of maximal oxygen uptake as race distances increased. Bruce et al. (1974) reported no change in performance capacity during maximal exercise testing after repeated ultraendurance exercise lasting approximately two months. Stroke volume and cardiac output were significantly decreased during all levels of exercise during the test. Compensatory increases in heart rate and arterial oxygen content were found to maintain oxygen uptake and performance capacity.

Literature Summary

Information regarding the cardiovascular responses to ultraendurance exercise is controversial. Several investigators have reported that ultraendurance exercise may cause cardiac dysfunction while others suggest that it does not. Significant post-exercise echocardiographic changes in cardiovascular responses to ultraendurance exercise have been documented leading to conclusions that cardiac dysfunction may occur (Douglas, 1989; Douglas et al., 1987; Niemela et al., 1984). The ability to maintain constant relative intensity for four or more hours without significant cardiovascular, thermoregulatory or metabolic changes has been reported with the conclusion that these systems may not be limiting in ultraendurance performance (Davies and Thompson 1986; O'Toole et al., 1987).

Thermoregulatory and fluid balance adaptations are of concern because heat injury and dehydration are the most common reasons for medical complications and possibly decreased performance. Recommendations for hydration practices have been published for endurance athletes but there is little information as to whether these recommendations are optimal for athletes participating in repeated ultraendurance events. The nature of repeated ultraendurance exercise predisposes the athlete to progressive physiological changes from day to day. The possibility of detrimental progressive changes in physiological function and performance during repeated ultraendurance exercise identifies a need for further investigation.

CHAPTER 3
Methodology

Introduction

This chapter describes the methodology used to investigate cardiovascular, thermoregulatory, metabolic and performance responses of highly trained athletes to four days of repeated ultraendurance cycling. The subjects, experimental design, instrumentation and procedures will be presented.

Subjects

Six healthy, highly trained, competitive, male cyclists were recruited from Mid-Atlantic area cycling teams to participate in this study. Mean age and weight respectively were 24 years and 72.2 kg. Appendix A details complete descriptive characteristics and training data for all subjects. Subjects were chosen based on performance times in local and regional races and were required to have a weekly training volume of 200-400 miles. Each subject was informed of the procedures of the study and signed an informed consent. All testing procedures were approved by the Human Subjects Committee of Old Dominion University.

Experimental Design

This study was part of a placebo crossover study investigating the effects of massage therapy on repeated ultraendurance cycling. The entire study spanned eight weeks. Two subjects were tested each week, one receiving a placebo treatment (inactivated short-wave diathermy) and the other receiving massage therapy. A two week interim period was observed between placebo and massage treatments. The data used in this study was measured during placebo treatment trials only. Each subject underwent a familiarization session prior to a four-day race simulation. The familiarization session was used to aquaint subjects with the testing equipment used, including the computerized ergometer, and to collect characterization data. Maximal testing was also performed during the familiarization session with each subject using his own bicycle mounted to the computerized ergometer. The race simulation consisted of four one hundred mile per day time trials performed on consecutive days. Subjects performed all exercise using their own bicycles attached to a Schwinn Velodyne® (Frontline technologies CA) ergometer. Workloads were programmed into the Velodyne ergometer prior to the start of the investigation. The one hundred mile race course was the same for each subject and was repeated on four consecutive days by each subject. A custom programmable computer chip was provided by Frontline Technologies which allowed workloads to be programmed in gradient percentages. Resistance was supplied by the ergometer roller which was in contact with the rear bicycle tire. Variations in resistance simulated grade changes. The ergometer was equipped with mounting brackets which allowed friction adjustment between the rear tire and roller. The mounting brackets were marked for specific placement of each subject's bicycle so that friction between the rear tire and ergometer roller was consistent during each time trial. The race course consisted of rolling terrain with 29 miles of gradients ranging from +1 to +10%, 43 miles with 0% gradient, and 28 miles with gradients from -1 to -5 % (Appendix B). Subjects competed for cash prizes awarded on a points system basis with the lowest performance times for each time trial receiving the greatest number of points. Heart rate, blood pressure, peak aortic velocity, peak aortic acceleration, stroke volume, rectal temperature, oxygen consumption and power output were collected at ten mile intervals during each time trial. Mean arterial pressure and rate pressure product were calculated for each ten mile interval. Fluid intake was measured during the event to the nearest milliliter and totaled for each day. Body weight was measured prior to each time trial. Total performance time for each time trial was recorded.

Instrumentation

Cardiovascular Measurements

Heart Rate. Heart rate was measured at each ten mile interval using an Eaton G2700 electrocardiograph (Eaton Medical Group, Ann Arbor, MI) and was obtained by measuring the R wave intervals from a six second rhythm recording. For each time trial, ten mile interval measurements were averaged. Mean heart rate for each day was obtained by averaging respective time trial means for all subjects combined.

Blood Pressure. Systolic and diastolic blood pressure were measured by auscultation of the left brachial artery with a mercurial sphygmomanometer and recorded at every ten mile interval. For each time trial, ten mile interval measurements were averaged. Mean blood pressure for each day was obtained by averaging respective time trial means for all subjects combined.

Rate Pressure Product. Rate pressure product was calculated by the product of systolic blood pressure and heart rate for each ten mile interval. For each time trial, ten mile interval measurements were averaged. Mean rate pressure product for each day was obtained by averaging respective time trial means for all subjects combined.

Mean Arterial Pressure. Mean arterial pressure was calculated by the addition of diastolic blood pressure to one third of the pulse pressure for each ten mile interval. For each time trial, ten mile interval measurements were averaged. Mean mean arterial pressure for each day was obtained by averaging respective time trial means for all subjects combined.

Peak Aortic Velocity, Acceleration and Stroke Distance. Left ventricular function was measured non-invasively using a Quinton three megahertz continuous wave Doppler ultrasound, Exerdop® (Quinton Instruments, Seattle, WA). At each ten mile interval the sound head was placed at the sternal notch approximately 20 degrees off the anterior chest wall. Coupling gel was used to enhance sound transmission of the incident and reflected signal. Audible and visual feedback were used to optimize localization of ascending aortic blood flow. A distinct audible and LED visual pattern differentiated aortic blood flow from blood flow in nearby vessels.

Ascending aortic blood flow was assessed for peak aortic velocity, peak aortic acceleration, and stroke distance (systolic velocity integral). All measurements were taken with each subject in the sitting position with the trunk upright during exercise. Peak aortic velocity, Peak aortic acceleration, and stroke distance were measured at each ten mile interval. These measurements were sampled for ten seconds and averaged by the Exerdop®. For each time trial, ten mile interval measurements were averaged. Mean peak aortic velocity, acceleration and stroke distance for each day was obtained by averaging respective time trial means for all subjects combined.

Thermoregulatory Measurements

Rectal Temperature. Core temperature was measured using a Yellow Springs Instruments (YSI) 2100 thermometer and YSI 401 rectal thermister (Yellow Springs Instruments, Yellow Springs, OH). Prior to each race simulation, subjects placed the rectal thermister four to six inches past the anal sphincter. Rectal temperature was recorded at every ten mile interval. For each time trial, ten mile interval measurements were averaged. Mean rectal temperature for each day was obtained by averaging respective time trial means for all subjects combined.

Fluid Intake. Fluid intake was measured in milliliters using a graduated cylinder. Total fluid intake was calculated for each time trial. Subjects were allowed to drink fluids ad libitum. Fluid provided included water and powder mixed Exceed® sports drink. Mean fluid intake for each day was obtained by averaging respective time trial means for all subjects combined.

Metabolic Responses

Oxygen Uptake. Expired oxygen and carbon dioxide were measured by Beckman OM-11 oxygen and LB-2 carbon dioxide analyzers (Sensormedics Corp., Yorba Linda, CA). A Screenmate pneumotach was used to measure expired air volumes (S&M Instruments, Doyleston,PA.). This data was integrated with an IBM PS 2 computer using S&M Metabolic Measurement

System software. Expired gases were sampled from a mixing chamber every 15 seconds. Oxygen uptake data points were averaged from two minute time periods at each ten mile interval. For each time trial, ten mile interval measurements were averaged. Mean oxygen uptake for each day was obtained by averaging respective time trial means for all subjects combined.

Body Weight. Body weight measured in kilograms, was recorded prior to each daily time trial. Mean body weight for each day was obtained by averaging respective time trial means for all subjects combined.

Performance Measurements

Power output. Power output, measured in watts, was measured by the Schwinn Velodyne® cycle ergometer via an electrically braked roller in contact with the rear wheel of the subjects bicycle and downloaded to an IBM compatible computer using a 15 second sampling rate and then averaged for each ten mile interval. Communication software was used to interface the IBM computer with the ergometer. Software was written to average power output data for each ten mile interval. For each time trial, ten mile interval measurements were averaged. Mean power output for each day was obtained by averaging respective time trial means for all subjects combined.

Performance Time. Performance time was measured and rounded to the nearest minute for each days time trial. Mean performance time for each day was obtained by averaging respective time trial means for all subjects combined.

Procedures

Pre-event Measurements

Each subject reported to the Old Dominion Wellness Institute and Research Center prior to the first day of testing. Procedures were explained, informed consent statements were signed, characterization data were collected, and subjects were familiarized with the Schwinn Velodyne computerized cycle ergometer. Characterization data included height, weight, and training and performance data. A maximal exercise test was performed using a protocol in which workload was increased by 25 watts per minute until exhaustion. ECG, blood pressures and maximal oxygen consumption were measured during the maximal exercise test.

Race Simulation

Each subject reported to the Wellness Institute and Research Center at Old Dominion University to prepare for testing. Prior to each time trial body weight was assessed and subjects were prepped for 12 lead ECG. Subjects performed self-placement of the rectal thermistor and were instructed to position the thermistor six inches past the anal sphincter. Each subject's rear bicycle wheel was weighed and front wheel removed prior to mounting the bicycle on the ergometer. Workloads were programmed into the Velodyne ergometer prior to the start of the investigation. A custom programmable computer chip was provided by Frontline Technologies which allowed workloads to be programmed in gradient percentages. Resistance was supplied by the ergometer roller which was in contact with the rear bicycle tire. Variations in resistance simulated grade changes. The ergometer was equipped with mounting brackets which allowed friction adjustment between the rear tire and roller. The mounting brackets were marked for specific placement of each subject's bicycle so that friction between the rear tire and ergometer roller was consistent during each time trial. The race course consisted of rolling terrain with 29 miles of gradients ranging from +1 to +10%, 43 miles with 0% gradient, and 28 miles with gradients from -1 to -5 % (Appendix B). The one hundred mile race course was the same for each subject and was repeated on four consecutive days by each subject. The subject's bicycle was then mounted on the ergometer and mounting brackets adjusted. The subjects were connected to physiological monitoring equipment including ECG, sphygmomanometer, metabolic cart, and thermal monitor. Resting ECG, blood pressure, metabolic and thermal data were collected at this time. The ergometer was then calibrated while the subject was seated and pedaling his bicycle. Rear wheel weight and the subject's body weight were entered into the ergometer computer. The subject then peddled his bicycle to a speed of 25 mile per hour at which time the ergometer computer prompted the subject to stop peddling and to coast. This routine was performed twice to allow the computer to calibrate the ergometer. The one hundred mile time trial was begun. Data were collected at ten mile intervals. Cardiovascular data included heart rate, blood pressure, peak aortic velocity, peak aortic acceleration and stroke distance. Thermal data included rectal temperature and fluid intake. Metabolic data included oxygen uptake. Subjects were allowed to consume fluid ad libitum. All fluid consumption was quantified to the nearest milliliter during each time trial. Performance times for each time trial were recorded. Each subject repeated this same procedure on four consecutive days.

Statistical Analysis

Heart rate, systolic and diastolic blood pressure, mean arterial pressure, rate pressure product peak aortic velocity, peak aortic acceleration, stroke distance, rectal temperature, oxygen uptake and power output were analyzed using a four by ten repeated measures analysis of variance. Variables were statistically tested for differences between each daily mean and differences between each ten mile interval distance measurement. Statistical significance was accepted when alpha levels were 0.05 or less. Newman Keuls follow up tests were used to identify specific differences between daily means. Body weight, fluid intake and performance time were statistically tested for differences among days by repeated measures analysis of variance.

CHAPTER 4

Results

Introduction

The purpose of this investigation was to describe the cardiovascular, thermoregulatory, metabolic and performance responses of highly trained cyclists to four days of repeated ultraendurance cycling. This chapter will provide results for each variable independently with a summary presented at the end of the chapter.

The one hundred mile race course was the same for each subject and was repeated on four consecutive days by each subject. The race course was programmed into the computerized ergometer in gradient percentages. Grade changes were simulated by variations in resistance supplied by the ergometer roller which was in contact with the rear tire of the subject's bicycle. The race course consisted of rolling terrain with 29 miles of gradients ranging from +1 to +10%, 43 miles with 0% gradient, and 28 miles with gradients from -1 to -5 % (Appendix B). It is important to note that the scaling used in figure one, the race course profile, was necessary for graphical representation but is not proportional.

Fluid intake and performance time were measured at the end of each daily time trial and analyzed for differences among days one through four. Body weight was measured prior to each time trial and analyzed for differences among days one through four. All other variables were analyzed for differences among daily means for each time trial with all subjects combined. The ten mile interval distance measurements for each time trial are presented in appendix B. Because this study was designed to investigate responses to repeated ultraendurance exercise, the primary focus of the results and discussion will be on day to day changes in the variables measured.

Cardiovascular Responses

Heart Rate (HR)

For each time trial, ten mile interval measurements were averaged. Mean heart rate for each day was obtained by averaging respective time trial means for all subjects combined. Heart rate on days one through four respectively was 153, 142, 141 and 142 beats per minute. Heart rate was significantly higher on day one than on days two through four. Mean exercise heart rates for day one and days two through four respectively were 81 and 75 percent of maximal heart rate.

Table 1

Heart Rate (HR) Daily Means (M) and Standard Deviation (SD) in Beats Per Minute

HR	M	SD
Day 1	153	13
Day 2	142	17
Day 3	141	17
Day 4	142	15

Systolic Blood Pressure (SBP)

For each time trial, ten mile interval measurements were averaged. Mean systolic blood pressure for each day was obtained by averaging respective time trial means for all subjects combined. Systolic blood pressure on days one through four respectively was 167, 160, 160 and 165 millimeters of mercury. There were no significant changes in systolic blood pressure among days one through four.

Table 2

Systolic Blood Pressure (SBP) Daily Means (M) and Standard Deviation (SD) in Millimeters Mercury

SBP	M	SD
Day 1	167	23
Day 2	160	18
Day 3	160	19
Day 4	165	18

Diastolic Blood Pressure (DBP)

For each time trial, ten mile interval measurements were averaged. Mean diastolic blood pressure for each day was obtained by averaging respective time trial means for all subjects combined. Diastolic blood pressure on days one through four respectively was 65, 66, 63 and 64 millimeters of mercury. There were no significant differences in diastolic blood pressure among days one through four.

Table 3

Diastolic Blood Pressure (DBP) Daily Means (M) and Standard Deviation (SD) in Millimeters Mercury

DBP	M	SD
Day 1	65	6
Day 2	66	7
Day 3	63	9
Day 4	64	10

Mean Arterial Pressure (MAP)

For each time trial, ten mile interval measurements were averaged. Mean mean arterial pressure for each day was obtained by averaging respective time trial means for all subjects combined. Mean arterial pressure on days one through four respectively was 99, 98, 95 and 97 millimeters of mercury. There were no significant differences in mean arterial pressure among days one through four.

Table 4

Mean Arterial Pressure (MAP) Daily Means (M) and Standard Deviation (SD) in Millimeters Mercury

MAP	M	SD
Day 1	99	8
Day 2	98	7
Day 3	95	9
Day 4	97	9

Rate Pressure Product (RPP)

For each time trial, ten mile interval measurements were averaged. Mean rate pressure product for each day was obtained by averaging respective time trial means for all subjects combined. Rate pressure product on days one through four respectively was 256, 230, 222 and 230. Rate pressure product was significantly higher on day one than on days two through four. Rate pressure product is measured as the product of millimeters mercury and beats per minute. Rate pressure product is divided by 100 when reported.

Table 5

Rate Pressure Product (RPP) Daily Means (M) and Standard Deviation (SD) in Millimeters Mercury Multiplied by Beats Per Minute and Divided by 100

RPP	M	SD
Day 1	256	48
Day 2	230	42
Day 3	222	43
Day 4	230	40

Peak Aortic Velocity (PKV)

For each time trial, ten mile interval measurements were averaged. Mean peak aortic velocity for each day was obtained by averaging respective time trial means for all subjects combined. Peak aortic velocity on days one through four respectively was 1.01, 1.01, 1.08 and 1.06 meters per second. There were no significant differences in peak aortic velocity among days one through four.

Table 6

Peak Aortic Velocity (PKV) Daily Means (M) and Standard Deviation (SD) in Meters Per Second

PKV	M	SD
Day 1	1.01	0.21
Day 2	1.01	0.21
Day 3	1.08	0.20
Day 4	1.06	0.17

Peak Aortic Acceleration (PKA)

For each time trial, ten mile interval measurements were averaged. Mean peak aortic acceleration for each day was obtained by averaging respective time trial means for all subjects combined. Peak aortic acceleration on days one through four respectively was 60, 58, 62 and 60 meters per second per second. There were no significant differences in peak aortic acceleration among days one through four.

Table 7

Peak Aortic Acceleration (PKA) Daily Means (M) and Standard Deviation (SD) in Meters Per Second Per Second

PKA	M	SD
Day 1	60	15
Day 2	58	19
Day 3	62	15
Day 4	60	16

Stroke Distance (Sd)

For each time trial, ten mile interval measurements were averaged. Mean stroke distance for each day was obtained by averaging respective time trial means for all subjects combined. Stroke distance on days one through four respectively was 7.9, 8.9, 8.9 and 9.6 centimeters. There were no significant differences in stroke distance among days one through four.

Table 8

Stroke Distance (SD) Daily Means (M) and Standard Deviation (SD) in Centimeters

Sd	M	SD
Day 1	7.9	1.5
Day 2	8.9	1.7
Day 3	8.9	1.6
Day 4	9.6	2.0

Thermoregulatory Responses

Rectal Temperature (Tr)

For each time trial, ten mile interval measurements were averaged. Mean rectal temperature for each day was obtained by averaging respective time trial means for all subjects combined. Rectal temperature on days one through four respectively was 38.2, 38.5, 38.4 and 38.5 degrees Celsius. There were no significant differences in rectal temperature among days one through four.

Table 9

Rectal Temperature (T_r) Daily Means (M) and StandardDeviation (SD) in Degrees Celsius

T_r	M	SD
Day 1	38.2	0.6
Day 2	38.5	0.5
Day 3	38.4	0.5
Day 4	38.5	0.5

Fluid Intake (FI)

Mean fluid intake for each day was obtained by averaging respective time trial means for all subjects combined. Fluid intake on days one through four respectively was 5247, 5095, 5178 and 5063 milliliters. There were no significant differences in fluid intake among days one through four. Average fluid intake for days one through four was 5146 milliliters per day. Average hourly fluid intake per day was 1.14 liters per hour.

Table 10

Fluid Intake (FI) Daily Means (M) and Standard Deviation (SD) in Milliliters

FI	M	SD
Day 1	5247	1951
Day 2	5095	1570
Day 3	5178	1724
Day 4	5063	1810

Metabolic Responses

Oxygen Uptake (VO_2)

For each time trial, ten mile interval measurements were averaged. Mean oxygen uptake for each day was obtained by averaging respective time trial means for all subjects combined. Oxygen uptake on days one through four respectively was 4.39, 4.46, 4.43 and 4.72 liters per minute. There were no significant differences in oxygen uptake among days one through four. Average oxygen uptake for days on through four was 4.5 liters per minute and 74 percent of maximal oxygen uptake.

Table 11

Oxygen Uptake (VO_2)Daily Means (M) and Standard Deviation (SD) in Liters Per Minute

VO_2	M	SD
Day 1	4.39	1.18
Day 2	4.46	1.57
Day 3	4.43	1.28
Day 4	4.72	1.40

Body Weight (BW)

Mean body weight for each day was obtained by averaging respective time trial means for all subjects combined. Body weight on days one through four respectively was 71.9, 71.9, 72.3 and 72.2 kilograms. There were no significant differences in body weight among days one through four. Average body weight for days one through four was 72.1 kilograms.

Table 12

Body Weight (BW) Daily Means (M) and Standard Deviation (SD) in Kilograms

BW	M	SD
Day 1	71.9	8.0
Day 2	71.9	7.8
Day 3	72.3	7.7
Day 4	72.2	7.9

Performance Responses

Power Output (PO)

For each time trial, ten mile interval measurements were averaged. Mean power output for each day was obtained by averaging respective time rial means for all subjects combined. Power output on days one through four respectively was 234, 215, 229 and 218 watts. There were no significant differences power output among days one through four.

Table 13

Power Output (PO) Daily Means (M) and
Satndard Deviation (SD) in Watts

PO	M	SD
Day 1	234	68
Day 2	215	60
Day 3	229	65
Day 4	218	51

Performance Time

Mean performance time for each day was obtained by averaging respective time trial means for all subjects combined. Performance time on days one through four respectively was 272, 268, 272, 272 minutes. There were no significant differences in performance time among days one through four.

Table 14

Performance Time (Time) Daily Means (M) and
Standard Deviation (SD) in Minutes

Time	M	SD
Day 1	272	29
Day 2	268	26
Day 3	272	34
Day 4	272	21

Results Summary

Heart rate and rate pressure product were significantly higher (p= 0.02 and 0.005 respectively) on day one of the race than days two through four. Blood pressure, mean arterial pressure, peak aortic velocity, peak aortic acceleration, stroke distance, rectal temperature, fluid intake, oxygen consumption, body weight, power output and performance time were not significantly different among days one through four.

Chapter 5
Discussion

Introduction

The purpose of this investigation was to describe the cardiovascular, thermoregulatory, metabolic and performance responses in highly trained cyclists to four days of repeated ultraendurance cycling. This chapter will provide a discussion of the results by category with a summary discussion at the end of the chapter.

Cardiovascular Responses

Although day mean heart rate and rate pressure product were significantly higher on day one than days two through four, there were no progressive declines from day two to day four. One previous case study of ultraendurance cycling found a progressive decrease in heart rate which was also accompanied by a decrease in cycling speed during a 24 hr cycling event (White et al., 1984). Two other case studies by Cahalin et al. (1990) and Cahalin and Randolph (1994) reported declining heart rates over several days of ultraendurance cycling during the Race Across America. Sleep deprivation was suggested to be related to declining heart rate responses. Subjects in the present investigation were not sleep deprived. There were no significant changes in other cardiovascular, thermoregulatory or metabolic measures and no significant changes in performance time among days one through four. Therefore the decrease in heart rate and rate pressure product on day one did not significantly affect normal physiological function or performance capacity. Increased heart rate and rate pressure product on day one may have been related to competitive effort by the subjects when they were unfamiliar with the race course. Alternatively, a type 1 error related to repeated statistical tests (14 ANOVAs) may have resulted in heart rate and rate pressure product being randomly significant. When alpha levels were adjusted for using the

Bonferroni technique (p= > 0.0036), heart rate and rate pressure product were no longer significantly different.

There were no significant changes in systolic, diastolic or mean arterial blood pressure among days one through four. These results along with normal heart rate responses indicate that normal cardiovascular function was maintained from day to day.

Peak aortic velocity, acceleration and stroke distance were maintained throughout the four day event without significant changes. Although no quantitative conclusions can be made regarding the absolute values, conclusions can be made regarding their qualitative merit with reference to previous investigations.

The integral of peak velocity over time, stroke distance, and the first derivative of peak velocity, peak acceleration, have been suggested to be clinically useful indicators of left ventricular function. Peak acceleration has been reported to represent maximum force exerted by the left ventricle in early systole and left ventricular power (Noble et al., 1966; Stein and Sabbah, 1976). Peak acceleration has also been reported to be a sensitive indicator of left ventricular inotropic state in dogs (Noble et al., 1966) and in man (Bennett et al., 1984). Stroke volume has been calculated using stroke distance and an independent measure of aortic root diameter determined echocardiographically. This measurement has been highly correlated with stroke volume and cardiac output measured by thermodilution technique at rest and during exercise (Chandraratna et al., 1984; Colocousis et al., 1977; Shaw et al., 1985). Stroke volume determined by the same method was found to be a reliable indicator of the Starling response induced by lower body positive pressure (Bennett et al., 1984).

Based on the conclusions of the previously cited investigations, peak aortic acceleration and stroke distance provide good indices of cardiac function. It can be concluded that the subjects in this study were able to maintain normal cardiovascular function without significant changes from day to day during four days of ultraendurance cycling.

Thermoregulatory Responses

In the present investigation rectal temperature was maintained without significant changes among days one through four. Maximum rectal temperature was 38.6 degrees Celsius which is clinically non-significant and within normal physiological values for exercise (Davies et al., 1976). These results are similar to previous results by Davies and Thompson (1986) who reported rectal temperature increases of 0.6 degrees Celsius (38.4 to 39.0 degrees Celsius) between the first and fourth hour during four hours of treadmill running. O'Toole et al. (1987) reported rectal temperature increases of 0.2 degrees Celsius (37.7 to 37.9 degrees Celsius) during five hours of cycling and 0.7 degrees Celsius (37.9 to 38.6 degrees Celsius) during three hours of running which immediately followed the cycling.

Fluid intake during this investigation averaged 1.14 liters per hour. Approximately five liters of fluid were consumed during each time trial which lasted an average of 271 minutes. Brouns et al. (1989) studied subjects during 280 minutes of cycling on two consecutive days which was comparable to exercise times during this investigation. They reported fluid intakes of 3.18 and 3.17 liters for days one and two of exercise respectively. Significant decreases in body weight were reported during exercise. Final event body weight was significantly decreased from initial body weight. No significant decreases in body weight were found among days one through four during the present investigation. Fluid intake was within recommended volumes for ultraendurance athletes (Brouns et al, 1989; Kreider, 1991).

These results show that normal thermoregulatory function was maintained by highly trained cyclists without significant day to day changes during the four day event.

Metabolic Responses

Davies and Thompson (1986) reported a nine percent increase in relative oxygen uptake over a period of three hours during four hours of running. However, O'Toole et al. (1987) found no significant differences in oxygen uptake in male subjects during eight hours of cycling and running at an exercise intensity of 45 to 64 percent of maximal oxygen uptake. During the present investigation there were no significant changes in oxygen uptake from day to day indicating that highly trained cyclists are able to maintain exercise intensity at a considerable fraction of their maximal aerobic capacity (74% VO_2 max) during four days of ultraendurance cycling.

There were no significant changes in body weight among days one through four during this study. Costill and Miller (1980) reported that body water loss equaling three percent of body weight may be detrimental to performance. Brouns et al. (1989) reported a significant decrease in body weight after two days of repeated ultraendurance cycling lasting 280 minutes each day. However, Saris et al. (1989) found no significant changes in post event body weight in four cyclists participating in the "Tour de France". They suggested that consistent and adequate fluid intake during the "Tour de France" was integral to the maintenance of body weight and performance capacity. Body weight was maintained with less than one percent loss among days one through four during this investigation. There were no significant differences in performance times or power output among days one through four.

Performance Responses

Davies and Thompson (1986) reported that maximal voluntary contraction of the quadriceps was reduced by 25 percent following ultraendurance running. They concluded that an observed increase in relative oxygen uptake was related to muscle fatigue and increased muscle fiber recruitment. Cahalin et al. (1990) studied physiological changes in an ultraendurance cyclist before and after the Race Across America and found a

24 percent decrease in post-event maximal workload. Power output was measured during exercise in this investigation. The results show that highly trained cyclists are able to maintain power output without significant changes from day to day.

Performance times were not significantly different from day to day during the four day event. The average 100 mile competitive performance time for these subjects prior to this investigation was 244 minutes which was considerably less than their average performance time of 271 minutes measured during this study. Foster et al. (1993) compared physiological responses during competitive conditions and simulated laboratory conditions and found that competitive responses can be significantly greater. Measurements in the laboratory more closely approximated competitive measurements under conditions in which subjects were able to control moment to moment power output rather than when work output was dictated by protocol. The direct competitive influence of other cyclists was not present in this study, however competition was provided by cash prizes awarded on a points-earned basis. The results show that highly trained cyclists are able to maintain performance capacity throughout four days of repeated ultraendurance cycling.

Discussion Summary

Heart rate and rate pressure product were significantly higher on day one of the race than days two through four. These changes may have been related to competitive effort by the subjects when unfamiliar with the race course. Alternatively, significant differences may have been random and related repeated statistical testing. When alpha levels were adjusted using the Bonferroni technique, heart rate and rate pressure product were no longer significantly different. Blood pressure, mean arterial pressure, peak aortic velocity, peak aortic acceleration, stroke distance, rectal temperature, fluid intake, oxygen consumption, body weight, power output and performance time were not significantly different among days one through four.

The results of this investigation suggest that highly trained competitive cyclists are able to maintain cardiovascular, thermoregulatory and metabolic function from day to day during four days of repeated ultraendurance cycling without detrimental changes in physiological function or performance.

CHAPTER 6

Summary, Conclusions and Recommendations

Summary

The purpose of this study was to describe cardiovascular, thermoregulatory, metabolic and performance responses in six highly trained cyclists during four days of repeated ultraendurance cycling. The null hypothesis was used that no significant changes would occur in any of the variables measured among days one through four. Each subject rode 100 miles per day on four consecutive days using their own bicycles mounted to a Schwinn Velodyne® computerized ergometer. The race course profile consisted of rolling and challenging terrain (table 1., figure 1.). The same race course was repeated by each subject during each of the four time trials. The computerized ergometer simulated grade changes in workload by varying resistance applied to the rear tire of the subjects bicycle via an electrically braked roller. Measurements for all data except body weight, fluid intake and performance time were made at ten mile intervals during each 100 mile time trial. Body weight was measured prior to each time trial. Total performance time and fluid intake for each time trial were recorded. For each time trial, ten mile interval measurements were averaged. Means for each day were obtained by averaging respective time trial means for all subjects combined. Data were analyzed for differences among days one through four using repeated measures analysis of variance.

Heart rate and rate pressure product were significantly higher on day one of the race than days two through four. These changes may have been related to competitive effort and unfamiliarity with the race course on day one. Alternatively, significant differences may have been random and related repeated statistical testing. When alpha levels were adjusted using the Bonferroni technique, heart rate and rate pressure product were no longer significantly different. Blood pressure, mean arterial pressure, peak aortic velocity, peak aortic acceleration, stroke distance, rectal temperature, fluid intake, oxygen consumption, body weight, power output and performance time were not significantly different among days one through four.

The results of this investigation suggest that highly trained competitive cyclists are able to maintain cardiovascular, thermoregulatory and metabolic function from day to day during four days of repeated ultraendurance cycling without detrimental changes in physiological function or performance.

Conclusions

1. There were no statistically significant differences in heart rate, systolic blood pressure, diastolic blood pressure, mean arterial pressure, rate pressure product, peak aortic velocity, peak aortic acceleration or stroke distance among days one through four. Highly trained cyclists are able to maintain normal cardiovascular function during four days of ultraendurance cycling.

2. There were no statistically significant differences in rectal temperature or fluid intake among days one through four. Highly trained cyclists are able to maintain normal thermoregulatory function during four days of ultraendurance cycling.

3. There were no statistically significant differences in oxygen uptake or body weight among days one through four. Highly trained cyclists are able to maintain normal metabolic function during four days of ultraendurance cycling.

4. There were no statistically significant differences in power output or performance time among days one through four. Highly trained cyclists are able to maintain normal performance capacity during four days of ultraendurance cycling.

Recommendations

Further investigation of continuous wave Doppler ultrasound as a non-invasive measurement of cardiac function in endurance exercise is needed to determine normal values and responses during endurance exercise in athletes.

APPENDIX A

Subject Physiological Profile and Performance Data

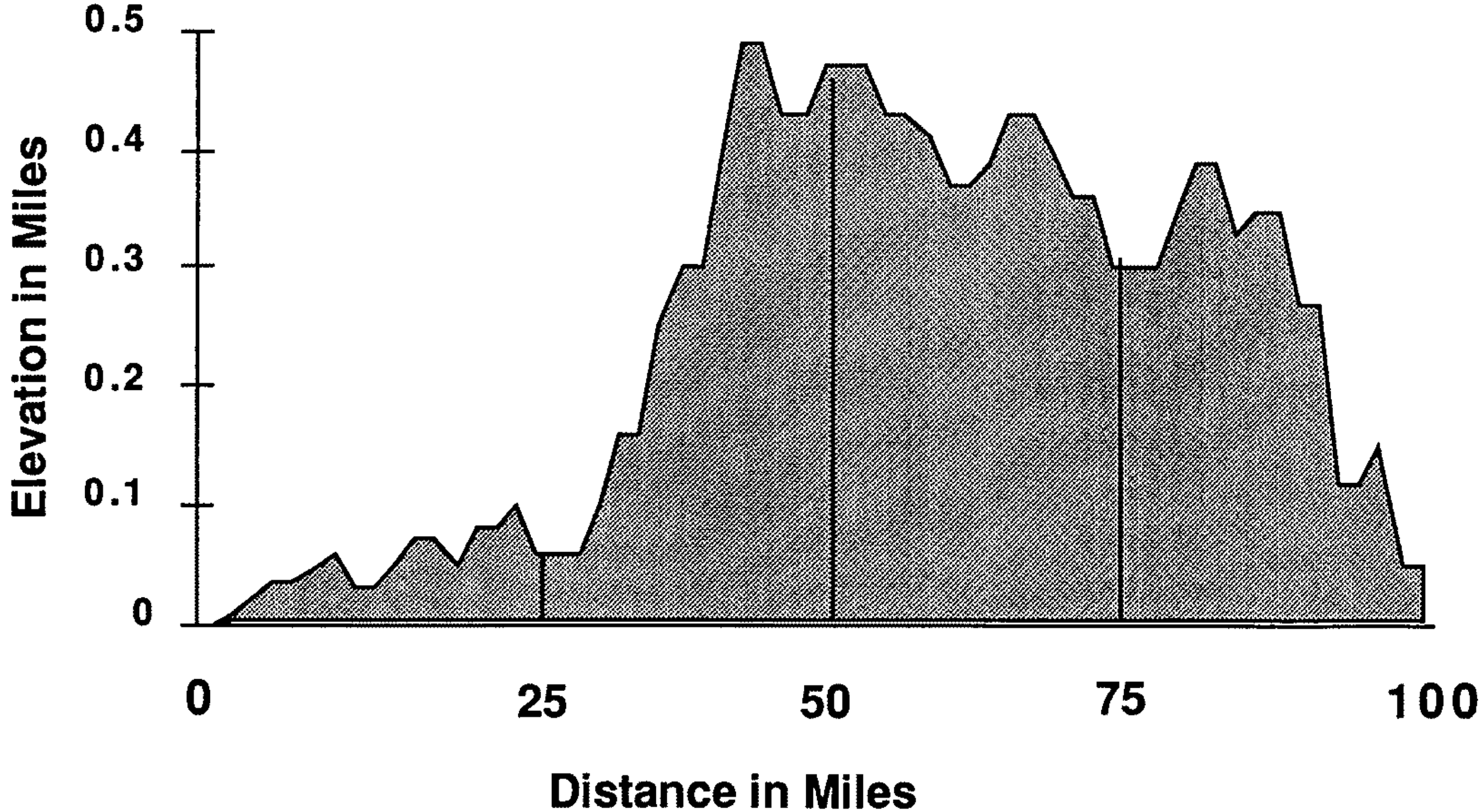
VARIABLE	Mean	Standard Deviation
Age (yrs)	24	5
Height (cm)	180	7
Weight (kg)	72.2	6.8
MAXIMAL PROFILE		
HR (bpm)	188	8
SBP (mmHg)	186	16
DBP (mmHg)	73	3
MAP (mmHg)	111	5
Power (watts)	367	40
VO_2 (l/min)	6.06	0.9
VO_2 (ml/kg/min)	83.6	5
PERFORMANCE DATA		
Years Training	5.5	1.5
Years in competition	4.5	1.9
Races in last 12 mo.	73	18
Training vol. (km/wk)	510	92
PERFORMANCE TIMES		
40 km (min)	55	2
80 km (min)	106	9
161 km (min)	244	28

APPENDIX B

Race Course Profile Table and Figure

Miles 1 - 25		Miles 25 - 50		Miles 50 - 75		Miles 75 - 100	
Dist. (miles)	Grade (%)	Dist. (miles)	Grade (%)	Dist. (miles)	Grade (%)	Dist. (miles)	Grade (%)
2	0	1	0	2	0	1	0
.5	2	1	4	2	-2	1	5
1	1	3	2	2	0	2	2
.5	3	2	0	2	-1	2	0
2	0	3	3	1	-4	2	-3
1	1	1	5	2	0	1	2
.5	3	2	0	1	2	2	0
1.5	-2	1	10	1	4	2	-4
2	0	3	3	2	0	2	0
1	2	2	0	3	-1	3	-5
2	1	2	-3	2	-2	2	0
2	0	2	0	2	0	1	3
2	-1	1	4	2	-3	2	-5
1	3	1	0	1	0	2	0
2	0						
1	2						
2	-2						
1	0						

Course Profile



APPENDIX C

Cardiovascular, Thermoregulatory, Metabolic and Performance Variable Distance Measurements

Heart Rate in Beats Per Minute

HR	mile 10	mile 20	mile 30	mile 40	mile 50	mile 60	mile 70	mile 80	mile 90	mile 100	Day Mean
Day 1	154	158	162	152	155	151	147	147	147	154	153
Day 2	142	144	140	143	141	131	142	141	143	158	142
Day 3	140	144	141	140	145	132	130	144	134	157	141
Day 4	136	142	137	143	153	139	137	143	138	155	142
Dist. Mean	143	147	145	145	148	138	139	144	141	156	

Systolic Blood Pressure in Millimeters Mercury

SBP	mile 10	mile 20	mile 30	mile 40	mile 50	mile 60	mile 70	mile 80	mile 90	mile 100	Day Mean
Day 1	181	180	175	161	165	160	163	157	159	168	167
Day 2	169	165	167	160	139	153	152	163	164	167	160
Day 3	166	167	159	158	157	152	153	153	151	180	160
Day 4	160	164	163	160	169	169	164	157	165	180	165
Dist. Mean	169	169	166	160	157	159	158	158	160	174	

Diastolic Blood Pressure in Millimeters Mercury

DBP	mile 10	mile 20	mile 30	mile 40	mile 50	mile 60	mile 70	mile 80	mile 90	mile 100	Day Mean
Day 1	65	64	63	61	63	64	66	64	66	69	65
Day 2	69	67	68	62	64	68	65	65	69	66	66
Day 3	64	65	64	63	65	62	61	59	60	65	63
Day 4	64	62	65	61	64	67	68	62	62	64	64
Dist. Mean	66	65	65	62	64	65	65	62	64	66	

Mean Arterial Pressure in Millimeters Mercury

MAP	mile 10	mile 20	mile 30	mile 40	mile 50	mile 60	mile 70	mile 80	mile 90	mile 100	Day Mean
Day 1	104	100	102	100	97	96	98	94	96	100	99
Day 2	102	99	101	95	93	97	94	98	100	100	98
Day 3	96	98	96	93	96	92	91	92	92	99	95
Day 4	98	96	97	93	102	99	100	93	96	101	97
Dist. Mean	100	98	99	95	97	96	96	94	96	100	

Rate Pressure Product in Millimeters Mercury Multiplied by Beats Per Minute and Divided by 100

RPP	mile 10	mile 20	mile 30	mile 40	mile 50	mile 60	mile 70	mile 80	mile 90	mile 100	Day Mean
Day 1	279	285	284	247	257	241	241	231	235	264	256
Day 2	241	238	235	230	210	202	217	232	233	266	230
Day 3	232	238	232	214	228	205	197	221	200	260	222
Day 4	220	216	216	223	265	226	228	217	228	263	230
Dist. Mean	243	244	242	228	240	218	220	225	224	263	

Peak Aortic Velocity in Meters Per Second

PKV	mile 10	mile 20	mile 30	mile 40	mile 50	mile 60	mile 70	mile 80	mile 90	mile 100	Day Mean
Day 1	1.11	1.08	1.08	1.06	.93	.89	.93	1.06	.96	1.05	1.01
Day 2	1.08	1.05	1.04	.99	.97	.92	1.03	1.02	1.12	.93	1.01
Day 3	1.13	1.12	1.22	1.17	1.05	.99	.93	.97	1.08	1.15	1.08
Day 4	1.02	1.07	1.00	.99	.98	1.06	1.19	1.11	1.15	1.04	1.06
Dist. Mean	1.08	1.07	1.08	1.05	.98	.96	1.02	1.04	1.07	1.04	

Peak Aortic Acceleration in Meters Per Second Per Second

PKA	mile 10	mile 20	mile 30	mile 40	mile 50	mile 60	mile 70	mile 80	mile 90	mile 100	Day Mean
Day 1	65	69	66	61	55	52	56	64	54	61	60
Day 2	63	59	60	56	55	49	58	58	60	58	58
Day 3	64	63	67	57	69	53	57	54	65	74	62
Day 4	52	62	54	59	57	59	68	58	64	64	60
Dist. Mean	61	63	62	58	59	53	59	58	61	64	

Stroke Distance in Centimeters

SD	mile 10	mile 20	mile 30	mile 40	mile 50	mile 60	mile 70	mile 80	mile 90	mile 100	Day Mean
Day 1	8.2	7.6	8.0	7.8	6.9	7.3	7.9	8.9	8.4	7.5	7.9
Day 2	10.1	9.1	8.5	9.0	8.6	9.0	8.6	9.4	9.9	7.1	8.9
Day 3	9.7	9.0	8.6	8.9	8.2	9.2	8.9	8.9	10.1	7.3	8.9
Day 4	9.7	8.7	9.4	9.4	7.1	10.5	11.0	10.6	11.0	8.0	9.6
Dist. Mean	9.4	8.6	8.6	8.8	7.7	9.0	9.1	9.5	9.9	7.5	

Rectal Temperature in Degrees Celsius

T_r	mile 10	mile 20	mile 30	mile 40	mile 50	mile 60	mile 70	mile 80	mile 90	mile 100	Day Mean
Day 1	38.2	38.3	38.6	38.6	38.4	38.2	38.1	38	37.9	38.2	38.2
Day 2	38	38.3	38.5	38.8	38.5	38.3	38.3	38.6	38.6	38.7	38.5
Day 3	38.1	38.4	38.5	38.5	38.6	38.4	38.3	38.4	38.4	38.4	38.4
Day 4	38	38.3	38.5	38.5	38.6	38.3	38.4	38.6	38.6	38.8	38.5
Dist. Mean	38.1	38.3	38.5	38.6	38.5	38.3	38.3	38.4	38.3	38.5	

Oxygen Uptake in Liters Per Minute

VO2	mile 10	mile 20	mile 30	mile 40	mile 50	mile 60	mile 70	mile 80	mile 90	mile 100	Day Mean
Day 1	5.26	5.30	4.61	4.5	4.34	3.77	4.24	3.90	3.79	4.24	4.39
Day 2	4.55	4.58	4.63	4.68	4.47	3.75	4.32	4.52	4.21	4.85	4.46
Day 3	4.63	4.5	4.84	4.54	4.23	3.84	3.89	4.25	4.14	5.37	4.43
Day 4	4.64	4.98	4.85	5.41	4.55	4.45	4.26	4.43	4.46	5.12	4.72
Dist. Mean	4.77	4.84	4.73	4.78	4.41	3.95	4.18	4.28	4.15	4.89	

Power Output in Watts

PO	mile 0-10	mile 10-20	mile 20-30	mile 30-40	mile 40-50	mile 50-60	mile 60-70	mile 70-80	mile 80-90	mile 90-100	Day Mean
Day 1	276	258	246	247	228	233	232	215	203	207	234
Day 2	232	225	222	229	208	198	199	202	201	232	215
Day 3	233	238	234	232	219	209	213	213	243	253	229
Day 4	217	217	220	209	209	217	212	223	222	239	218
Dist. Mean	239	234	230	229	216	214	214	213	217	233	

APPENDIX D

ANOVA Statistical Summary Table

Variable	F ratio	P value
Heart Rate	4.39	0.02
Systolic Blood Pressure	2.07	0.15
Diastolic Blood Pressure	1.30	0.31
Rate Pressure Product	6.53	0.005
Mean Arterial Pressure	1.81	0.19
Peak Aortic Velocity	1.45	0.27
Peak Aortic Acceleration	0.66	0.59
Stroke Distance	2.84	0.07
Rectal Temperature	0.48	0.70
Fluid Intake	0.17	0.92
Oxygen Uptake	0.27	0.85
Body Weight	0.57	0.64
Power Output	1.68	0.21
Performance Time	0.08	0.97

WORKS CITED

Bennett, E.D., Barclay, S.A., Davis, A.L., Mannering, D., Mehta, N. "Ascending Aortic Blood Velocity and Acceleration Using Doppler Ultrasound in the Assessment of Left Ventricular Function." Cardiovascular Research 18 (1984): 632-38.

Brouns, F., Saris,W.H.M., Stroecken, J., Beckers, E., Thijssen, R., Rehrer,N.J. Hoor, F. Ten. "Eating, Drinking and Cycling. A Controlled Tour de France Simulation Study, Part I." International Journal of Sports Medicine 10 (1989): S32-40.

Bruce, R.A., Kusumi, F., Culver, B.H., Butler, J. "Cardiac Limitation to Maximal Oxygen Transport and Changes in Components After Jogging Across the US." Journal of Applied Physiology 39 (1974): 958-964.

Cahalin,L., Ice, R. "Ultramarathon Bicycling and the Cardiopulmonary System." Cardiopulmonry Physical Therapy 5 (1994): 9-16.

Cahalin, L., Ice, R., Saseo, R. "Exercise Heart Rates During the Race Across America. " Medicine and Science in Sports and Exercise 22 (1990): S67 (abstract).

Chandraratna, P.A., Nanna, M., McKay, C., Nimalasuriya, A., Swinney, R., Elkayam, U., Rahimtoola, S.H. "Determination of Cardiac Output by Trancutaneous Continuous-Wave Ultrasonic Doppler Computer." American Journal of Cardiology 53 (1984): 234-37.

Colocousis, J.S., Huntsman, L.L., Curreri, P.W. "Estimation of Stroke Volume changes by Ultrasonic Doppler." Circulation 56 (1977): 914-17.

Costill, D.L. and Miller, J.M. "Nutrition for Endurance Sport: Cxarbohydrate and Fluid Balance" International Journal of Sports Medicine 1 (1980): 2-14.

Davies, C.T.M., Brotherhood, J.R., Zeidifard, E. "Temperature Regulation During Severe Exercise with some Observations on Effects of Skin Wetting." Journal of Applied Physiology 41 (1976): 772-76.

Davies, C.T.M. and Thompson, M.W. "Aerobic Performance of Female and Male Ultramarathon Athletes." European Journal of Applied Physiology 41 (1979): 233-45.

Davies, C.T.M. and Thompson, M.W. "Physiological Responses to Prolonged Exercise in Ultramarathon Athletes." Journal of Applied Physiology 61 (1986): 611-17.

Douglas, P.S., O'Toole, M.L., Hiller,W.D., Hackney, K., Reichek, N. "Cardiac Fatigue After Prolonged Exercise." Circulation 76 (1987): 1206-13.

Douglas, P.S. "Cardiac Considerations in the Triathlete. " Medicine and Science in Sports and Exercise 21 (1989): S214-18.

Ekelund, L.G. "Circulatory and Respiratory Adaptations During Prolonged Exercise in the Supine Position." Acta Physiologica Scandinavia 68 (1966): 382-96.

Ekelund, L.G. and Holmgren, A.. "Circulatory and Respiratory Adaptation, During Long Term, Non-Steady State Exercise, in the Sitting Position." Acta Physiologica Scandinavia 62 (1964): 240-55.

Ekelund, L.G., Holmgren, A., Ovenfors, C.O.. "Heart volume During Prolonged Exercise in the Supine and Sitting Position. " Acta Physiologica Scandinavia 70 (1967): 88-98.

Foster, C., Green, M.A., Snyder, A.C., Thompson, N.N. "Physiological Responses During Simulated Competition" Medicine and Science in Sports and Exercise 25 (1993): 877-882.

Hamilton, M.T., Gonzalez-Alonso, J., Montain, S.J., Coyle, E.F. "Fluid Repalcement and Glucose Infusion During Exercise Prevent Cadiovascular Drift." Journal of Applied Physiology 71(1991): 871-7.

Hiller, W.D. "Dehydration and Hyponatremia during triathlons." Medicine and Science in Sports and Exercise 21 (1989): S219-21.

Kaman, R.L., Raven, P.B., Patton, R.W., Ayres, J., Goheen, B. "The effects of Near Maximum Exercise on Serum Enzymes: The Exercise Profile Versus The Cardiac Profile." Cilinical Chimica Acta 81 (1977): 145-52.

Kielblock, A.J., Manjoo, M., Booyens, J., Katzeff, I.E. "Creatine Phosphokinase and Lactate Dehydrogenase Levels After Ultra Long Distance Running." South African Medical Journal 55 (1979): 1061-64.

King, D.W. and Gollnick, P.D. "Ultrastructure of Rat Heart and Liver After Exhaustive Exercise." American Journal of Physiology 218 (1970): 1150-55

Kitamura, K., Jorgenson, C.R., Gobel, F.L., Taylor, H.L., Wang, Y. "Hemodynamic Correlates of Myocardial Oxygen Consumption During Upright Exercise." Journal of Applied Physiology 32 (1972): 516-522.

Krieder, R.B. "Physiological Considerations of Ultraendurance Performance." International Journal of Sports Nutrition 1 (1991): 3-27.

Laird, R.H. "Medical Complications of During the Ironman Triathlon World Championship." Annals of Sports Medicine 3 (1987): 113-16.

Mehdirad, A.A., Williams, G.A., Labovitz, A.J., Bryg, R.J., Chaitman, B.R. "Evaluation of Left Ventricular Function During Upright Exercise: Correlation of Exercise Doppler with Postexercise Two-dimensional Echocardiographic Results." Circulation 75 (1987): 413-19.

Mehta, N., Boyle, G., Bennett, D., Gilmour, S., Noble, M.I., Mills, C.M., Pugh, S. "Hemodynamic Response to Treadmill Exercise in Normal Volunteers: An Assessment by Doppler Ultrasonic Measurement of Ascending Aortic Blood Velocity and Acceleration." American Heart Journal 116 (1988): 1298-1307.

Murphy, P. "Ultrasports Are In-- In Spite of Injuries." Physician and Sports Medicine 14 (1986): No.1, 180-190.

Nadel, E.R. "Temperature Regulation and Prolonged Exercise." In Perspectives in Exercise and Sports Medicine: Volume 1; Prolonged Exercise, D.R. Lamb and R. Murray (Eds.), Indianapolis, IN.: Benchmark Press, 1988, pp 145-147.

Niemela, K., Palatsi, I., Ikaheimo,M., Takkunen, J., Vuori, J. "Evidence of Impaired Left Ventricular Performance After an Uninterrupted Competitive 24 Hour run." Circulation 70 (1984): 350-56.

Niemela, K., Airaksinen, J., Ikaheimo, M., Palatsi, I., Takkunen, J. "Impaired Left Ventricular Diastolic Function in Athletes After Uttlerly Strenuous Prolonged Exercise." International Journal of Sports Medicine 8 (1987): 61-65.

Noakes, T.D., Opie, L., Beck, W., McKechnie, J., Benchimol, A., Desser, K. "Coronary Heart Disease in Marathon Runners." Annals of New york Academy of Sciences 301 (1977): 593-619.

Noble, M.I, Trenchard, D., Guz, A. "Left Ventricular Ejection in Conscious Dogs: Measurement and Signifigance of the Maximum Acceleration of Blood form the Left Ventricle." Circulation Research 19 (1966): 139-146.

O'Toole, M.L., Hiller, W. D.B., Douglas, P.S., Pisarello, J.B., Mullen, J.L. "Cardiovascular Responses to Cycling and Running." Annals of Sports Medicine 3 (1987): 124-130.

Raven, P.B. and Stevens, G.H.J. "Cardiovascular Function and Prolonged Exercise." In Perspectives in Exercise and Sports Medicine: Volume 1; Prolonged Exercise, D.R. Lamb and R. Murry (Eds.), Indianapolis, IN: Benchmark Press, 1988, pp 43-74.

Rowell, L.B. "Human Cardiovascular Adjustments to Exercise and Thermal Stress." Physiological Reviews 54 (1974): 75-159.

Rushmer R.F. "Initial Ventricular Impulse. A Potential Key to Cardiac Evaluation." Circulation 29 (1964): 268-283.

Salmasi, A.M., Salmasi, S.N., Doré, C., Nicolaides, A.N. "Non-invasive Assessment of Changes in Aortic Blood Velocity and its Derivatives with exercise in Normal Subjects by Doppler Ultrasound" Journal of Cardiovascular Sugery 28 (1987): 321-327.

Saltin, B. and Stenberg, J. "Circulatory Responses to Prolonged Severe Exercise" Journal of Applied Physiology 19 (1964): 833-38.

Saris, W.H.M., vanErp-Baart, M.A., Brouns, F., Westerterp, K.R., Hoor, F. Ten. "Study on Food Intake and Energy Expenditure During Extreme Sustained Exercise: The Tour de France." International Journal of Sports Medicine 10 (1989): S26-31.

Seals, D.R., M.A. Rogers, J.M. Hagberg, C. Yamamoto, P.E. Cryer, and A.A. Ehsani. "Left Ventricular Dysfunction After Prolonged Exercise in Healthy Subjects." Ameican Journal of Cardiology 61(1988): 875-79.

Shaw, J.G., Johnson, E.C., Voyles, W. F., Greene, E.R. "Noninvasive Doppler Determination of Cardiac Output During Submaximal and Peak Exercise." Journal of Applied Physiology 59 (1985): No 3, 722-31.

Stein, P.D., Sabbah, H.N. "Rate of Change of Ventricular Power. An Indicator of Ventricular Performance During Ejection." American Heart Journal 91 (1976): 599-606.

White, J.A., Ward, C., Nelson, H., "Ergogenic Demands of a 24 Hour Cycling Event." Brittish Journal of Sports Medicine 18 (1984): 165-171.

Zoltic, J.M., R. Virmani, J. Kishel, W. Fitzgerald, M. Robinowitz, and J. Bedynek. "Cardiovascular Screening and Autopsy Findings in Sudden Cardiac Death in Middle Aged Males." Medicine and Science in sports and Exercise 19 (1987): S91 (abstract).