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TEMPORAL SPECIFICITY IN EXERCISE TRAINING

THESIS

Presented to the Graduate Council of the
University of North Texas in Partial
Fulfillment of the Requirements

For the Degree of

MASTER OF SCIENCE

By

Jennifer A. Leiferman, B.S.

Denton, Texas

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The primary purpose of this study was to investigate the effect of training at a particular time of day on anaerobic capacity in the morning and in the afternoon. Six college age women trained on the cycle ergometer in the morning; six others trained in the afternoon. After training for 4 d·wk⁻¹ for 5 wk, subjects completed two exhaustive constant power cycle ergometer tests, one in the morning and one in the afternoon. Results of a two-way ANOVA (time of day of training by time of day of testing) revealed significant interaction effects on time to exhaustion ($F_{1,10} = 8.24$, $p = 0.02$) and anaerobic capacity ($F_{1,10} = 7.95$, $p < 0.02$), with both measures tending to be higher in subjects when determined at the time of day of training.

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CHAPTER I

INTRODUCTION

Circadian (24h) rhythms are cyclical fluctuations that occur over the course of about a day. Characteristic circadian rhythms occur in almost all physiological responses; classic examples of these rhythms are demonstrated in body temperature and heart rate. Values of these variables tend to slowly increase throughout the day beginning with a trough between 0200h and 0600h and showing peaks between 1500h and 2100h (Sollberger, 1965). Temperature and resting heart rate are often used as markers of circadian rhythmicity in other studies (Hill & Smith, 1991; Melhim, 1993).

Circadian rhythms have been observed in maximum oxygen uptake (Hill & Smith, 1991), anaerobic power and capacity (Hill & Smith, 1991; Melhim, 1993; Reilly & Marshall, 1991) and in performance time (Hill, Borden, Darnaby, Hendricks, & Hill, 1992). These fluctuations in physiological responses tend to be associated with rhythms in temperature.

Exercise performance and physiological responses to exercise are also influenced by training. The principle of specificity in training is that the training effects tends to be greater when training consists of using the same muscles (Clausen, Klausen, Rasmussen, & Trap-Jensen, 1973)

and the same mode of training (Gergley, McArdle, DeJesus, Toner, Jacobowitz, and Spina, 1984) as subsequent testing.

Past research has shown that both circadian rhythms and training specificity affect exercise performance. Research suggests that responses to exercise may be specific to the time of day, and it has been shown that responses of training may be specific to the time of day (Torii et al., 1992). While there is a strong rationale for a time of day effect on responses to training, researchers have investigated this possibility only with respect to aerobic training (Torii et al, 1992; Hill, Cureton, and Collins, 1989). This present study examined circadian specificity but focused on high-intensity anaerobic exercise training.

Purpose

The purpose of this study was to test the hypothesis that training at a particular time of day will result in greater levels of related performance variables, when testing is at the same time of day as the training.

Delimitations

1. Subjects were 12 females, aged 19-23 years.
2. The training and testing mode was the cycle ergometer.
3. Subjects were tested at two different times: one test in the morning and once in the afternoon.

Limitations

1. Subjects were not randomly selected or assigned to experimental groups.
2. Subjects were tested at only two particular times during the day: once in the morning and once in the afternoon.

CHAPTER II

LITERATURE REVIEW

The primary purpose of this study was to determine whether high-intensity training at a particular time of day results in greater cardiovascular, metabolic levels, or performance levels, when testing is at the same time of day as the training. This chapter will review research supporting the following topics: circadian rhythms, oxygen deficit, specificity of training, and circadian specificity. The chapter consists of four sections, with each section containing an overview and a detailed review of several individual studies.

Circadian Rhythms

Overview

Circadian (24h) rhythms are cyclical fluctuations that occur over the course of about a day. Characteristic circadian rhythms occur in almost all physiological responses. Many physiological responses to exercise are a function of the time of day (Reilly & Brooks, 1982; Reilly, Robinson, & Minors, 1984).

Classic examples of these rhythms are demonstrated in body temperature and resting heart rate (Faria & Drummond, 1982; Reilly & Brooks, 1982; Reilly et al., 1984;

slowly increase throughout the day with a trough between 0200h and 0600h, a sharp increase toward 1200h, and a peak between 1500h and 2100h.

The existence of circadian rhythmicity in responses to maximal exercise is equivocal. For example, Reilly and Brooks (1990) found no evidence of a circadian rhythm in physiological responses to maximal exercise, whereas Hill, Cureton, Collins, and Grisham (1989) did show evidence of circadian rhythmicity in various physiological responses during maximal exercise. Also, studies are equivocal concerning whether rhythms exist in anaerobic power and capacity. Some studies show no evidence of a circadian rhythm in anaerobic capacity and power (Reilly & Down, 1992) whereas several studies show evidence of a rhythm in anaerobic power and capacity (Hill & Smith, 1991; Hill et al., 1992; Melhim, 1993). Finally, studies show a circadian rhythm in performance time during high-intensity constant power exercise (Hill et al., 1992).

Individual Studies

Resting Measures. Faria and Drummond (1982) studied 31 subjects who performed 24 separate treadmill tests, 48 hours apart. Resting heart rate and body temperature were lower in the morning than in the afternoon or evening. The lowest values occurred in the morning at 0600h and they peaked at 1800h.

Reilly and Brooks (1982) studied six male subjects over 16 weeks. At rest, a significant time of day effect was apparent in resting heart rate and body temperature with a trough at 0200h and a peak at 1400h. Specifically, body temperature rose from 36.7°C at 0600h to 37.3°C at 1800h.

Reilly and Brooks (1984) examined 10 male athletes, aged 19-22 yr. The subjects were observed at four different times: 0300h, 0900h, 1500h, and 2100h. A significant circadian rhythm was found in resting heart rate, showing a peak at 1500h.

Reilly and Brooks (1990) studied 15 male subjects, aged 22-28 yr. The subjects' heart rate at rest peaked at 1400h. Rectal temperature also demonstrated a circadian rhythm, with a fluctuation of 0.44°C about the mean of 37°C showing a peak in the afternoon compared to the morning.

Hickey, Costill, Vukovich, Kryzanski, and Widrick (1993) investigated responses in eight trained men at rest, during static exercise, and during dynamic exercise at 0600-0800h and at 1600-1800h. Blood pressure was recorded at rest and during one and two minutes of exercise. Systolic arterial pressure was significantly higher in the morning than in the afternoon at rest. There was no significant temporal pattern in diastolic or mean arterial pressure.

McMurray, Hill, and Field (1990) studied fourteen men during exercise at 75% of their maximal capacity at four distinct times throughout a day: 0600h, 1200h, 1800h, and

2400h. The study found circadian rhythmicity in resting measurements of heart rate and core temperature, with lowest values occurring at 0600h and highest values occurring at 1800h. However, the study found no significant differences in resting systolic or diastolic pressure at various times throughout the day.

Responses to Maximal Exercise.

Reilly and Brooks (1990) studied 15 male subjects, aged 22-38 yr, during six maximal cycle ergometer tests. The tests were scheduled at regular intervals throughout the day and took place on six separate days. The subjects performed 5-minute bouts at 82 and 147 watts followed by a gradual increase of work rate every two minutes until exhaustion. The study found no significant circadian rhythms in maximal oxygen uptake. Specifically, oxygen consumption during maximal exercise was $3.04 \pm 0.43 \text{ l}\cdot\text{min}^{-1}$ at 0600h and $3.95 \pm 0.44 \text{ l}\cdot\text{min}^{-1}$ at 1800h.

Hill et al. (1992) studied 14 college students during four all-out cycle ergometer tests. Subjects were randomly tested, once in the morning (0730-0900h) and once in the afternoon (0400-0530h). The work rate was constant, $5.0 \text{ W}\cdot\text{kg}^{-1}$ (six women) and $6.0 \text{ W}\cdot\text{kg}^{-1}$ (eight men), throughout the exercise test. The subjects showed a 14.3% greater aerobic contribution in the afternoon test compared to the morning test.

Hill (unpublished data) studied 20 college students during three all-out cycle ergometer tests. The latter two tests were randomly assigned one in the morning and one in the afternoon. The results showed a time of day effect on maximal oxygen uptake. Maximal oxygen uptake was 7% higher in the afternoon ($3.40 \pm 0.96 \text{ l} \cdot \text{min}^{-1}$) than in the morning ($3.19 \pm 0.81 \text{ l} \cdot \text{min}^{-1}$). These findings suggest a circadian rhythm in maximal oxygen uptake.

Hill, Cureton, Collins, and Grisham (1988) studied twenty-seven subjects during incremental cycle ergometer test during the morning and the afternoon. Evidence of a circadian rhythm was found in body temperature with a trough in the morning $35.7 \pm .1^\circ\text{C}$ and a peak in the afternoon at $36.0 \pm .1^\circ\text{C}$. Also, a circadian rhythm seemed apparent in maximal oxygen uptake with maximal oxygen uptake being lower in the morning and higher in the afternoon. This was especially evident when the work rate was above the ventilatory threshold, specifically, during 120-160 watts. This evidence supports the existence of a circadian rhythm in maximal oxygen uptake.

Anaerobic Power and Capacity

Reilly and Marshall (1991) found circadian rhythms in mean and peak power output of fourteen swimmers. Seven male and seven female swimmers were tested at six equidistant times throughout a day using a swim bench. At 1800h mean and peak power were 11% and 14% above their mean values.

The peak in anaerobic power and capacity coincided with the peak in temperature and heart rate.

Hill and Smith (1991) found similar results by studying six college men. The subjects performed four separate modified Wingate anaerobic tests at 0300h, 0900h, 1500h, and 2100h. The test order was randomly assigned. Peak power, highest power output throughout a 5-s period, had a 8% higher mean at 2100h compared to 0300h. Also, anaerobic capacity showed a similar pattern across the day with values at 1500h and 2100h being 5% higher than at 0300h and 0900h. These findings suggest a circadian rhythm may be present in anaerobic power and capacity.

Reilly and Down (1992) studied 12 male subjects, aged 18-22 years, on three different performance measures: the stair run test, the broad jump test, and the Wingate anaerobic test. Data were obtained on two separate occasions at each of the following times: 0200h, 0600h, 1000h, 1400h, 1800h, and 2100h. Data supported evidence of a circadian rhythm in body temperature with a peak at 1800h and a significant difference from the trough at 0600h of 0.76°C ($p < 0.001$). The data showed a circadian rhythm similar to this in the stair run, with the amplitude of the rhythm $0.41 \text{ W} \cdot \text{kg}^{-1}$ and its peak at 1800h. The evidence for a rhythm in the broad jump was similar being in phase with the rhythm showed in body temperature. However, no significant rhythm was apparent concerning performance in

peak or mean power on the Wingate anaerobic test.

Hill, Borden, Darnaby, Hendricks, and Hill (1992) studied 14 college students, six women and eight men, during four separate cycle ergometer tests performed until exhaustion. The third and fourth tests were randomly administered one in the morning (0700-0900h) and one in the afternoon (1600-1800h). The study found a 9.6% greater performance in total work in the afternoon tests compared to the morning tests. Hill et al. (1992) attributed this increase in total work to a 5.1% higher aerobic power and a 5.6% larger anaerobic contribution, thus, showing evidence of a circadian rhythm in anaerobic capacity.

Melhim (1993) found similar evidence supporting circadian rhythms in mean and peak power in women. Thirteen women, aged from 18-21 years, were tested for peak and mean power at four times of day: 0300h, 0900h, 1500h, and 2100h. Peak power was 7% higher at 1500h compared to 0300h. The mean power was 15% to 16% higher at 1500h and 2100h than at 0300h.

Performance Time.

Hill (unpublished data) studied 20 college students, 10 women and 10 men, during three all-out cycle ergometer tests. The latter two tests were randomly assigned, one in the morning (approximately 0800h) and one in the afternoon (approximately 1600h). The results showed

that the time to exhaustion in the afternoon was 9% greater ($p < 0.01$) in the afternoon than during the morning tests.

Hill et al. (1992) studied fourteen college students during four all-out cycle ergometer constant power tests ($5.0 \text{ W} \cdot \text{kg}^{-1}$ for six women; $6.0 \text{ W} \cdot \text{kg}^{-1}$ for eight men). The subjects were tested in random order once in the morning (0730h - 0900h) and once in the afternoon (0400h - 0530h). The subjects' performance time during the afternoon exercise test was 9.1% longer in duration compared to the morning test.

Oxygen Deficit

Overview

Because of the high intensity of exercise used in the training and testing in this study, it was assumed that performance would reflect anaerobic capacity, and that training would improve anaerobic capacity. Anaerobic capacity can be defined as the maximal amount of ATP supplied by the anaerobic processes of phosphocreatine and glycogen breakdown (Medbø & Tabata, 1989). High intensity exercise, in which the ATP generation rate exceeds the rate of the oxygen transporting system depends strongly on the anaerobic ATP-forming processes. Oxygen deficit has been calculated and utilized in studies to determine the magnitude of a subject's anaerobic capacity. Presently, many researchers believe oxygen deficit is one of the only

measurements capable of quantifying anaerobic capacity (Medbø, Mohn, Tabata, Bahr, Vaage, Sejersted, 1988; Scott, Roby, Lohman, Bunt, 1990).

Individual Studies

Medbø et al. (1988) determined oxygen deficits for 11 male volunteers during five separate treadmill tests. The study method to determine maximally accumulated oxygen deficit requires extrapolation from the submaximal steady state $\dot{V}O_2$ work rate relationship to estimate the O_2 demand of supramaximal exercise. The accumulated oxygen deficit was calculated as the difference between the extrapolated demand of oxygen and the amount of oxygen accumulated during each of the five supramaximal tests. The treadmill speed varied during the five tests to elicit exhaustion within 15 s, 30 s, 1 min, 2 min, and 4 min. Oxygen deficit was three times greater after the 2-min test compared to after the 15 sec test ($p < 0.001$). There was no significant difference in oxygen deficit between 2 and 5 minutes. Thus, the study suggests oxygen deficit can be a direct quantitative expression of anaerobic capacity if test duration is two to five minutes.

Medbø and Tabata (1989) studied 17 men, aged 19-35 yr, who were tested on the cycle ergometer until exhaustion. The work rate was kept constant and was selected to elicit exhaustion within 30 sec to 3 min. The subject's oxygen uptake was measured throughout exercise and their oxygen

deficit was calculated by using the method described in their previous paper (Medbø et al., 1988). The authors found that the oxygen deficit was higher during exercise with a duration greater than 2 min ($2.42 \pm 0.08 \text{ mmol} \cdot \text{kg}^{-1}$) compared to exercise lasting 1 min ($2.25 \pm 0.06 \text{ mmol} \cdot \text{kg}^{-1}$) or 30 sec ($1.86 \pm 0.07 \text{ mmol} \cdot \text{kg}^{-1}$) at thirty seconds of exercise to for one minute duration to during exercise lasting longer than two minutes. The accumulated oxygen uptake increased linearly as a function of the duration of exercise. Specifically, the study found that 60% of the total work was performed anaerobically at 30 s, 50% during 1 min, and 35% during exercise over 2 min.

Scott et al. (1991) studied 16 subjects, four distance trained runners, five middle-distance trained runners, three trained sprinters, and four controls (no active participation in track and field). The subjects' O_2 deficits were calculated by the maximally accumulated oxygen deficit method used by Medbø et al. (1988). Each subject participated in at least five supramaximal treadmill runs in which accumulated oxygen uptake and post exercise blood lactate were determined. In addition, each subject performed two Wingate tests, with total work computed for each 5-s interval of the 30s test. Finally, all subjects (excluding controls) participated in field tests of running 300m, 400m and 600m. The study found that the maximally accumulated oxygen deficit was larger for sprinters and

middle-distance runners than for long distance trained runners and the controls. Scott et al. (1988) found that during the supramaximal oxygen deficit tests the sprinters' anaerobic contribution was 39%, the middle distance runners to be 37% and the long distance runners was 30% ($p < 0.05$). Finally, the study's findings suggest a high correlation between results obtained using the maximally accumulated oxygen deficit method described by Medbø et al (1988) with other anaerobic test measures such as work performance in the Wingate test.

Graham and McLellan (1989) studied four male trained cyclists on the cycle ergometer. Subjects performed submaximal exercise at various work rates, and the VO_2 data were extrapolated. A regression line was then used to predict the oxygen demand. The cyclists then performed all-out tests until exhaustion to determine their maximal oxygen uptake. Oxygen deficit was determined afterward by the difference between the predicted maximal oxygen uptake and the accumulated oxygen measured during exercise. The authors found no significant difference between time to exhaustion and oxygen deficit during the four supramaximal tests. Therefore, the authors concluded that oxygen deficit is a reliable measure of anaerobic capacity.

Training Specificity

Overview

The effect of training specificity has been well demonstrated (Pierce, Weltman, Seip, Snead, 1990; Withers, Sherman, Miller, Costill, 1981). Performance tends to be enhanced when the same mode used during training is also used during testing. Training adaptations tend to highly coincide with the specific musculature involved during exercise. Training specificity has a beneficial effect on the efficiency of specific muscle fiber recruitment. The following studies propose that training specificity affects the subjects maximal oxygen uptake during specific endurance performance tests.

Individual studies

Pierce et al. (1990) studied sixteen subjects and found a significant finding between the percent increase in maximal oxygen uptake and different testing protocols. The 10-wk study consisted of three groups: a control group, a cycling group, and a running group. The study found that subjects had a higher percent increase in their maximal oxygen uptake at lactate threshold (VO_{2LT}) when tested using the testing mode that they had used during training. Specifically, the cycling training group showed a 38.7% increase in their VO_{2LT} when tested on the cycle ergometer, whereas they showed no significant increase when tested on

the treadmill. The running group's results amplify these findings illustrated by a 58.5% increase in their VO_2LT during the treadmill tests compared to a 20.3% increase during the cycling test. These results suggest that the percent increase of VO_2LT increase may be specific to the mode of exercise and the specific testing protocol.

Withers et al. (1981) showed a similar finding using maximal oxygen uptake ($\dot{\text{V}}\text{O}_{2\text{max}}$) as an indicator by designing a study consisting of 20 subjects: 10 endurance trained runners and 10 endurance trained cyclists. The study found cyclists performed better on the cycling ergometer test compared to the treadmill test ($4.5 \text{ l}\cdot\text{min}^{-1}$ compared to $4.3 \text{ l}\cdot\text{min}^{-1}$, respectively). The running group had a significant higher $\dot{\text{V}}\text{O}_{2\text{max}}$ during the treadmill test compared to the cycling test ($68.1 \text{ ml}\cdot\text{kg}\cdot\text{min}^{-1}$ compared to $61.7 \text{ ml}\cdot\text{kg}\cdot\text{min}^{-1}$, respectively). Thus, the group of runners showed a 10.4% higher $\dot{\text{V}}\text{O}_{2\text{max}}$ during the treadmill test compared to the cycling test and the group of cyclists showed a 4.5% higher $\dot{\text{V}}\text{O}_{2\text{max}}$ during the cycling test compared to the treadmill test. This study suggests that specificity of training does have an impact on performance measured using certain testing protocols.

McArdle, Magel, Delio, Toner, and Chase (1978) studied 19 college-aged male swimmers. Eleven subjects were assigned to a 10-wk run training program and the remaining eight subjects served as controls. Following the training

period, subjects were tested during treadmill running and tethered swimming, with testing order being randomly assigned. The study showed a training adaptation in $\dot{V}O_{2\max}$. Specifically, a significant increase of $252 \text{ ml}\cdot\text{min}^{-1}$ was found in treadmill $\dot{V}O_{2\max}$ following training. A smaller but statistically significant improvement of $87 \text{ ml}\cdot\text{min}^{-1}$ was found in $\dot{V}O_{2\max}$ during the swimming tests following training. The control group showed no significant change in $\dot{V}O_{2\max}$ measurement during the running test and swimming test. This study illustrates the effect of aerobic training in producing specific improvement in $\dot{V}O_{2\max}$ which is accentuated when testing involves similar musculature used during training.

Gergley et al. (1984) studied 25 college-aged male swimmers. The subjects were divided into three groups: a control group, a 10-wk swim training group, and a group training on a standard bench pulley. The control group and the standard bench training group did not swim during the 10-wk training period. Following the 10-wk period, subjects were tested on the swim bench ergometer, on the treadmill, and using tethered swimming. A significant training effect was evident in the swim training and standard bench training groups for body weight and lean body weight. This training effect was not evident in the control group. Also, an improvement in maximal aerobic power was shown. Specifically, there was a $0.53 \text{ l}\cdot\text{min}^{-1}$ (18%) increase in

tethered swimming for the swim training group and a $0.38 \text{ l} \cdot \text{min}^{-1}$ (21%) increase in the standard bench ergometry for the standard bench training group. This study further supports the specificity of training and aerobic testing due to adaptation of specific musculature used in a specific exercise protocol.

Circadian Specificity

Overview

Research suggests that responses to exercise may be specific to the time of day (Hill et al., 1992; Melhim, 1993). Also, training adaptations tend to highly correlate with specific musculature producing a beneficial effect on the efficiency of specific muscle fiber recruitment (Pierce et al., 1990; Gregory et al., 1984). Thus, it has been speculated that the responses to training may also be specific to the time of day (Hill et al., 1989; Torii et al., 1992).

Individual studies

Hill et al. (1989) examined the possibility of circadian specificity in training in responses to incremental exercise. Twenty-seven subjects were randomly assigned to either the morning training group, the afternoon training group or a control group (no training). Before and after six weeks of cycle ergometer training, subjects performed cycle ergometer tests in the morning and in the

afternoon. Testing order was randomly assigned. The study found typical benefits of training, such as a decline in submaximal ventilation and heart rate, and a 7.7% increase in maximal oxygen uptake and a 9.1% increase in performance time. These findings illustrate the benefits of training. Although subjects had higher post-training ventilatory threshold during the testing time at which they had previously trained, there was no evidence of circadian specificity in any other variables.

Torii et al. (1991) found aerobic training to be most effective in the afternoon. The testing protocol consisted of 20 sessions, each 30 minutes in duration at 60% $\dot{V}O_{2max}$. Subjects who trained on the cycle ergometer during the afternoon showed a greater increase in their estimated $\dot{V}O_{2max}$ than the subjects who trained in the evening or in the morning. Specifically, the afternoon group showed an increase of 12% compared to an 8.2% increase in the evening group and a 0.5% increase in the morning group.

There is a strong rationale for a time of day effect in responses to training. However, only Hill et al. (1989) and Torii et al. (1992) have investigated the possibility of circadian specificity and only with regard to aerobic training.

Summary

Circadian rhythms in various physiological responses to maximal exercise have been shown (Reilly & Brooks, 1990;

Hill & Smith, 1991). Past studies have found that training specificity affects maximal oxygen uptake during specific endurance performance tests (Pierce et al., 1990; Withers et al., 1981). Also, studies have shown evidence of circadian specificity, that is, that responses to training may be a function to the time of day of training and testing (Torii et al., 1991; Hill et al., 1989). Past studies investigating circadian specificity involved aerobic exercise training and testing. Therefore, this study was designed to investigate the possibility of circadian specificity in responses to high-intensity exercise training. The primary variables investigated were anaerobic capacity (oxygen deficit), and performance (time to exhaustion). Secondary variables were maximal aerobic power ($\dot{V}O_{2\max}$) and other cardiorespiratory and metabolic variables measured at rest and during exercise.

CHAPTER III

RESEARCH METHODS

The primary purpose of this study was to determine whether training at a particular time of day results in greater cardiovascular or metabolic responses when testing is at the same time as the training. This chapter contains the methods used during collection and analysis of the data. The chapter consists of six sections: research design, overview of data collection, subjects, training program, data collection, and statistical analysis of data.

Research Design

The study used a non-randomized posttest only time-series design. The study involved two experimental groups. One experimental group performed cycle ergometer training in the morning, and the other experimental group performed cycle ergometer training in the afternoon. After a 5-wk period of training, all subjects were tested in the morning and in the afternoon. Post training morning and afternoon means of the two groups were compared to determine a time of day effect after training at a particular time of day.

Data Collection Overview

All of the subjects provided written informed consent recognizing the guidelines and procedures established by the

Institutional Review Board of the University. Upon first visiting the lab, all subjects completed an informed consent and medical history form. As part of the screening process, resting heart rate and blood pressure were measured.

Then, subjects trained regularly, either in the morning or in the afternoon, for five weeks. All training and testing involved high-intensity cycle ergometer exercise. After training, each subject underwent testing once in the morning (0700h-0900h), and once in the afternoon (1300h-1500h). All data were collected in a climate controlled laboratory with a temperature of approximately 20°C. Testing performance was recorded using three variables: time to exhaustion (measured to the nearest second), maximal oxygen uptake (measured in $\text{ml}\cdot\text{kg}\cdot\text{min}^{-1}$), and oxygen deficit (measured in $\text{ml}\cdot\text{kg}^{-1}$). All data were collected during the two long semesters in 1994.

Subjects

Twelve college students volunteered to participate in this study. The subjects were women of mean (SD $\pm$) age 20 $\pm$ 1 yr, height 168 $\pm$ 9 cm, and weight 68.5 $\pm$ 16 kg. All of the women were actively involved in recreational activities, but none of the activities consisted of systematic training. All of the subjects provided voluntary written informed consent.

Training Protocol

All twelve subjects used a Ergoline electronically braked cycle ergometer during training. The cycle ergometer provided power output independent of the subject's pedal cadence. Six subjects were assigned to the morning training group in which training took place between 0700-0900h. The remaining six subjects were assigned to the afternoon training group in which training took place between 1500h-1700h. The training consisted of 20 sessions, four days a week for five weeks. All sessions were individualized based on the subject's body weight and were intermittent in nature. Sessions consisted of: Mondays, 4 by 2 min at $2.5 \text{ W} \cdot \text{kg}^{-1}$ with 4 min recoveries; Tuesdays and Thursdays, 8 by 1 min at $3.0 \text{ W} \cdot \text{kg}^{-1}$ with 2 min recoveries; and Wednesdays, 3 by 3 min at $2.2 \text{ W} \cdot \text{kg}^{-1}$ with 2 min recoveries. Missed sessions were made up on Fridays or after the 5-wk period, as the schedule permitted.

Data Collection

After five weeks of training on the cycle ergometer, all subjects performed three all-out tests using the same cycle ergometer used during training. The first test served as a learning trial to familiarize the subject with the testing procedures and to ensure no learning effect occurred. Since learning between first and second trial may bias the results, it was performed in place of the last training session. The remaining two tests were performed

one in the morning and one in the afternoon. The tests were counterbalanced by randomly assigning subjects from the training groups to different testing orders. During each all-out test expired gases were analyzed on a breath-by-breath and 15-s interval basis using a MedGraphics CPX metabolic cart (St. Paul, MN). The cart was calibrated in accordance to the manufacturer's instructions prior to each test.

Prior to each test, resting heart rate, blood pressure, and temperature were measured. Oral temperature was measured by using a YSI tele-thermometer (Yellow Springs, Ohio) with an attached probe. Heart rate was measured by palpation at the wrist until two successive 15-s counts were identical. During each test subjects warmed-up for 5 min at 50 W to elicit a heart rate of approximately 120-140 beats per minute. After a 5 min rest, subjects accelerated to 80 rpm. Then the calculated work rate of $2.6 \text{ W} \cdot \text{kg}^{-1}$ was administered, and the stop watch started. Subjects received verbal encouragement to continue as long as possible. The cycle ergometer provided power output independent of the pedal cadence. Subjects were instructed to watch the digital cadence readout and try to maintain the rpm level near 80 rpm. When pedal cadence dropped below 50 rpm the test was terminated. The three testing performance exercise responses of interest were: time to exhaustion (measured to

the nearest second), maximal oxygen uptake (measured in $\text{ml}\cdot\text{kg}\cdot\text{min}^{-1}$), and oxygen deficit (measured in $\text{ml}\cdot\text{kg}^{-1}$).

Statistical Analysis

A two factor ANOVA with repeated measures over the time of day of testing and with subjects nested in time of day of training was utilized. The primary effect of interest was the interaction between time of day of testing and time of day of training. If a significant interaction was found, post hoc t-tests were employed to separately compare morning versus afternoon results in the subjects who trained in the morning and in the subjects who trained in the afternoon. The significance level used was 0.05.

CHAPTER IV

RESULTS AND DISCUSSION

The primary purpose of this study was to determine whether the training at a particular time of day results in greater cardiovascular or metabolic measures when testing is performed at the same time of days the training. The first section of this chapter will present the results of the study. The second section of this chapter will entail a discussion of the results.

Results

Rest Measures.

Data collected at rest are summarized in Table 1. Values were means ($\pm$ SD) for the two groups of subjects, those who trained in the morning (AM) and those who trained in the afternoon (PM). All subjects were tested both in the morning and in the afternoon. Both resting heart rate and resting oral temperature were higher in the afternoon than in the morning. There was no morning - afternoon difference in resting systolic or diastolic blood pressure ($F_{1,10} = 0.68$, $p = 0.43$; $F_{1,10} = 3.16$, $p = 0.11$, respectively). However, there was a significant interaction effect on resting systolic and diastolic blood pressure ($F_{1,10} = 7.54$, $p = 0.02$; $F_{1,10} = 5.31$, $p = 0.04$). Mean values for the two

groups are presented in table 1. The results of the post hoc tests revealed that for the subjects who trained in the morning, systolic blood pressure and diastolic blood pressure tended to be lower in the morning than in the afternoon, $t_s = 1.2$, $p = 0.13$; $t_s = 0.73$, $p = 0.25$, respectively); for the subjects who trained in the afternoon, systolic and diastolic blood pressure tended to be higher in the morning ($t_s = -1.97$, $p = 0.52$, $t_s = -3.87$, $p = 0.03$, respectively).

Table 1

Resting Values.

Group	Time of day of the exercise test	
Trained in AM (n=6)	AM	PM
Heart rate (beats·min ⁻¹)	75±8	79±8
Systolic (mmHg)	109±10	114±11
Diastolic (mmHg)	65±13	68±6
Temperature (°C)	35.6±0.4	35.7±0.6
Trained in PM (n=6)		
Heart rate (beats/min)	75±8	78±9
Systolic (mmHg)	119±12	110±10
Diastolic (mmHg)	74±0	62±3
Temperature (°C)	35.4±0.4	36.2±0.6

Maximal Exercise Measures

Data collected during maximal exercise are summarized in Table 2. Values are means ($\pm$ SD) for the two groups of subjects, those who trained in the morning (AM) and those who trained in the afternoon (PM). All subjects were tested both in the morning and in the afternoon. There was a significant morning - afternoon difference in $\dot{V}O_{2\max}$, ($F_{1,10} = 11.49$, $p = 0.0069$), $\dot{V}CO_{2\max}$, ($F_{1,10} = 4.43$, $p = 0.062$), and $\dot{V}_E\max$, ($F_{1,10} = 5.33$, $p = 0.044$). However, there was no significant group by time of day interaction, ($F_{1,10} = 0.15$, $p < .71$, $F_{1,10} = 0.14$, $p = 0.72$, and $F_{1,10} = 0.16$, $p = 0.70$, respectively).

Table 2

Maximal Exercise Responses

Group	Time of day of the exercise test	
Trained in AM (n=6)	AM	PM
$\dot{V}O_{2\max}$ (ml $\cdot$ kg $^{-1}$)	2425 $\pm$ 421	2559 $\pm$ 408
$\dot{V}CO_{2\max}$ (ml $\cdot$ min $^{-1}$)	3128 $\pm$ 780	3269 $\pm$ 654
$\dot{V}_E\max$ (l $\cdot$ min $^{-1}$)	110 $\pm$ 33	115 $\pm$ 30
Trained in PM (n=6)		
$\dot{V}O_{2\max}$ (ml $\cdot$ kg $^{-1}$)	2250 $\pm$ 408	2357 $\pm$ 388
$\dot{V}CO_{2\max}$ (ml $\cdot$ min $^{-1}$)	2820 $\pm$ 313	3022 $\pm$ 553
$\dot{V}_E\max$ (l $\cdot$ min $^{-1}$)	98 $\pm$ 16	106 $\pm$ 18

Anaerobic Capacity

Data collected concerning anaerobic capacity (oxygen deficit) are summarized in Table 3. Values were means ($\pm$ SD) for the two groups of subjects, those who trained in the morning (AM) and those who trained in the afternoon (PM). All subjects were tested both in the morning and in the afternoon. Results of ANOVA (time of day of training X time of day of testing) revealed a significant interaction on anaerobic capacity (oxygen deficit), ($F_{1,10} = 7.95$, $p = 0.02$). Post hoc analysis revealed that, in the six subjects who had trained in the morning, oxygen deficit tended to be higher in the morning than in the afternoon ($t_s = -1.45$, $p = 0.11$); in the subjects who trained in the afternoon, oxygen deficit was higher in the afternoon, ($t_s = 3.01$, $p = 0.02$).

Table 3

Anaerobic Capacity

Group	Time of day of the exercise test	
	AM	PM
Trained in AM (n=6)		
O ₂ deficit (ml·kg ⁻¹)	64±24	50±11
Trained in PM (n=6)		
O ₂ deficit (ml·kg ⁻¹)	50±23	68±25

Performance Time

Data collected regarding performance time are summarized in Table 4. Values were means ($\pm$ SD) for the two groups of subjects, those who trained in the morning (AM) and those who trained in the afternoon (PM). All subjects were tested both in the morning and in the afternoon. Results of ANOVA (time of day of training X time of day of testing) revealed a significant interaction effect on time to exhaustion, $F_{1,10} = 8.24$, $p < 0.02$. Post hoc analysis revealed that, in six subjects who had trained in the morning, oxygen deficit tended to be higher in the morning than in the afternoon, $t_5 = -1.73$, $p = 0.07$; in the subjects who trained in the afternoon, oxygen deficit tended to be higher in the afternoon, $t_5 = 2.54$, $p = 0.03$.

Table 4

Performance Time

Group	Time of day of the exercise test	
	AM	PM
Trained in AM		
Time (s)	398 $\pm$ 258	351 $\pm$ 216
Trained in PM		
Time (s)	373 $\pm$ 222	422 $\pm$ 252

Discussion

The primary purpose of this study was to determine whether training at a particular time of day has an effect on levels of performance related variables, when testing is at the same time of day as the training. The major finding in this study was the significant interaction between the time of day of training and the time of day of testing on anaerobic capacity and performance time. The significant interaction effects, along with the results of the following analysis, suggested that the time of day of training influences the effect of time of day of testing on the magnitude of these variables. That is, the results supported the working hypothesis, that performance would be greater at the time of day of training, and gives strong evidence of circadian specificity in high intensity exercise training. A discussion of the influences (or lack of influence) of the time of day of training on all variables examined in this study follows.

Resting measures.

Circadian variations have been illustrated in various resting measurements. Classic examples of these rhythms have been demonstrated in body temperature and resting heart rate (Faria & Drummond, 1982; Reilly & Brooks, 1982; Reilly et al., 1984; Sollberger, 1965). This study found evidence of a circadian rhythm, in the 12 subjects considered together, in resting heart rate and temperature, with

highest values occurring in the afternoon. Consistent with the results of McMurray et al. (1990), no circadian rhythm was found in blood pressure. However, there was a group by time of day of testing interaction effect, and results of the follow-up tests revealed that the subjects in the morning group did exhibit a circadian rhythm in resting systolic and diastolic blood pressure with values in the morning lower at the time of training. Blood pressure tended to be lower in the afternoon in the subjects who trained in the afternoon. Blood pressure might be expected to be lower in the morning (Hickey et al. 1993), since temperature and heart rate are lower then. Thus, subjects in the morning group may simply be demonstrating an expected circadian rhythm. However, since values tended to be lower in the afternoon in the subjects who trained in the afternoon, the time of day of training seems to be implicated as a factor in the observed results. Since resting blood pressure is lower after training (although it is usually lower only if initially elevated), the findings may reflect circadian specificity in physiological responses to training. Alternatively, higher blood pressure at the time of day at which subjects were not accustomed to coming to the exercise physiology laboratory may simply reflect the stressful nature of being tested under unaccustomed conditions. Two facts argue for this latter hypothesis, rather than for their being circadian specificity in the

blood pressure response to training. First, resting heart rate did not show the same pattern as blood pressure. Secondly, the high-intensity training would not be expected to elicit a training response in resting blood pressure, especially in young normotensives.

Maximal exercise measurements.

The results of this study revealed no significant time of day of testing by time of day of training interaction effect on maximal exercise responses. However, there was evidence of a circadian rhythm in $\dot{V}O_{2\max}$, $\dot{V}_{E\max}$ and $\dot{V}CO_{2\max}$, with all variables being higher in the afternoon than in the morning. These findings are similar to those of Hill et al. (1989) who reported no interaction effect on $\dot{V}O_{2\max}$ and $\dot{V}CO_{2\max}$. However, Hill et al. (1989) did find a time of day difference in $\dot{V}_{E\max}$ of two groups, with each group recording highest values during the testing time coinciding with the training time.

The present study found evidence of a circadian rhythm (independent of the time of day of training) in $\dot{V}O_{2\max}$, $\dot{V}_{E\max}$, and $\dot{V}CO_{2\max}$, that was, the subjects' cardiovascular and respiratory responses were higher in the afternoon than in the morning, regardless of the time of day training took place. It is likely that these rhythms were present before training (such rhythms have been shown by Hill et al. (1989) and Hill, unpublished observation) and that they persisted

through training program. The very high intensity training employed in this study, which limited the duration of the single longest exercise training bout to 3 min, would not be expected to affect $\dot{V}O_{2\max}$. With no training effect on $\dot{V}O_{2\max}$, one would not expect any time of day of training effect.

Anaerobic capacity measures.

Hill and Smith (1991) found anaerobic capacity to be 5% greater during the afternoon than during the morning when comparing time of day effects in a Wingate anaerobic test. Results of the present study did not show a significant finding of a time of day effect (PM>AM) for the 12 subjects considered together. Rather, anaerobic capacity was greatest at the time of day training occurred. One possible mechanism to support this finding is that the training at a particular time of day resulted in greater adaptations at that time of day. It is also possible that training at a particular time of day influenced the phase of circadian response to exercise, amplifying a Zeitgeber effect of the circadian response to exercise. It is more likely that there was a specific adaptation in anaerobic capacity (and perhaps also a psychological component) rather than an inversion or 12-h phase advance of the circadian rhythms. This conclusion is based on the fact that other markers of circadian rhythmicity, such as temperature and heart rate,

as well as other exercise responses, such as $\dot{V}O_{2\max}$, did not demonstrate the same post-training temporal pattern as oxygen deficit and performance time.

Performance time.

Regardless of the mechanism, the significant interaction between time of day of testing and the time of day of training shows circadian specificity. Performance time was greatest when testing took place at the same time of day as the training.

The finding of circadian specificity supports Torii et al. (1991) findings illustrating the existence of diurnal variation in the training effect. Torii et al. (1991) reported that subjects performed better during submaximal exercise when testing was performed at the same time of day training took place. However, in that study, there were morning, afternoon, and evening training groups, but all testing occurred in the afternoon. The afternoon training group had the greatest increase in $\dot{V}O_{2\max}$ and performance time compared to the morning and evening training groups.

Summary

Although circadian specificity was not apparent in maximal exercise response measures, there was evidence of a diurnal variation coinciding with the resting circadian rhythm found in resting heart rate and temperature in $\dot{V}O_{2\max}$, $\dot{V}CO_{2\max}$, and $\dot{V}_{\max}$ through a 5-wk period of

training, regardless of whether training is during the morning or afternoon. However, my results do suggest that the time of day of training and testing can affect certain performance measures, with greatest values for anaerobic capacity and performance time being higher when testing occurred at the time of training. Therefore, these results suggest that testing should occur at the same time of day as the training to receive optimal performance gains.

CHAPTER V

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

Summary

The primary purpose of this study was to determine whether training at a particular time of day had an effect in levels of performance variables, when testing is at the same time of day as the training. Results of the study revealed evidence of a circadian rhythm in several variables at rest and during maximal exercise. In addition, a significant interaction was found between the time of day of training and the time of day of testing on anaerobic capacity and performance time.

Conclusion

These findings support past research of evidence of a circadian rhythm in certain resting and maximal performance variables. In addition, circadian specificity was evident in anaerobic capacity, as reflected by oxygen deficit, and in time to exhaustion in a high-intensity "anaerobic" exercise test. Thus, it appears that training at a particular time of day resulted in greater adaptation at that time of day. These results suggest that training should be undertaken at the same time of day as subsequent exercise training to receive optimal performance gains.

Recommendations

Further research is needed to confirm circadian specificity. First, a larger sample size is recommended. Secondly, a more diverse sample is recommended with various ages and men being included. Third, training should incorporate an aerobic stressor in addition to an anaerobic component, and, testing should involve measurement of aerobic and anaerobic performance variables, in this way, it could be determined if circadian specificity is limited to factors related to anaerobic, but not aerobic, energy production.

APPENDIX A

UNIVERSITY OF NORTH TEXAS**DEPARTMENT OF KINESIOLOGY****CONSENT TO ACT AS A HUMAN SUBJECT**

Subjects Name (print): _____ Date: _____

1. I hereby volunteer to participate as a subject in the study entitled "Temporal Specificity in Anaerobic Exercise Training". I understand that the purpose of this study is to learn if the time of day at which training is performed has an effect on an individual's response to the training. I understand that I will be tested in the Exercise Physiology Laboratory at the University of North Texas on 6 separate days and that each test requires an all-out effort. Then I will participate in 32 training sessions (4 per week, for 8 weeks). I will be retested on 4 separate days. I will be expected to follow guidelines about eating and drinking during the study. These guidelines required that I abstain from drinking alcoholic beverages for 12 hours prior to each test and that I restrict my caffeine intake for 4 hours prior to each test. It is recommended that I not eat 2 to 3 hours prior to any testing.

I hereby authorize David W. Hill and/or assistants as may be selected by him to perform on me the following procedures, on different days.

A: The baseline testing:

(a) to measure my height, weight, and skinfold thickness;

(b) to have me complete questionnaires to assess my personality type;

B: The pre- and post-training tests:

(c) to have me wear a noseclip and breathe through a mouthpiece and pedal on a cycle ergometer against a high resistance, and to have me continue to pedal until I cannot maintain the pedalling cadence or until I want to stop for whatever reason, in order to assess my anaerobic capacity. (A total of 10 times: 6 times before training and 4 times after training, with half of the tests scheduled in the morning and half in the late afternoon). I understand that these are all-out tests;

(d) to have me complete a POMS questionnaire to assess my mood;

C: The training:

(e) to have me attend 32 training sessions which will be scheduled in the exercise physiology lab at a particular time of day, and perform repeated high-intensity exercise bouts. I understand that this exercise will not be totally exhaustive like the all-out tests, but that I will work very hard and feel very tired.

2. The procedures outlined in paragraph 1 [(a) through (e) above] have been explained to me by David W. Hill.

3. I understand that the procedures described in paragraph 1 (above) involve the following risks and discomforts: temporary muscle pain and soreness is expected. There is a possibility of abnormal changes in my heart beat or blood pressure, or even of a heart attack during the tests. However, I understand that my EKG will be monitored during testing, and that I can terminate any test at any time at my discretion.

4. I have been advised that the following benefits will be derived from my participation in this study: aside from the educational benefit of learning about anaerobic testing or about my fitness level, there are no direct benefits to me.

5. I understand that David W. Hill and/or appropriate assistants as may be selected by him will answer any inquiries that I may have at any time concerning these procedures or investigations.

6. I understand that all data concerning myself will be kept confidential and available upon my written request. I further understand that in the event of publication, no association will be made between the reported data and myself.

7. I understand that there is no monetary compensation for my participation in this study.

8. I understand that in the event of physical injury directly resulting from participation, compensation cannot be provided. Medical treatment will be available at the University Health Center and the laboratory has an outside telephone line to the City of Denton emergency services.

9. I understand that I may terminate participation in this study at any time without prejudice to future care or any possible reimbursement of expenses, compensation, employment status, and that owing to the scientific nature of the study, the investigator may terminate the procedures and/or investigations at any time.

10. I understand that I may contact the chairperson of the Kinesiology Department's Committee on the Use of Human Subjects in Research, Dr. Allen Jackson (Physical Education Building, Room 210-R, 817-565-2651), on any matters concerning any participation in this study or if I feel that there is infringement on my rights.

Subjects Signature: _____

Witness: _____ Date: _____

APPENDIX B

INDIVIDUAL SUBJECT DATA

PM Training Group - Resting Values

Last name	Time of test	RHR	RSBP	RDBP	RTEMP
Blackburn	AM	71	98	60	35.8
Blackburn	PM	68	100	62	36.0
Brown	AM	78	118	64	*
Brown	PM	81	120	62	*
Hagedorn	AM	88	120	80	35.3
Hagedorn	PM	86	116	65	35.8
Trevino	AM	74	120	80	35.0
Trevino	PM	76	108	65	36.7
True	AM	78	135	78	35.1
True	PM	88	120	60	37.0
Watts	AM	64	122	80	36.0
Watts	PM	68	96	58	35.0

cont'd.

PM Training Group - Maximal Values

Lastname	Time of test	MaxWatts	MaxHR	MaxVO ₂	MaxVCO ₂
Blackburn	AM	170	*	1606	2438
Blackburn	PM	170	*	1736	2688
Brown	AM	240	*	2434	3107
Brown	PM	240	*	2786	3946
Hagedorn	AM	160	181	2420	3154
Hagedorn	PM	160	181	2622	3438
Trevino	AM	150	199	1956	2458
Trevino	PM	150	221	2062	2535
True	AM	155	196	2600	2960
True	PM	155	206	2502	2864
Watts	AM	160	196	2485	2808
Watts	PM	160	195	2434	2662

cont'd.

PM Training Group - Maximal Values

Last name	Time of test	MaxRER	MaxV _E	Time	O ₂ def
Blackburn	AM	1.5	79	201	4299
Blackburn	PM	1.5	88	294	6338
Brown	AM	1.3	91	243	6615
Brown	PM	1.4	112	269	7216
Hagedorn	AM	1.3	109	335	2134
Hagedron	PM	1.3	108	328	2469
Trevino	AM	1.3	83	234	2969
Trevino	PM	1.2	83	252	3326
True	AM	1.1	120	793	1273
True	PM	1.1	131	909	3846
Watts	AM	1.1	104	432	2929
Watts	PM	1.1	112	479	4308

cont'd.

AM Training Group

Last name	Time of test	RHR	RSBP	RDP	RTEMP
<hr/>					
Bufkin	AM	86	120	50	36.0
Bufkin	PM	82	118	65	35.5
Duncan	AM	64	110	80	36.0
Duncan	PM	82	128	74	36.0
Garner	AM	78	97	50	35.0
Garner	PM	70	97	58	34.5
Hansen	AM	68	108	76	35.5
Hansen	PM	68	119	69	35.8
Newberry	AM	76	122	72	35.8
Newberry	PM	86	119	75	36.0
Storz	AM	82	102	67	35.5
Storz	PM	88	103	69	36.2

cont'd.

AM Training Group - Maximal Values

Last name	Time of test	MaxWatts	MaxHR	MaxVO ₂	MaxVCO ₂
Bufkin	AM	175	193	2804	3586
Bufkin	PM	175	192	2938	3625
Duncan	AM	280	184	3030	4479
Duncan	PM	280	186	3121	4398
Garner	AM	120	212	1920	2325
Garner	PM	120	212	2116	2637
Hansen	AM	185	196	2424	2774
Hansen	PM	185	192	2624	3150
Newberry	AM	180	180	2133	2912
Newberry	PM	180	182	2196	3066
Storz	AM	155	187	2238	2691
Storz	PM	155	185	2360	2737

cont'd.

AM Training Group - Maximal Values

Last name	Time of test	MaxRER	MaxV _E	Time	O ₂ Def
Bufkin	AM	1.3	156	457	3088
Bufkin	PM	1.2	158	464	3476
Duncan	AM	1.5	143	201	8608
Duncan	PM	1.4	132	120	3955
Garner	AM	1.2	80	881	2532
Garner	PM	1.2	99	725	1886
Hansen	AM	1.1	87	363	7521
Hansen	PM	1.2	92	299	4666
Newberry	AM	1.4	110	183	3173
Newberry	PM	1.4	130	205	4117
Storz	AM	1.2	82	304	2853
Storz	PM	1.2	80	230	4200

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