1987

Effects of menstrual cycle phase on selected performance variables in athletes and nonathletes

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Recommended Citation

Clement, Lynn Marie, "Effects of menstrual cycle phase on selected performance variables in athletes and nonathletes" (1987). *Ithaca College Theses.* Paper 53.

EFFECTS OF MENSTRUAL CYCLE PHASE ON SELECTED PERFORMANCE VARIABLES IN ATHLETES AND NONATHLETES

by

Lynn Marie Clement

An Abstract
of a Thesis Submitted in Partial Fulfillment
of the Requirements for the Degree of
Master of Science in the School
of Health, Physical Education,
and Recreation at
Ithaca College

September, 1987

Thesis Advisors: Dr. D. Paul Thomas
Dr. Robert R. Jenkins

ABSTRACT

Five endurance trained female athletes (A, $\dot{V}O_2max = 59.3 \pm 3$ ml/kg/min) and five sedentary nonathletes (NA, $\dot{V}O_2max = 41.0 \pm 3$ ml/kg/min) were studied during the follicular and luteal phases of the menstrual cycle to determine if any phase-induced alterations in aerobic capacity could be assessed by an incremental, discontinuous treadmill test. Subjects included normally menstruating undergraduate students from Ithaca College. Quadriceps strength, power, and endurance were measured on a Cybex II isokinetic dynamometer. In addition, resting and posttreadmill $\dot{V}O_2max$, plasma glucose, and lactate values, as well as delta scores (Δ glucose, Δ lactate) representing changes from the beginning to the end of the treadmill test, were obtained at luteal and follicular phases. Plasma glucose (mg/100 ml) was determined with the o-toluidine method (Hyvarinen & Nikkala, 1962), while lactic acid (mg/100 ml) was assessed by the enzymatic method (Mohme-Lundholm, Svedmyr, & Vamos, 1965). Using a MANOVA design, a significantly higher aerobic capacity (52.9 ± 4 vs. 47.7 ± 4 ml/kg/min) was observed during the follicular phase in both A and NA groups (despite a lowered ventilatory drive, $\dot{V}Emax$). During the same phase, Δ glucose and Δ lactate were also elevated above luteal phase values. In contrast, greater isokinetic strength, power, and endurance were observed in all subjects during the luteal phase despite significant differences in absolute values between A and NA groups. The results

indicate that optimal performance is phase-dependent regardless of training status, while the type of activity being performed determines the menstrual phase of choice (follicular vs. luteal). When compared to the A subjects, the NA subjects showed greater phase-induced changes in all cardiopulmonary and Cybex isokinetic measures. The smaller phase-induced differences in cardiopulmonary measures and in quadriceps isokinetic strength, power, and endurance implied a training-induced adaptation to the hormonal fluctuations associated with different phases of the menstrual cycle.

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A Thesis Presented to the Faculty of
the School of Health, Physical
Education, and Recreation
Ithaca College

In Partial Fulfillment of the
Requirements for the Degree
of Master of Science

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by

Lynn Marie Clement

September, 1987

Ithaca College
School of Health, Physical Education, and Recreation
Ithaca, New York

CERTIFICATE OF APPROVAL

MASTER OF SCIENCE THESIS

This is to certify that the Master of Science Thesis of

Lynn Marie Clement

submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Health, Physical Education, and Recreation at Ithaca College has been approved.

Thesis Advisors:

Committee Member:

Candidate:

Chairman, Graduate Programs in Physical Education:

Dean of Graduate Studies:

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Date: 10·31·87

ACKNOWLEDGMENTS

The investigator would like to extend sincere appreciation and gratitude to the following:

1. The Ithaca College undergraduate women who were participants in this study, for their time and patience.

2. Dr. D. P. Thomas, my thesis advisor, whose guidance and encouragement made all of this possible.

3. Dr. Robert R. Jenkins, my thesis advisor, whose vast knowledge and sense of humor made it a pleasure to work in his laboratory.

4. Dr. Pat Frye, for her willingness to help and her continued patience while making sense out of my statistics.

5. Dr. C. D. Ciccone, for excellent suggestions regarding my initial search for a suitable research design.

6. Ed and Lori, my brother and sister, for their interest and support of all my endeavors.

7. Lynda, for her constant encouragement and endless hours of help during the completion of my thesis.

8. Ellen and Meg, who seemed to always know of my capabilities before I did.

9. Jeff, whose long-lasting friendship I can always count on.

DEDICATION

This thesis is dedicated to my parents, Edmund and Patricia Clement, whose love and understanding have always been behind my accomplishments and failures. To follow in your footsteps is the highest form of respect I can show you.

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Chapter 1

INTRODUCTION

The impact of the menstrual cycle on the female must be addressed in order to answer the many questions being raised in this era of biofitness. Both physiological and psychological effects of the menstrual cycle must be examined if we are to fully understand its implications. The psychological factors may manifest themselves through anxiety, fatigue, nervousness, and other more disturbed emotional states. However, there are many myths and preconceived ideas about "the menstrual woman" that need to be abolished (Gendel, 1976). Although there are definite physiological changes that occur with varying menstrual phases, there is not enough combined statistical evidence to cause the prevention of participation in athletics at any particular phase. Albohm (1976) asserted that the small amount of blood lost during the menstrual phase does not alter performance as long as iron intake is adequate. Erdelyi (1976) asserted that exercise often has both physical and mental benefits, the most notable being relief of certain symptoms associated with the premenstrual syndrome.

The premenstrual syndrome and its symptoms may be one factor that alters a female's athletic performance. Researchers are also investigating the roles that gonadotrophic hormones, ovarian hormones, water weight retention, body fat, and catecholamine release play in the woman's response to exercise during various phases of the menstrual cycle. Evidence has indicated that certain phases are more conducive to increased coordination and performance. Consequently, the question regarding the alteration of the cycle with hormonal pills has recently been raised. Birth control pills, as a means of delaying or altering the menstrual flow, are thought by some experts to be a form of blood doping. However, Erdelyi (1976) stated that hormonal pills are merely restoring the best phase of the cycle and are not increasing the original capability of the athlete. This question of the alteration of the menstrual cycle, along with many other questions, is continually being raised, especially by the high level performer. Thus, at the point when both female participation in athletics and the questions regarding exercise and menstruation are on the rise, more precise information is warranted.

Scope of Problem

The effects of the follicular and luteal phases of the menstrual cycle on the physical performance of female athletes and nonathletes were examined. The performance parameters studied were maximal aerobic capacity ($\dot{V}O_2max$), muscular strength, power, and endurance, and the plasma glucose and lactate response to exercise. Maximal aerobic capacity was determined with a treadmill test, and muscular strength, power, and endurance were measured with the Cybex II Isokinetic Dynamometer.

The subjects were five female nonathletes and five female athletes competing in a spring sport at Ithaca College. Each subject was tested twice--once during the follicular phase and once during the luteal phase (14 days after the onset of menstruation).

Statement of Problem

The effects of the follicular and luteal phases on the maximal aerobic capacity ($\dot{V}O_2max$), muscular strength, power, and endurance, and plasma glucose and lactate levels (determined prior to and after the treadmill test) of athletes and nonathletes were investigated.

Null Hypothesis

The hypothesis of the study was as follows:

There is no difference in performance parameters of athletes and nonathletes measured during the follicular and luteal phases of the menstrual cycle.

Assumptions of Study

The following assumptions were made for the purpose of the study:

1. Fitness levels will not be appreciably increased during the 2-week testing span of each individual subject.

2. The Cybex II Isokinetic Dynamometer test is an adequate measure of muscular strength, power, and endurance.

3. The treadmill test is an adequate measure of maximal aerobic capacity.

4. The participation on a varsity spring sport provides a sufficient basis for the categorization of athletes and nonathletes.

5. The subjects responded fully to the instructions and encouragement offered by the investigator.

6. Investigator bias was minimized through the use of a single blind set-up, in which a mediator recorded the phase of the subject's menstrual cycle.

Definition of Terms

For the purpose of the study, the following terms are defined below:

1. Cybex II Isokinetic Dynamometer: an isokinetic device which imposes a resistance only as great as the force which the subject can generate.

2. Maximal Aerobic Capacity ($\dot{V}O_2max$): the point, expressed at STPD, during incremental exercise at which the oxygen consumption plateaus and shows no further increase or only a slight change as workload (power output) is increased.

3. STPD: the volume of gas expressed under standard conditions of temperature (273° K), pressure (760 mmHg), and dry (no water vapor).

4. V1 and V2: the volume of expired air measured from the Parkinson-Cowen Meter, where V1 is the initial meter reading, and V2 is the final reading taken after the expired

air has passed through the meter for the desired collection time. Also, V1 - V2 = total volume of gas expired through the meter.

5. Steady State: a condition in which there is a balance between the oxygen requirement and the oxygen supply.

6. Follicular Phase: the first half of the menstrual cycle, beginning with the onset of menstruation.

7. Luteal Phase: the second half of the menstrual cycle, beginning with the onset of ovulation.

8. Cybex Isokinetic Strength: the peak slow-speed torque obtained at the 60 degree per second setting.

9. Cybex Isokinetic Power: the peak fast-speed torque obtained at the 180 degree per second setting.

10. Cybex Isokinetic Endurance: the number of repetitions to 50% fatigue during a maximal effort functional speed test.

Delimitations of Study

The delimitations of the study were as follows:

1. Only normally menstruating subjects (those who consistently menstruate once per month) were utilized in this study.

2. Only undergraduate students (*N* = 10) at Ithaca College were used for this study.

3. All subjects performed a 5-minute warm-up prior to testing.

4. Only the Cybex II was utilized to determine muscular strength, power, and endurance.

5. A noncontinuous treadmill protocol was used to determine $\dot{V}O_2max$.

Limitations of Study

The limitations of the study were as follows:

1. Results apply only to undergraduate females ranging in age from 19 to 22.

2. Results apply only to normally menstruating females.

3. Muscular strength, power, and endurance results apply only to the Cybex II Isokinetic Dynamometer.

4. $\dot{V}O_2max$ results apply only to noncontinuous treadmill protocols.

5. Performance results may have been influenced by uncontrolled environmental factors, such as sleep, illness, and diet.

Chapter 2

REVIEW OF RELATED LITERATURE

Current interest in the area of menstruation and exercise has focused on two overlapping areas: (a) the effect that exercise has on menstrual function, and (b) the effect of the menstrual cycle on hormonal, metabolic, cardiovascular, and physiological responses to exercise. This discussion will focus on the latter of the two areas, preceded by a short introduction on normal menstrual function.

Normal Menstrual Function

A woman's life may be divided into three stages based on reproductive function. These stages include childhood immaturity before puberty, child-bearing years, and menopausal years. Puberty is recognized by the beginning of the first menstrual period, or menarche. The menarche marks the beginning of the reproductive function of the ovaries. The menstrual cycle is regulated by the anterior pituitary gland, which is responsible for the secretion of the gonadotropic hormones (VandeWiele, Bogumil, Dyrenfurth, Ferin, Jewelewicz, Warren, Rizkallah, & Mikhail, 1970).

The gonadotropic hormones consist of follicle stimulating hormones, which initiate the development of the follicle, and luteinizing hormones, which bring about the growth of the corpus luteum. The gonadotropic hormones, in turn, stimulate the ovaries to produce the ovarian hormones, estrogen and progesterone, which have a profound effect on the lining of the uterus. Specifically, follicle-stimulating hormones stimulate the follicle to produce estrogen, which has an influence on the endometrium during the follicular stage, or the first half of the menstrual cycle. Estrogen causes a slight thickening of the uterine wall with some glandular proliferation. Estrogen essentially prepares the uterus for the action of progesterone, which is the second ovarian hormone.

Progesterone is secreted under the influence of luteinizing hormone. Progesterone causes a considerable thickening of the endometrium, an increase in the blood supply to the uterus, and an increase in the mucous secretions coating the uterine wall. This progestational phase may also be referred to as the luteal phase, or the second half of the menstrual cycle. If an unfertilized ovum reaches the uterus, the entire structuring of the uterine wall ceases, its inner layer detaches, disintegrates, and leaves the uterus along with blood, resulting in the menstrual flow (Knobil, 1980).

There are considerable individual differences regarding the age of onset of the menstrual flow, the duration of each of the menstrual cycle stages, and the impact of the menstrual cycle on women. This impact on the physiological responses of the woman will be expanded upon in the following sections.

Plasma Hormones

Plasma hormonal variations during the menstrual cycle have been noted by many investigators. Bonen, Belcastro, Ling, and Simpson (1981) measured the concentrations of luteinizing hormone, follicle-stimulating hormone, progesterone, and estrogen in a group of teenage swimmers during one complete menstrual cycle. The swimmers, who trained 2 to 4 hours daily, were compared with a group of moderately active teenage women and a group of fertile adult women. The menstrual cycle of the swimmers (20.0 ± 1.8 days) was shorter than that of the adult women (28.5 ± 3.4 days) and that of the teenage control group (28.3 ± 6.4 days). The luteal phases of the control and adult groups were also significantly shorter (p < .05) than that of the teenage swimmers. In the follicular phase the swimmers' luteinizing hormone concentrations were elevated, and their follicle-stimulating hormone concentrations were decreased in comparison with the other groups (p < .05). The time from the luteinizing hormone surge to the onset of menses (luteal phase) was very short in the swimmers (4.5 ± 0.6 days) in comparison with the length of these phases in both the adult (13.4 ± 1.7 days) and control group (7.8 ± 3.0 days). Gonadotropin concentrations and luteal phase progesterone concentrations were not significantly different in the adult and teenage control groups. The luteinizing hormone concentrations in the swimmers during the luteal phase were not significantly below normal. The finding of no difference in luteinizing hormone concentrations is particularly interesting, because a deficiency of luteinizing hormone in the luteal phase can cause a decrease in progesterone, while exercise has been shown to produce large increases in progesterone (Bonen et al., 1981).

Researchers have found that increased production of ovarian androgens inhibits follicular maturation. Jurkowski (1982) determined that linear increases in the ovarian hormones, estrogen and progesterone, occurred with high intensity exercise. Those ovarian hormone increases were greater in the luteal phase (Jurkowski, 1982), but were abolished by training (Bonen et al., 1981). Subjects who participated in Jurkowski's (1982) study were exercised on a bicycle ergometer for 20 minutes at 30% of maximum power output (Wmax), 20 minutes at 60% Wmax, and to exhaustion at 90% Wmax. Increases in progesterone were found during the luteal phase, and in estrogen during the follicular phase, only at exhaustion. There was a longer time to exhaustion at 90% Wmax in the luteal phase combined with a lower plasma lactate level during heavy and exhaustive exercise in the luteal phase (when compared to the follicular phase). During the follicular phase, Jurkowski (1982) also noted no change in progesterone levels and definite increases in estrogen with exercise especially at the exhaustive stage. Luteinizing hormone increased with exercise during the follicular phase. However, during the luteal phase there was no consistent alteration. In addition, follicle-stimulating hormone concentrations were greater at exhaustion during the follicular phase, with no change during the luteal phase (Bonen et al., 1981; Jurkowski, 1982).

Sutton, Jurkowski, Keane, Walker, Jones, and Toews (1980) also found results similar to those of Jurkowski (1982) in a study designed to examine the effects of exercise on plasma catecholamines, insulin, glucose, and lactate in relation to the menstrual cycle. Their results showed that plasma progesterone increased from 0.73 ± 0.07 ng/ml in the follicular phase to 6.0 ± 2.5 ng/ml in the luteal phase, and plasma estrogen increased from 65.7 ± 3.5 pg/ml to 153.4 ± 15.7 pg/ml. A pattern of hormonal response to exercise, which included an elevation of the plasma levels of the ovarian hormones independent of pituitary gonadotropic control, was evident.

Orenstein, Boat, Stern, Doershuk, and Light (1977) stated that both endogenous and exogenous progesterone increased minute ventilation and reduced alveolar PCO_2. They postulated that their findings may have resulted from an increased sensitivity of the respiratory center to CO_2 that was mediated by progesterone. Sutton et al. (1980) suggested that the higher levels of estrogen in the luteal phase may have caused a negative feedback response that suppressed the luteinizing and follicle-stimulating hormonal response at the level of the pituitary.

Metabolic and Thermoregulatory Responses

Menstrual cycle changes that occur in the female body not only influence the hormonal response to exercise, but also induce metabolic and thermoregulatory variations. Sutton et al. (1980) studied the effects of the menstrual cycle on plasma catecholamines, insulin, glucose, and lactate levels in relation to exercise intensity. Subjects were exercised at 45% and 80% of maximal aerobic capacity ($\dot{V}O_2$max) in the follicular and luteal stages. Plasma epinephrine was found to have increased at both 45% and 80% $\dot{V}O_2$max, but the increase was greater with the heavier exercise. During the heavy exercise, significantly greater increases ($p < .05$) were seen during the follicular phase (78.2 ± 2.1 to 480.6 ± 70.2 pg/ml) then during the luteal phase (44.8 ± 8.1 to 297.5 ± 35.2 pg/ml). Plasma norepinephrine also increased with exercise, however, the differences between the phases were not significant. It was also determined that insulin levels during exercise were not affected by the phase of the menstrual cycle (Sutton et al., 1980). Jurkowski (1982) reported results similar to those of Sutton et al. (1980). From them she concluded that the epinephrine increase during exercise seen in the follicular phase may explain the higher glucose levels also found in this phase, because catecholamines, particularly epinephrine, are known to influence rates of glycolysis.

Menstrual cycle phase has been shown to be related to blood lactate concentrations, as was illustrated in several studies. Jurkowski, Jones, Toews, and Sutton (1981) demonstrated that after heavy exercise blood lactate was increased more in the follicular phase than in the luteal phase (6.62 ± 0.8 mmol/l vs. 4.92 ± 0.5 mmol/l, respectively). Blood lactate at exhaustion was also higher in the follicular phase than the luteal phase (8.12 ± 0.9 mmol/l vs. 6.76 ± 0.6 mmol/l). Sutton et al. (1980) also stated that plasma glucose and lactate were greater in the follicular phase during heavy exercise. Thus, when estrogen and progesterone are low during the follicular phase, plasma lactate is higher in response to heavy exercise. Consequently, endurance time is decreased in the follicular phase, when lactate levels are highest. In other words, high intensity exercise is improved during the luteal phase as lactate production is decreased (Jurkowski et al., 1981). All of the studies reviewed have demonstrated that plasma catecholamines increased with exercise in females and that the phase of the menstrual cycle is important in determining the magnitude of the response. Higher levels of plasma epinephrine, glucose, and lactate in the follicular phase are consistent with an increased stimulation of muscle and liver glycogenolysis in the follicular phase.

Stephenson, Kolka, and Wilkerson (1982) studied the metabolic and thermoregulatory responses to exercise during the various phases of the menstrual cycle. Each subject exercised on a bicycle ergometer on 5 separate days (Days 2, 8, 14, 20, and 26 of the menstrual cycle) at submaximal and maximal exercise intensities. The mean change in core temperature was found to be elevated on days 14 and 20 at all exercise intensities, which implied a dissociation of metabolic responses from thermoregulatory responses to exercise during the menstrual cycle. The variation in metabolic and thermoregulatory responses, in relation to the phases of the menstrual cycle, was assumed to be a possible cause for cyclic changes in the observed cardiorespiratory response to exercise.

Cardiovascular and Respiratory Responses

Controversy surrounds the cardiorespiratory response to exercise during the menstrual cycle. Jurkowski et al. (1981) investigated nine normally menstruating women in midfollicular and midluteal phases of the menstrual cycle exercising at 33%, 66%, and 90% of maximum power output (light, heavy, and exhaustive exercise, respectively). There were no differences found in heart rate, ventilation, oxygen uptake, or cardiac output between the two phases during light and heavy exercise. There was no difference found in heart rate measured during midfollicular and midluteal phases at exhaustion, and the phase of testing did not alter cardiac output when measured halfway between light and heavy exercise. The researchers concluded that the phase of the menstrual cycle did not influence aerobic performance and cardiorespiratory adaptations to exercise.

In a later study conducted by Jurkowski (1982) oxygen uptake again was not influenced by the phase of the cycle. Gamberale, Strindberg, and Wahlberg (1975) also determined that the phase of the menstrual cycle did not alter heart rate or oxygen uptake. Similarly, Littler, Bojorges-Bueno, and Banks (1974) found no difference between the luteal and follicular phases when cardiac index, pulmonary arterial distensibility, heart rate, and systemic blood pressure were examined.

Petrofsky, LeDonne, Rinehart, and Lind (1976) examined isometric strength, isometric endurance, and associated heart rate and blood pressure responses in women throughout the normal menstrual cycle. The investigators concluded that the magnitude of the blood pressure and heart rate response to isometric exercise was not related to either endurance time to fatigue or the phase of the menstrual cycle.

Similarly, Stephenson et al. (1982) found that neither cycle day nor exercise intensity influenced $\dot{V}O_2$max. Mean $\dot{V}O_2$max and average work time to exhaustion were no different during the various phases of the menstrual cycle. Also, cycle day did not seem to influence expiratory volumes, mean tidal volume, respiratory rate, or respiratory exchange ratio.

In contrast, Schoene, Robertson, Pierson, and Peterson (1981) did find cyclic variations in respiratory drive. Schoene et al. (1981) investigated the relationship between cycle phase and ventilatory responses in athletes and nonathletes. In normally menstruating subjects, higher resting minute ventilation ($p < .0001$) and mouth occlusion pressures ($p < .02$) were found during the luteal phase. In addition, hypoxic and hypercapnic ventilatory responses were increased in the luteal phase ($p < .01$). $\dot{V}O_2$max was significantly ($p < .05$) decreased during the luteal phase among the nonathletes. Schoene et al. (1981) indicated that ventilatory equivalents ($\dot{V}E/\dot{V}O_2$) were increased during the luteal phase, while Gamberale et al. (1975) found an increase specifically during the menstrual phase. Because endurance-trained athletes exhibit low ventilatory responses to hypoxia and hypercapnia, there may be an advantage of low respiratory drives for optimal performance. Indeed, the nonathletic group did show a significant decrease in endurance performance with respect to the increase in respiratory drive during the luteal phase. However, the athletes did not show a decrease in performance during the same phase. Thus, some phases of the cycle may be more conducive to optimal exercise performance than others. Also, there is ample evidence that progesterone affects ventilation (Bonen et al., 1981; Jurkowski et al., 1981).

A direct effect of increased progesterone may be a primary metabolic acidosis, and hyperventilation may be a compensatory response. England and Fahri (1976) observed a decrease in end-tidal carbon dioxide pressure and in base excess. The curve for end-tidal carbon dioxide pressure indicated that the tension dropped from a mean value of 39.8 to 36.7 mmHg 10 days after ovulation. There was a parallel decrease in base excess resulting in a pH of 7.38 to 7.40. The authors concluded that the primary disturbance could be either a ventilatory or a metabolic response to an increase in progesterone during the luteal phase. In either case, the authors asserted that a considerable decrease in body CO_2 stores would result from these changes.

Physical Performance

The physical performance of female athletes and nonathletes is greatly dependent upon their cardiorespiratory, metabolic, and hormonal responses relative to the menstrual phase. A study conducted by Stephenson, Kolka, and Wilkerson (1980) examined the effects of the menstrual cycle on anaerobic threshold, working capacity, and perceived exertion. The results indicated that relative perceived exertion, maximal anaerobic capacity, and work intensity remain unchanged throughout the menstrual cycle. These results are in conflict with the majority of the research, which states that menstrual cycle phase does alter performance.

Wearing, Yuhasz, Campbell, and Love (1972) conducted a study in which seven tests of physical performance were evaluated at four different times throughout the menstrual cycle (premenstrual, menstrual, postmenstrual, and intermenstrual). The results indicated that the poorest achievement on each of the seven tests occurred during the menstrual phase. The best achievement on all tests was seen during the intermenstrual phase. The investigators concluded that the ideal time for an athlete to perform is immediately following the postmenstrual phase. Similarly, Gamberale et al. (1975) determined that reaction time was slightly impaired during the menstrual phase, although no change in mental work capacity was observed.

Petrofsky et al. (1976) determined that the isometric endurance of women not taking oral contraceptives varied sinusoidally, with peak endurance midway through the ovulatory phase and lowest endurance midway through the luteal phase. After immersion in water at 37°C , the isometric endurance of those subjects not on oral contraceptives was measured. Maximal endurance was seen at the beginning and end of their cycles, with the lowest endurance at mid-cycle.

Diddle (1983) ascertained that women who suffer from premenstrual tension apparently have a diminution in working capacity. This athletic inefficiency, however, may have been due to factors other than the physiological changes that accompany the normal menstrual cycle, such as psychological manifestations.

Timonen and Procope (1971) compared athletes, casual gymnasts (noncompetitive), and nonathletes in a survey based study. The athletes were found to have the fewest symptoms of premenstrual tension, especially headache and dysmenorrhea. There were no significant differences between the casual gymnasts and the nonactive females.

Bale and Davies (1983) argued that the most common deleterious effects on sports performance often result from changes in balance between estrogen and progesterone before and during menstruation. The investigators examined the effects of menstruation on the physical performance of 109 physical education students. Of the students surveyed, 69.7% stated that menstrual problems affected their performance. Performance was mainly affected on the days immediately preceding menstruation and during the first 2 days of the period. Of the students who did experience dysmenorrhea, two-thirds felt that exercise helped to alleviate the problems, while one-sixth thought exercise exacerbated their symptoms. The researchers believed that the effect of the menstrual problems on performance may have been more psychological than physiological.

Morris and Udry (1970) investigated variations in pedometer activity as related to the menstrual cycle in 34 women for at least one full menstrual cycle. The results indicated that human female activity is increased around the time of ovulation, which is consistent with findings in lower vertebrates.

Higgs and Robertson (1981) investigated changes in perceived exertion (RPE), work capacity, and strength during the four phases of the menstrual cycle. Results indicated that RPE at $\dot{V}O_2max$ was significantly higher ($\underline{p} < .01$) during the precycle and Day 1 cycle phases than at midcycle. The run time on a treadmill at 7 miles per hour (mph) and 7.5% grade was significantly ($p < .01$) decreased in the premenstrual and Day 1 phase. Thus, it would appear that when work levels are intensive, RPE is higher and work capacity is lower during the premenstrual and menstrual phase than in midcycle.

Zaharieva (1965) conducted a survey of sportswomen at the Tokyo Olympics. Results showed that depending on the athletes's particular event, 60% to 80% of the athletes continued to train, 20% to 36% often interrupted the training, and 4% to 5% never trained during menses. The highest percentage of sportswomen who never trained during menses were swimmers (33%). Data on the performance level of athletes during menses showed that in 37% of the cases it made no difference and in 17% the performance was invariably worse.

In addition to the apparent effects of estrogen and progesterone balance on performance, dysmenorrhea syndrome can adversely affect an athlete's ability to function (Shangold, 1980). Prokop (1972) stated that although great individual differences do exist, continuous, highly strenuous performance, supercooling, and shock should be avoided immediately before and during the menstrual flow. Prokop (1972) reasoned that hormonal adaptions create a special stress situation, predisposing to faulty reactions, accidents, and performance-reducing circumstances. In contrast to the above findings, Gendel (1976) asserted that a poor performace should not be blamed on events in the cycle that might coincidentally coexist with the time of the participation.

Albohm (1976) argued that the influence of estrogen causes the retention of sodium and chloride which, in turn, causes water retention. Also, weight increases during the premenstrual phase, peaks on the 2nd day of menstruation, and then decreases until the 8th day. Albohm (1976) also indicated that women are more active during the luteal phase because of the peak levels of estrogen. The factors affecting performance may be greater among very high level competitors, and although the change in efficiency may be very small, the superior athlete may be highly tuned to any difference, no matter what the magnitude (Albohm, 1976).

These observed cyclical changes in performance could hold great implications for scientifically developed training schedules. Individual schedules based on the various phases of the menstrual cycle might be indicated, especially at the professional level. That is, training might be intensified during the luteal phase and diminished around the time of menstruation.

Summary

During the menstrual cycle there are definitely physiological and psychological changes that could alter athletic performance. The cyclic changes of the basal metabolic concentrations of estrogen and progesterone influence many functions of the body. Some of the variables that may be influenced include heart rate, blood pressure, body temperature, electrolyte and water exchange, and sensory perception and awareness. Hormonal variations were indicated by Bonen et al. (1981) when they found greater increases in ovarian hormones with high intensity exercise during the luteal phase. There were no changes in progesterone levels with exercise during the follicular phase (Jurkowski et al., 1981). Plasma epinephrine was also found to be increased during light and heavy exercise intensities, especially during the follicular phase (Sutton et al., 1980). However, changes in plasma nonepinephrine did not seem as significant. Jurkowski (1982) also found that when estrogen and progesterone were low (during the follicular phase) plasma lactate was higher in response to exercise. The results of most research indicate there are also cardiorespiratory differences in response to exercise, although this is controversial.

Perhaps the most controversial issue involving women and exercise is whether menstruation does indeed alter performance. There is an abundance of recent evidence that indicates that performance, work capacity, and perceived exertion are altered during various phases of the cycle. Most of the evidence indicates a decrease in physical performance during the premenstrual phase of the cycle (Albohm, 1986; Diddle, 1983; Jurkowski et al., 1981; Wearing et al., 1972).

Chapter 3

METHODS AND PROCEDURES

This chapter describes the following methods and procedures: (a) selection of subjects, (b) testing instruments and methods of data collection, (c) scoring of data, (d) treatment of data, and (e) summary.

Selection of Subjects

Ten normally menstruating undergraduate females from Ithaca College served as subjects for this study. The subjects were further categorized according to athletic status. The nonathletic control group consisted of five students who were not participating in a varsity sport. The athletic group consisted of five women's track and field or lacrosse athletes.

Each subject consented to participate and signed an Informed Consent Form (see Appendix A) approved by the All-College Review Board on Human Subjects Research. Only those subjects falling into Category A of the Health Status Evaluations of Participants for Exercise Testing, as classified by the American College of Sports Medicine (see Appendix B), were utilized as subjects. Each subject's status was determined from a thorough pretest history taken by the investigator.

Testing Instruments and Methods of Data Collection

Testing instruments were used to obtain physiological measurements in the following areas: (a) cardiorespiratory endurance, (b) quadriceps isokinetic strength, power, and endurance, and (c) plasma glucose and lactic acid.

Cardiorespiratory Endurance

The criterion for cardiorespiratory endurance was maximal aerobic capacity, which was determined by the open circuit method from expired air samples collected during a discontinuous, incremental workload test on a treadmill. The workload on the treadmill was gradually increased by altering the grade, while the speed remained constant at 5 mph. A 5-min warm-up period at 5 mph and 6% grade preceded all testing. The duration of each stage of testing was 3 minutes. At the conclusion of each stage, the subjects were given a 1- to 3-min rest period. Time was monitored using a clock with a 60-sec sweep hand.

Pulmonary ventilation was assessed by the collection of expired air during the last minute of each stage. The gas temperature was measured in degrees Celsius with a standard thermometer, and a standard mercury barometer was used to determine barometric pressure. While on the treadmill, each subject breathed through a mouthpiece attached to a low-resistance, high-flow, two-way plastic valve. Nose clips were utilized during the testing to allow for total gas collection. A 1-inch diameter plastic hose connected the respiratory valve to a Parkinson-Cowen (P-C) flow meter.

After passing though the P-C flow meter (which allowed for measurement of ventilation), the expired air passed through several baffles into a mixing chamber. The plastic mixing chamber measured 12 inches in length and 6 inches in diameter and consisted of two baffle plates dividing the chamber into three compartments. From the mixing chamber, a small sample of gas was drawn by a vacuum pump via plastic tubing into a Costill-Wilmore gas sampling valve. The gas sampling system consisted of three 2-liter anesthesia bags that could be rotated 120 degrees to allow emptying of the bag containing the 1-min collection sample into the gas analyzers.

Oxygen (O_2) and carbon dioxide (CO_2) concentrations were determined from aliquots using an Applied Electrochemistry Model S-3A O_2 analyzer and a Beckman F_2CO_2 analyzer. Each analyzer was calibrated prior to each treadmill test using a calibration gas of known concentration. An Exersentry portable digital heart rate meter was utilized to determine heart rate during the final 1-min collection period at each stage.

A true $\dot{V}O_2$max value was considered to have been obtained when the following criteria were met: (a) an increase in oxygen consumption of less than 2 ml/kg/min, or a plateau effect with increasing workload during a new stage, (b) the achievement of age-predicted maximal heart rate, and (c) the attainment of a respiratory quotient of at least 1.0.

Quadriceps Strength

Strength (peak slow-speed torque) of each subject's right quadriceps muscle group was determined using a Cybex II Isokinetic Dynamometer. Due to the nature of the isokinetic device, the resistance to the subject is only as great as the force that the subject can generate. The subject was given verbal instruction regarding the following:

1. The speed control knob was adjusted to 60 degrees/sec, the torque range scale adjusted to 180 ft.lbs., and the position angle degree scale set at 150 degrees.

2. The subject was positioned on the apparatus in a reproducible body position to allow for testing of the right quadriceps muscle group.

3. Pelvic and thigh stabilization straps were secured as tightly as was comfortable for each subject.

4. The axis of rotation of the joint movement pattern was aligned with the dynamometer input shaft.

5. The input accessory arm length was adjusted to match the individual's limb segment length.

6. The subject was instructed to move her leg into the anatomical zero position (full extension) to allow for the zero baseline to be set. After setting the zero baseline with the electrogoniometer, the input direction was adjusted to counter-clockwise.

7. The investigator checked that alignment of rotational axes and accessory arm length were correct.

8. With the recorder chart speed on "standby," the subject performed 10 warm-up/familiarization repetitions at each of the test speeds to be used.

9. The subject was informed to push as hard and as fast as possible from the beginning to the end of each repetition.

10. The chart speed was set to 5 mm/sec, and the subject was instructed to perform five maximal repetitions.

11. The subject was instructed to stop, and the chart speed was reset to "standby."

12. All muscular tests performed on each subject were plotted on a single piece of chart paper for later evaluation.

13. Upon completion of the strength test, power and endurance were evaluated.

Quadriceps Power

Power (peak fast-speed torque) was also determined using the Cybex II, with the speed control knob adjusted to 180 degrees/sec. Following the five maximal repetitions performed at the 60 degrees/sec setting, the speed selector was quickly changed to the faster, 180 degrees/sec setting. The subject was asked next to perform five maximal repetitions. The subject was then instructed to stop, and the chart speed was reset to "stand-by." Upon completion of the power test, muscular endurance was determined.

Quadriceps Endurance

Quadriceps endurance (defined as the number of repetitions to 50% fatigue during a maximum effort) was determined with the Cybex II set at 180 degrees/sec. Immediately upon completion of the three power repetitions, the subject was instructed to perform maximal repetitions until told to stop by the investigator. The stopping point was determined by the point when the subject could no longer perform 50% of the highest torque achieved at the beginning of the endurance test. Once the 50% mark was reached, three repetitions past this point were counted to assure that the first repetition below 50% was not a "by-chance" finding.

Plasma Glucose and Lactic Acid

Glucose and lactate calibration curves were determined from standard solutions prior to blood assaying. Prior to and immediately following the treadmill test, two 20-ul samples of blood to be used for the plasma glucose analysis were placed into a plastic centrifuge tube containing 200 ul of 3% trichloracetic acid (TCA) with .25 g of sodium floride (NaF). The procedure was followed for both the before-testing (prior to the treadmill test) and after-testing (immediately following the treadmill test) blood samples, and the centrifuge tubes were labeled accordingly. The plasma glucose was determined with the o-toluidine method (Hyvarinen & Nikkala, 1962). A difference (delta) score was obtained for each individual by subtracting the before-treadmill sample from the after-treadmill sample of analyzed blood glucose. The 20-ul samples of blood that were used for the enzymatic determination of plasma lactate were placed into centrifuge tubes containing 20-ul of 8% perchloric acid. The blood samples were stored at -60° C until analyzed by the investigator. Plasma lactic acid was determined by the enzymatic method (Mohme-Lundholm et al., 1965).

Blood glucose was determined for each subject at the two testing periods as follows:

1. The 20 ul blood samples (before-exercising and after-exercising) that were pipetted into the plastic centrifuge tubes containing 200-ul of 3% TCA and NaF were centrifuged for 6 minutes.

2. Then 80 ul of the supernatant obtained from the centrifugation in step 1 were pipetted into a test tube containing 400 ul of o-toluidine reagent.

3. The test tubes were mixed, closed with Parafilm, and incubated for exactly 8 minutes.

4. After a 10-min cooling period, the absorbance of each sample was read in a 10-mm microcuvette at 630 nm against a blank which contained redistilled water in place of the blood supernatant. Normal values for blood glucose are considered to fall between 70 and 110 mg glucose/100 ml of blood.

5. Individual difference (delta) scores were obtained by subtracting the before-treadmill values from the after-treadmill workout values.

Lactate concentrations were determined spectrophotometrically by measuring the equimolar formation of NADH. The following procedure was utilized:

1. The 20-ul before- and after-exercise blood samples that were pipetted into the plastic centrifuge tubes containing 20 ml of 8% perchoric acid were centrifuged for 6 minutes and then stored at -60°C.

2. The supernatant obtained from the centrifugation in step 1 was diluted volume to volume with redistilled water.

3. The following reagents were pipetted into a centrifuge tube: (a) 200 ml glycine buffer .5M, pH 9, with hydrazine .4M, (b) 20 ml NAD solution 2.7×10^{-2}M, (c) 20 ml diluted supernatant, and (d) 5 ml LDH.

4. The solution was incubated for 1 hour at 25°C and transferred into a 10-ml microcuvette.

5. The absorbance was read at 340 nm against a blank containing redistilled water. Normal values for plasma lactate are 10-15 mg lactate/100 ml blood.

6. Difference (delta) scores were obtained by subtracting before-treadmill values from after-treadmill values of lactic acid.

Scoring of Data

Data from the cardiorespiratory endurance evaluation, quadriceps strength, power, and endurance tests, and plasma glucose and lactate assays were obtained for each subject during the follicular and luteal phases.

Cardiorespiratory Endurance

Initial readings of ventilation, room temperature, and barometric pressure were recorded prior to testing. Temperature of the expired gas from the P-C flow meter was recorded after each 1-min collection period. Those measurements were utilized to correct all oxygen consumption values to STPD. The weight of each subject was recorded in pounds and kilograms before the beginning of each test.

During the final 1-min collection period, the expired gas was collected, heart rate was recorded, and fractional O_2 and CO_2 levels were determined from the gas analyzers. The raw maximum ventilatory volume ($\dot{V}E$max) was converted to STPD, and that value was combined with the other necessary values to compute O_2 consumption, CO_2 production, respiratory exchange ratio (R), and $\dot{V}O_2$max in l/min. Individual O_2 consumption (ml/kg/min) was calculated by dividing the corrected values (obtained in millimeters) by the body weight (kg).

Quadriceps Strength, Power, and Endurance

The Cybex II Chart Data Card was utilized to compute strength and power values. The appropriate edge of the grid was aligned with each graph to allow for measurement. Peak slow-speed torque (strength) and peak fast-speed torque (power) were recorded in foot-pounds. Muscular endurance of the quadriceps muscle group was determined by counting the number of repetitions to 50% fatigue during each maximum effort functional speed test.

Plasma Glucose and Lactic Acid

The concentrations of the resultant determined for glucose and lactate plasma assays were read by a spectrophotometer, and all data were recorded. Upon completion of all testing, each absorbance reading was utilized to calculate mg of lactate/100 ml blood and mg of glucose/100 ml blood. Plasma glucose and lactic acid difference scores were determined for each subject according to calibration curves at the follicular and luteal testing phases.

Treatment of Data

The statistical procedure utilized to compare the follicular and luteal phase performance changes between the two groups of subjects consisted of a three-way multivariate analysis of variance (MANOVA). Univariate ANOVAs were run on each variable independently regardless of the MANOVA results, so that the results of this study could be compared to previous investigations (all of which reported univariate statistics). F ratios beyond the .05 level of probability were accepted as significant.

Summary

Subjects for this study were 10 undergraduate college students who had normal menstruation patterns. The subjects were further categorized by athletic status into athletes (n = 5) and nonathletes (n = 5). The nonathletic and athletic groups underwent testing to determine values for cardiorespiratory endurance, quadriceps strength, power, and endurance, and plasma glucose and lactate levels. Each subject was studied during the follicular phase and the luteal phase. Follicular and luteal phase data for the two groups were analyzed by using a three-way MANOVA.

Chapter 4

ANALYSIS OF DATA

This study was conducted to determine the effects of the follicular and luteal phases of the menstrual cycle on the physical performance of athletes and nonathletes. The performance parameters measured were cardiorespiratory endurance ($\dot{V}O_2$max), maximum ventilation ($\dot{V}$Emax), quadriceps isokinetic strength, power, endurance, and plasma glucose and lactate changes during exercise. The performance data of athletes and nonathletes were subjected to three multivariate analyses of variance (MANOVAs) to identify the differences between the two menstrual cycle phases for the two groups. In all cases, F ratios beyond the .05 level of probability were accepted as significant. This chapter presents the results of the statistical analyses of the data in the following four sections: (a) cardiorespiratory endurance, (b) quadriceps strength, power, and endurance, (c) plasma glucose and lactic acid, and (d) summary.

Cardiorespiratory Endurance

The raw values, means, and standard errors of the cardiorespiratory endurance ($\dot{V}O_2$max) and maximum ventilatory ($\dot{V}$Emax) data determined from the treadmill test are shown in Appendices C and D, respectively. In the MANOVA procedure the between-group factor (athletic status) and the within-group factor (test time) were first tested for any interactions. The combined pulmonary data indicated no significant interaction with $F(2, 7) = 2.71$, $p > .05$.

The multivariate between-group difference between athletes and nonathletes was not significant, as shown with $F(2, 7) = 4.51$, $p > .05$. The multivariate difference between the follicular and luteal phases was found to be significant on combined $\dot{V}O_2max$ and $\dot{V}Emax$ data with $F(2, 7) = 20.75$, $p < .05$. The discriminant function analysis identified the percentage of contribution to the within-group difference between the follicular and luteal phases for the pulmonary variable. For the phase-dependent test time difference, $\dot{V}O_2max$ contributed 84.9% to the discriminant function, while $\dot{V}Emax$ contributed 15.1%.

Figure 1 indicates that athletes and nonathletes both had significantly higher $\dot{V}O_2max$ scores in the follicular phase than in the luteal phase, $F(1, 8) = 37.37$, $p < .05$. Although the pattern of change was the same for both groups, athletes had consistently higher $\dot{V}O_2max$ values, $F(1,8) = 8.98$, $p < .05$. The ANOVA for $\dot{V}Emax$ indicated no significant difference between athletes and nonathletes, $F(1, 8) = 1.85$, $p > .05$. However, there was a significant ordinal interaction of phase by group, $F(1, 8) = 6.16$, $p < .05$. A further analysis indicated that, although $\dot{V}Emax$ was significantly higher for both groups in the luteal phase, $F(1, 8) = 25.60$, $p < .05$, the difference between follicular

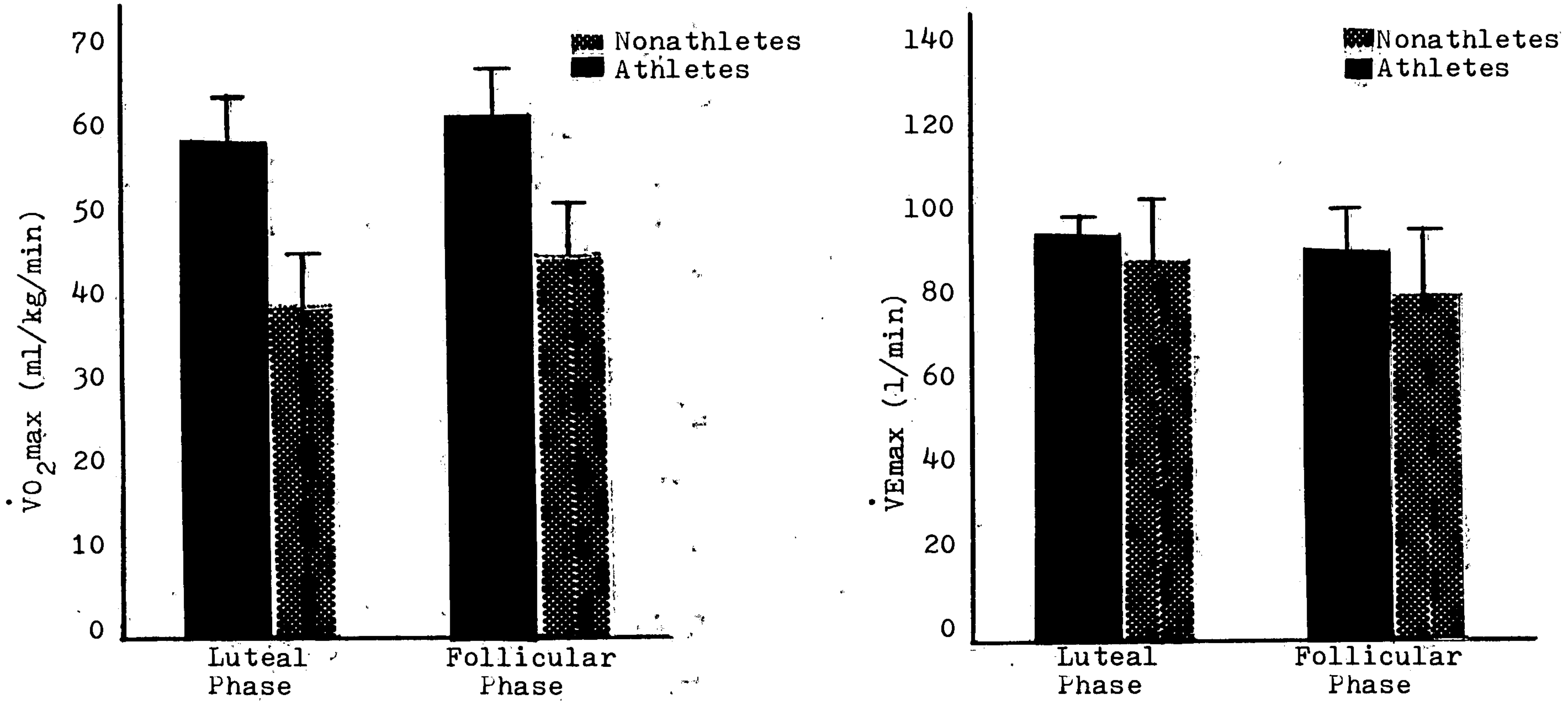

Figure 1. Maximum aerobic capacity and maximum ventilation of athletes and nonathletes in two menstrual cycle phases.

and luteal values was significantly greater for nonathletes than for athletes (see Figure 2).

Quadriceps Strength, Power, and Endurance

The raw values, means, and standard errors of the Cybex test variables (quadriceps isokinetic strength, power, and endurance) are presented in Appendices E, F, and G, respectively. The combined Cybex data indicated no significant interaction, $F(3, 6) = 1.37$, $p > .05$. The multivariate between-group difference between athletes and nonathletes was significant, $F(3, 6) = 5.55$, $p < .05$. For the between-groups difference, quadriceps endurance contributed 92.2% and quadriceps strength 7.3% to the discriminant function. The multivariate within-group difference between cycle phases was also significant, $F(3, 6) = 39.09$, $p < .05$. The discriminant function analysis indicated that quadriceps endurance contributed 87.4% and quadriceps strength added 9.9% to the cycle phase difference.

Figure 3 indicates that both athletes and nonathletes had significantly higher ($p < .05$) Cybex scores in the luteal phase than in the follicular phase: (a) isokinetic strength, $F(1, 8) = 75.49$, (b) isokinetic power, $F(1, 8) = 61.97$, and (c) isokinetic endurance, $F(1, 8) = 104.0$. Although the pattern of change was the same for both groups, athletes had significantly higher ($p < .05$) Cybex values than the nonathletes: (a) strength, $F(1, 8) = 10.96$, (b)

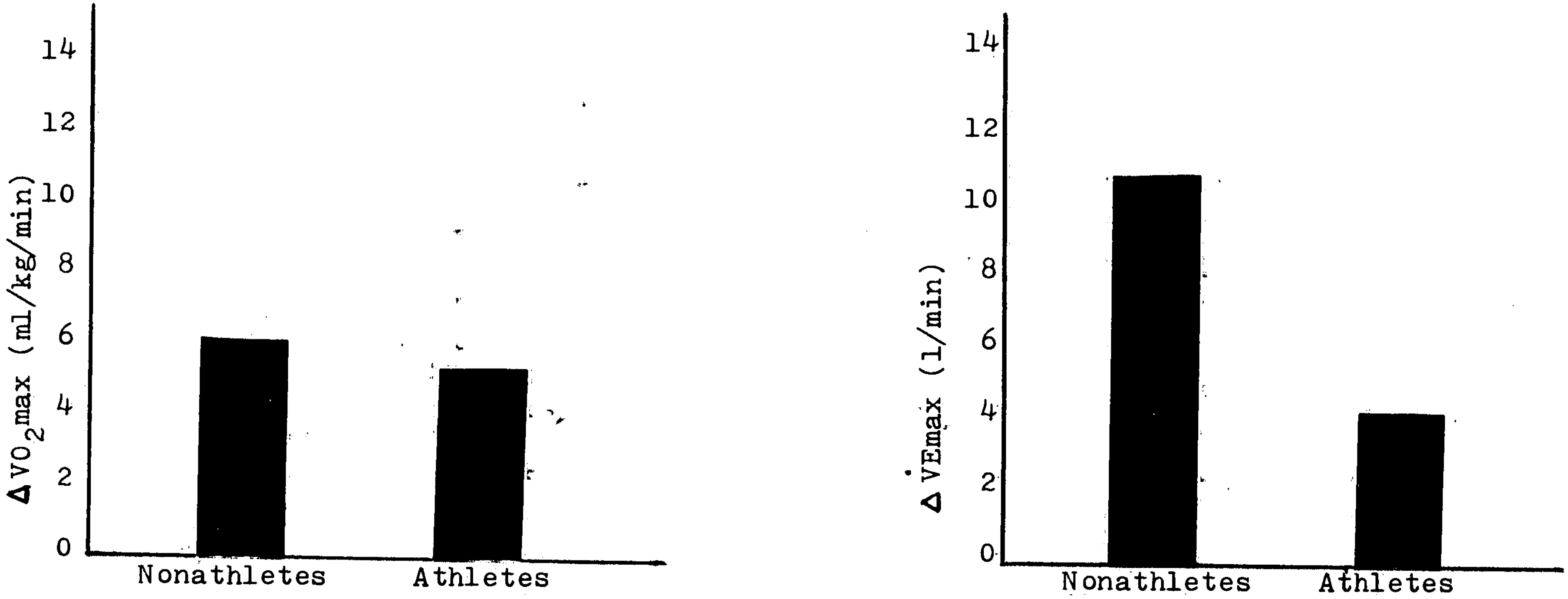

Figure 2. $\Delta\dot{V}O_2$max and $\Delta\dot{V}$Emax between luteal and follicular phases for nonathletes and athletes.

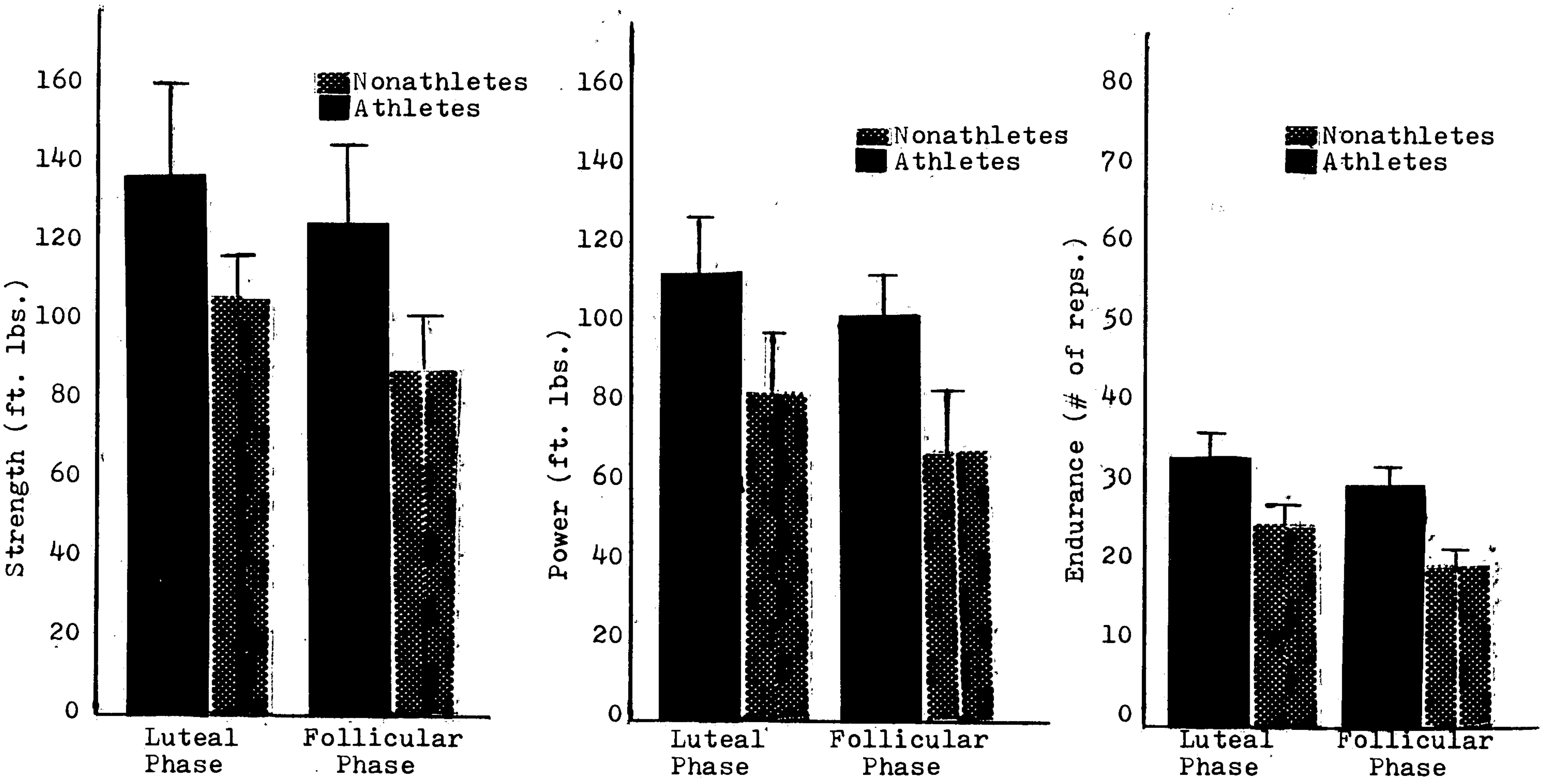

Figure 3. Quadriceps isokinetic strength, power, and endurance of athletes and nonathletes in two menstrual cycle phases.

power, F(1, 8) = 15.45, and (c) endurance, F(1, 8) = 15.73. A further analysis indicated that the difference between follicular and luteal values was greater for nonathletes than for athletes (see Figure 4). It should be noted that some subjects were tested first during the follicular phase, and others tested first during the luteal phase, to control for any learning effect. In addition, the Cybex test administrator had no knowledge of the particular subject's menstrual phase.

Plasma Glucose and Lactic Acid

The raw values, delta scores, means, and standard errors of the plasma glucose and lactate levels measured before and after the treadmill test are presented in Appendices H and I, respectively. Follicular and luteal delta scores were derived by subtracting plasma values obtained after the workout. The combined plasma level data indicated no interaction, F(2, 7) = .54, $p > .05$. There was no significant difference between athletes and nonathletes when plasma glucose and lactate delta scores were examined in combination, F(2, 7) = .27, $p > .05$. In addition, the ANOVA for plasma glucose, F(1, 8) = .48, and for lactic acid, F(1, 8) = .35, indicated no significant differences ($p > .05$) between athletes and nonathletes. The plasma values for athletes and nonathletes were combined because there was no significant difference between the groups. For the combined groups, the multivariate difference between the

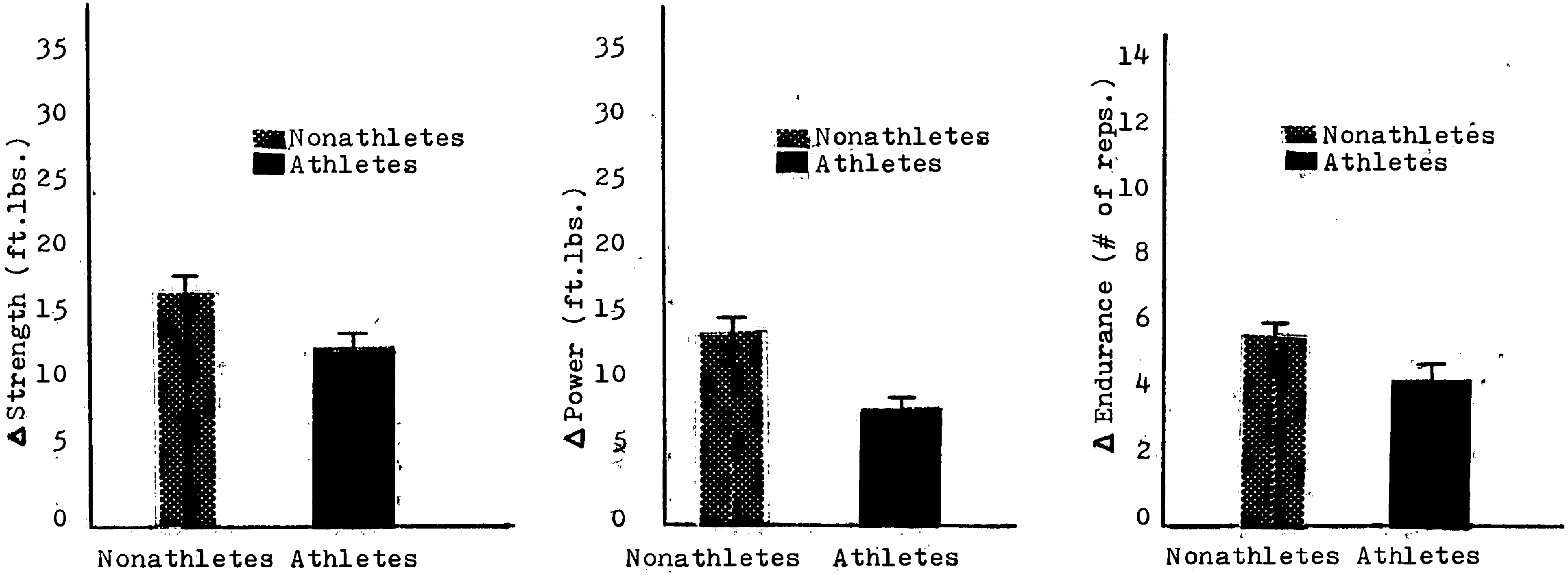

Figure 4. Δstrength, Δpower, and Δendurance between luteal and follicular phases for nonathletes and athletes.

follicular and luteal testing phases was determined to be significant for combined plasma data, F(2, 7) = 24.15, _p_ < .05.

The discriminant function analysis indicated that plasma lactate contributed 88.8% and plasma glucose 11.2% to the cycle phase difference.

Figure 5 indicates that athletes and nonathletes combined had significantly higher glucose delta scores in the follicular phase than in the luteal phase, F(1, 8) = 20.23, _p_ < .05. The ANOVA for plasma lactate delta scores also showed significantly higher values in the follicular phase than in the luteal phase, F(1, 8) = 23.52, p < .05. Combining the values for athletes and nonathletes, plasma glucose was determined to have increased from 12.95 to 22.90 mg/100 ml and plasma lactate from 4.00 to 8.00 mg/100 ml during the follicular phase.

Summary

There were significant differences found between follicular and luteal testing phases (_p_ < .05) when cardiorespiratory endurance, quadriceps strength, power, and endurance, and hematological variables were subjected to a MANOVA. The multivariate difference between testing phases was found to be significant on combined cardiorespiratory data, on combined Cybex data, and also on combined plasma data. However, there was only a significant multivariate difference between athletes and nonathletes for combined Cybex data.

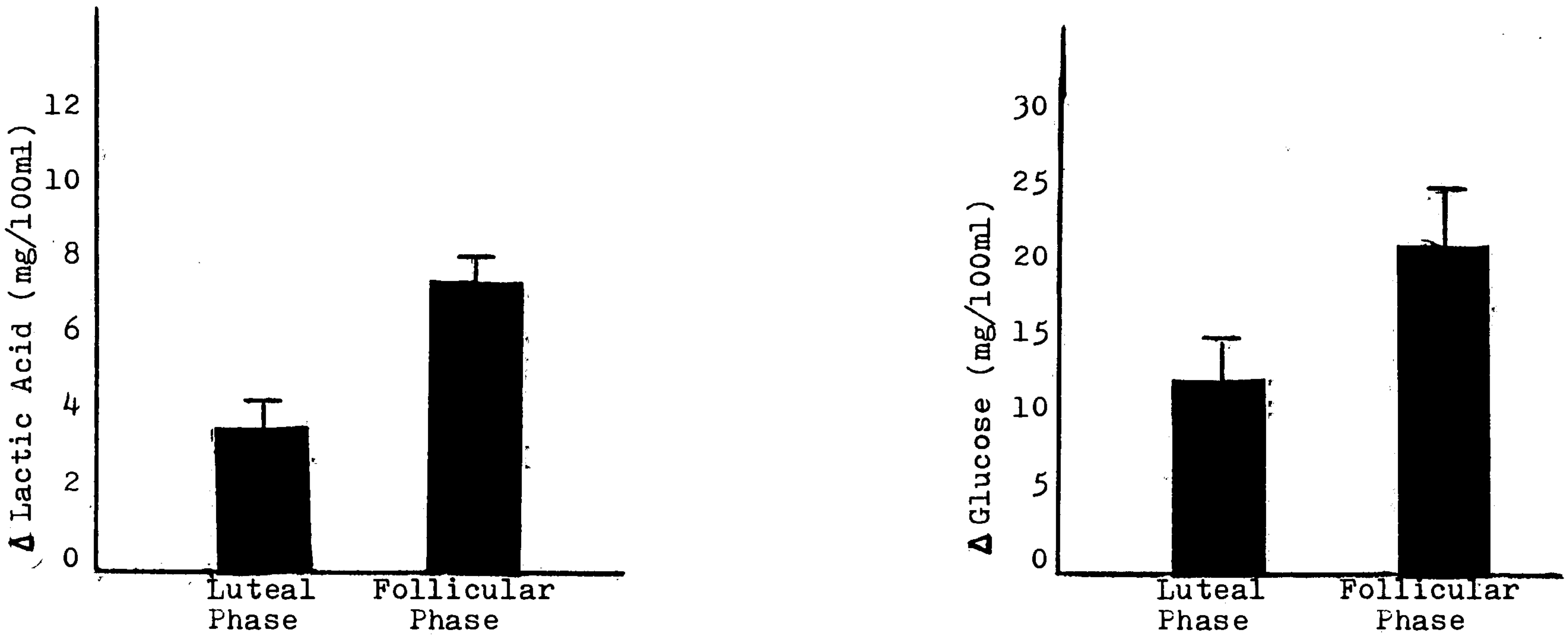

Figure 5. Plasma lactic acid and glucose difference (Δ) scores before and after treadmill run for all subjects (N = 10).

The ANOVA for $\dot{V}O_2$max indicated that both athletes and nonathletes had significantly higher cardiorespiratory endurance values during the follicular phase than during the luteal phase. Athletes had consistently higher $\dot{V}O_2$max values. The ANOVA for $\dot{V}$Emax indicated no significant difference between athletes and nonathletes. When athletes and nonathletes were combined, $\dot{V}$Emax was significantly higher during the luteal phase. The difference between testing phases for $\dot{V}O_2$max and $\dot{V}$Emax were consistently greater for the nonathletes than for the athletes.

Athletes and nonathletes both had significantly higher Cybex scores in the luteal phase than in the follicular phase. While the pattern of change was the same for both groups, ahtletes had significantly higher Cybex scores than the nonathletes. A further analysis indicated that the difference between follicular and luteal values was greater for the nonathletes than for the athletes.

There were no significant differences between athletes and nonathletes when plasma glucose and lactate delta scores were analyzed. Athletes and nonathletes combined had significantly higher glucose and lactate delta values in the follicular phase than in the luteal phase.

Chapter 5

DISCUSSION OF RESULTS

This study examined the effects of the follicular and luteal phases of the menstrual cycle on the physical performance of athletes and nonathletes. A treadmill test was used to determine each subject′s maximal aerobic capacity. Blood samples were drawn before and after the treadmill workout and assayed for plasma glucose and lactate levels. Individual delta scores were obtained by subtracting the before- from the after-treadmill values. A Cybex II Isokinetic Dynamometer was utilized to determine quadriceps isokinetic strength (peak slow-speed torque), power (peak fast-speed torque), and endurance. MANOVA was used to identify any changes in the performance parameters. The discussion has been divided into the following sections: (a) cardiorespiratory endurance, (b) quadriceps strength, power, and endurance, (c) plasma glucose and lactic acid, and (d) summary.

Cardiorespiratory Endurance

There was a significant difference between the luteal and follicular testing phases in the maximal aerobic capacity and maximum ventilation of athletes and nonathletes. $\dot{V}O_2max$ values were significantly decreased from the follicular to the luteal testing phase in both groups. Maximum ventilation ($\dot{V}$Emax) was shown to be higher during the luteal phase in both groups. It should be noted that endurance trained athletes exhibited low respiratory drives, which enhance optimal aerobic performance. These results were consistent with the findings from a previous study conducted by Schoene et al. (1981). The present study determined that cardiorespiratory endurance was enhanced during the luteal phase. These results may be supported by a previous study conducted by Albohm (1976), who stated that the high levels of estrogen found during the follicular phase are accompanied by an increased heart rate, an increased cardiac contractile force, and higher arousal levels, which have been associated with increased sensory perception. However, the present study's results were inconsistent with the investigators who found no cyclic variations in performance (Gamberale et al., 1975; Jurkowski et al., 1981; Sutton et al., 1980).

There were significantly smaller differences in $\dot{V}O_2$max and $\dot{V}$Emax between phases for the athletes than for the nonathletes. In summary, both groups did show a significant decrease in VO max values and an increase in VEmax values during the luteal phase.

Alterations in Cybex Isokinetic Parameters

In both athletes and nonathletes there was a significant difference between luteal and follicular testing phases when quadriceps strength, power, and endurance were measured. Consistently smaller scores in all Cybex isokinetic parameters were found in both groups during the follicular testing phase. These results are consistent with the findings from several previous studies (Albohm, 1976; Bale & Davies, 1983; Higgs & Robertson, 1981; Wearing et al., 1972). A further analysis indicated that the difference between luteal and follicular values was greater for the nonathletes than for the athletes. Perhaps the athletes' response to exercise was more highly tuned to day-to-day physiological fluctuations that may better adapt them to a change in efficiency. These results were inconsistent with the findings from a previous study conducted by Timonen and Procope (1971). Those researchers found no significant difference between gymnasts and inactive females when the subjects were asked to describe menstruation-related symptoms.

Alterations in Plasma Glucose and Lactic Acid

Plasma glucose and lactate delta scores determined from before- and after-treadmill samples were shown to differ significantly between the luteal and follicular testing phases. Plasma glucose delta scores increased from 12.95 mg/100 ml in the luteal phase to 22.90 mg/100 ml in the follicular. Plasma lactate delta scores increased from 4.00 mg/100 ml in the luteal phase to 8.00 mg/100 ml in the follicular testing phase. The findings of the present study are consistent with the results of previous studies

(Jurkowski, 1982; Jurkowski et al., 1981; Sutton et al., 1980). Jurkowski (1982) speculated that the higher glucose levels found during the follicular phase may be related to the increase in catecholamines that she also found in this phase. It should be noted that $\dot{V}O_2max$ values decreased from the follicular to the luteal testing phase as did the plasma lactate delta values (difference of after- minus before-treadmill values). The decline in $\dot{V}O_2max$ and plasma lactate was consistent with the significant decrease in treadmill time ($p < .05$) that occurred during the luteal testing phase.

Summary

The results of this study were compared and contrasted to the findings of previous related studies. There were significant differences between the follicular and luteal testing phases in all physical parameters measured. Maximal aerobic capacity ($\dot{V}O_2max$) was significantly reduced from the follicular to the luteal testing phase. Activities that require maximal cardiorespiratory endurance would benefit from participation during the follicular phase of the cycle, when lactic acid increases are better tolerated. Maximum ventilation was significantly increased from the follicular to the luteal phase. The difference between follicular and luteal $\dot{V}O_2max$ and $\dot{V}Emax$ values was greater for nonathletes than for athletes. Perhaps the athletes' response to exercise was more highly tuned to day-to-day physiological fluctuations that may enable them to better adapt to a change in efficiency.

Quadriceps isokinetic strength, power, and endurance decreased during the follicular phase. If quadriceps strength, power, and endurance are representative, then optimal isokinetic performance would be expected during the luteal phase. There was also a significant difference between athletes and nonathletes in all Cybex parameters. While the pattern of change was the same for both groups, athletes had significantly higher Cybex values than nonathletes. However, the difference between follicular and luteal values was greater for the nonathletes than for the athletes.

The results of this study were consistent with previous studies that indicated that the menstrual cycle phase did affect physical performance and, in general, that observed differences varied with fitness levels. Specifically, cardiorespiratory endurance, plasma glucose delta scores, and lactate delta scores were lower, while quadriceps isokinetic strength, power, and endurance were higher during the luteal phase than during the follicular phase of the menstrual cycle.

Chapter 6

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS FOR FURTHER STUDY

Summary

The purpose of this study was to determine whether the menstrual cycle phase affected physical performance and physiological parameters measured in athletes and nonathletes. This study was conducted on 10 subjects, 5 who were classified as athletes, and 5 who were classified as nonathletes. Each subject was tested twice, once during the follicular phase and again during the luteal phase. Separate measurements were collected for cardiorespiratory endurance and maximum ventilation (as determined by a treadmill workout), quadriceps strength, power, and endurance (as assessed by a Cybex II Isokinetic Dynamometer), and plasma glucose and lactate delta scores (calculated as the difference between before- and after-exercise blood samples) during both the follicular and luteal testing phases.

There were significant differences between luteal and follicular phases ($p < .05$) when cardiopulmonary, Cybex, and plasma parameters were examined. Athletes and nonathletes exhibited larger values in $\dot{V}O_2max$ and in plasma glucose and lactate delta values, and smaller values in $\dot{V}Emax$ and in quadriceps strength, power, and endurance, in the follicular phase than in the luteal phase. Athletes had significant higher $\dot{V}O_2$max, quadriceps strength, power, and endurance values than the nonathletes. There was no significant difference between athletes and nonathletes when changes in plasma glucose and lactic acid values were analyzed. For the cardiopulmonary and Cybex parameters, the nonathletes exhibited a significantly greater difference between menstrual phases. The above changes were significant at the .05 level of probability when MANOVA statistical procedures were utilized. Therefore, the null hypothesis that stated there is no difference in performance parameters of athletes and nonathletes measured during the follicular and luteal menstrual phases was rejected.

Conclusions

The findings of this study support the following conclusions:

1. If $\dot{V}O_2$max and $\dot{V}$Emax are representative, then activities that require maximal cardiorespiratory endurance would benefit from participation during the follicular phase.

2. If lactic acid and glucose levels are representative, activities that require maximal cardiorespiratory endurance would benefit from participation during the follicular phase of the cycle, when lactic acid increases are better tolerated.

3. If quadriceps strength, power, and endurance are representative, then optimal isokinetic performance would be expected during the luteal phase.

4. The lesser phase-dependent differences (in all cardiopulmonary and Cybex isokinetic parameters) found in the athletes could be attributed to the fact that athletes are more highly tuned to their total physiology.

Recommendations for Further Study

The findings of this study led the investigator to suggest the following recommendations for further studies:

1. Involve a larger number of subjects in each group to control for individual variations.

2. Examine performance parameters at all four menstrual phases (premenstrual, menstrual, intermenstrual, postmenstrual).

3. Examine the effects of various phases of the menstrual cycle on insulin binding.

4. Obtain plasma glucose and lactate delta scores from blood samples taken before and after testing on the Cybex II Dynamometer.

Appendix A

INFORMED CONSENT FORM

I. a) Purpose of the study: Research is being conducted to determine the effects of the follicular and luteal phases of the menstrual cycles on cardiovascular endurance ($\dot{V}O_2max$), muscular strength, power, and endurance, and plasma glucose and lactate levels of athletes and nonathletes.

b) Benefits: The resulting information may prove useful in answering the many questions women have regarding their menstrual cycle and exercise, particularly during menstrual flow.

II. Method: As a subject, you will be asked to participate in the following manner:

a) Monitor your menstrual activity for 1 month prior to participating in the study, and submit this information to the investigator.

b) During the following month, you will be asked to report to the electrophysiology lab, Room 209, in the New Academic Facility for one Cybex II test at a specified date according to your menstrual activity. This device is used to record muscular strength, power, and endurance of your quadriceps muscle group. The Cybex II Isokinetic Dynamometer is an exercise device similar to Nautilus exercise equipment. This test will take from 20 to 30 minutes. The same day you will be asked to report to the training room in the Ceracche Center to participate in a treadmill cardiovascular test to determine your maximal aerobic capacity. This test will consist of a gradual increase in work level until a predetermined heart rate is achieved. The treadmill test will take from 30-40 minutes. Following the treadmill test, a small sample of blood will be taken by trained personnel to determine glucose and lactate levels during exercise. The blood sample will be drawn from your fingertip using a simple fingertip prick technique.

c) According to your menstrual history, you will be asked to return approximately 2 weeks after the first battery of tests to undergo the identical Cybex II, treadmill, and blood tests in the same sequence.

III. Will this hurt? There are no apparent physical or psychological risks involved in this study. The Cybex II is a device routinely used in muscular force evaluations in which the safety of the subject is maximized. Due to the isokinetic nature of this device, the resistance on the subject is only as great as the force that the subject can generate. The treadmill ($\dot{V}O_2$max) test is the equipment routinely used in cardiovascular endurance testing. The minimal risk involved for the cardiovascular testing can be equated to that of other physically exhaustive exercises.

Only individuals who do not fall into a risk category as classified by the American College of Sports Medicine will be allowed to participate in this study. The treadmill apparatus is commonly used in the rehabilitation of cardiac patients. The minimal risk involved in the blood tests will be reduced as only qualified personnel will be taking the samples.

IV. Need more information? If you wish to know more about the study or the final results, please feel free to contact me: Lynn Clement, School of HPER, Ithaca College, Ithaca, New York, 14850, or Dr. D. P. Thomas at x3139.

V. Withdrawal from the study. Participation is voluntary, and your initial agreement to participate does not prevent you from discontinuing your participation at any time.

VI. Will the data be maintained in confidence? It is assured that names in this study will be kept in the strictest confidence. You will not be personally identified by name, initials, or any other means during the interpretation or final presentation of the data. Individual identification will be discarded after the results have been tabulated in the form of means and standard deviations.

VII. I have read the above and I understand its contents. I agree to participate in the study. I acknowledge that I am 18 years of age or older and that I have been identified as an individual who does not fall into a risk category for stress-testing as classified by the ACSM.

______________________________ ________________

Signature Date

Appendix B

CLASSIFICATION BY AGE AND HEALTH STATUS OF PARTICIPANTS FOR EXERCISE TESTING

Category	
A	Asymptomatic, physically active persons of any age without CHD risk factors or disease
B	Asymptomatic, physically inactive persons less than 35 years of age without CHD risk factors or disease
C	Asymptomatic, physically inactive persons 35 years and older without CHD risk factors or disease
D	Asymptomatic, physically inactive persons of any age with CHD risk factors but no known disease
E	Asymptomatic persons of any age with known disease
F	Symptomatic, physically active persons clinically stable for 6 months or longer
G	Symptomatic, physically inactive persons clinically stable for 6 months or longer
H	Symptomatic persons with recent onset of CHD or a change in disease status (Example: Recent myocardial infarction, unstable angina, coronary artery bypass surgery)
I	Persons for whom exercise is contraindicated

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[a] From American College of Sports Medicine. Classification by age and health status of participants for exercise testing. Guidelines for Graded Exercise Testing and Exercise Prescription, 1980, p. 3.

Appendix C

$\dot{V}O_2max^a$ DURING TWO PHASES OF MENSTRUAL CYCLE

Group		Luteal	Follicular	M	SE
Nonathletes		46.4	51.9	41.2 ±	3.3
		30.6	34.1		
		51.2	58.8		
		32.0	42.4		
		31.0	33.2		
	M	38.2 ±	44.1 ±		
	SE	4.4	5.0		
Athletes		64.2	69.1	59.4 ±	2.8
		55.1	57.0		
		61.2	65.0		
		41.7	49.3		
		63.1	68.6		
	M	57.1 ±	61.8 ±		
	SE	4.2	3.8		
Combined	M	47.65 ±	52.94 ±		
	SE	4.2	4.2		

[a] Values reported as ml/kg/min.

Appendix D

$\dot{V}$Emax[a] DURING TWO PHASES OF MENSTRUAL CYCLE

Group		Luteal	Follicular	M	SE
Nonathletes		97.8	86.9	82.8 ±	4.3
		79.0	69.2		
		105.3	95.1		
		87.5	71.7		
		70.9	65.0		
	M	88.1 ±	77.6 ±		
	SE	6.2	5.7		
Athletes		89.9	81.7	91.7 ±	2.1
		89.6	82.4		
		98.5	102.5		
		91.8	91.0		
		97.9	92.2		
	M	93.5 ±	89.9 ±		
	SE	1.9	3.8		
Combined	M	90.8 ±	89.9 ±		
	SE	3.2	3.8		

[a] Values reported as l/min.

Appendix E

MUSCULAR STRENGTH[a] DURING TWO PHASES OF MENSTRUAL CYCLE

Group		Luteal	Follicular	M	SE
Nonathletes		120	105	96.8 ±	5.0
		98	81		
		120	95		
		103	86		
		89	71		
	M	106.0 ±	87.6 ±		
	SE	6.1	5.8		
Athletes		104	98	130.9 ±	6.1
		148	127		
		138	131		
		158	147		
		139	119		
	M	137.4 ±	124.4 ±		
	SE	9.1	8.0		
Combined	M	121.7 ±	106.0 ±		
	SE	7.4	7.7		

[a] Values reported as ft. lbs.

Appendix F

MUSCULAR POWER[a] DURING TWO PHASES OF MENSTRUAL CYCLE

Group		Luteal	Follicular	*M*	*SE*
		95	87		
		71	57		
Nonathletes		96	76	72.7 ±	5.4
		78	62		
		61	44		
	M	80.2 ±	65.2 ±		
	SE	6.8	7.5		
		93	89		
		114	101		
Athletes		107	103	106.6 ±	3.7
		126	118		
		115	100		
	M	111.0 ±	102.2 ±		
	SE	5.4	4.6		
Combined	*M*	95.6 ±	83.7 ±		
	SE	6.6	7.4		

[a] Values reported as ft. lbs.

Appendix G

MUSCULAR ENDURANCE[a] DURING TWO PHASES OF MENSTRUAL CYCLE

Group	Luteal	Follicular	M	SE
	23	18		
	27	21		
Nonathletes	28	20	20.9 ±	1.3
	21	16		
	20	15		
M	23.8 ±	18.0 ±		
SE	1.6	1.1		
	28	25		
	26	24		
Athletes	34	29	30.2 ±	1.5
	36	30		
	38	32		
M	32.4 ±	28.0 ±		
SE	2.3	1.5		
Combined M	28.1 ±	23.0 ±		
SE	2.0	1.9		

[a] Values reported as number of repetitions.

Appendix H

PLASMA GLUCOSE[a] DURING TWO PHASES OF MENSTRUAL CYCLE

Group		Luteal			Follicular		
		Before	After	Δ	Before	After	Δ
Nonathletes		97.9	119.2	21.3	109.4	134.7	25.3
		86.3	100.1	13.8	89.8	126.7	36.9
		126.1	150.6	24.5	120.9	149.1	28.2
		89.1	99.1	10.0	91.4	111.3	19.9
		90.6	100.5	9.9	76.8	86.9	10.1
	M	98.0	113.9	15.6 ±	97.7	121.7	23.6 ±
	SE			2.9			4.4
Athletes		94.6	114.9	20.3	84.6	124.4	39.8
		78.0	85.2	7.2	73.0	90.4	17.4
		95.9	98.1	2.2	96.2	110.3	14.1
		77.1	90.1	13.0	77.2	98.6	21.4
		84.1	93.6	9.5	85.9	106.3	20.4
Combined	M	85.9	96.4	10.3 ±	83.4	106.0	22.2 ±
	SE			3.0			4.4

[a] Values reported as mg/100ml.

Appendix I

PLASMA LACTATE[a] DURING TWO PHASES OF MENSTRUAL CYCLE

Group		Luteal			Follicular		
		Before	After	Δ	Before	After	Δ
Nonathletes		13.0	20.2	7.2	13.8	29.7	15.9
		13.7	15.5	1.8	13.6	17.4	3.8
		15.4	17.5	2.1	13.9	18.9	5.0
		13.6	18.0	4.4	14.5	20.8	6.3
		11.0	15.2	4.2	12.2	19.2	7.0
	M	13.3	17.3	3.6 ±	13.6	21.2	7.2 ±
	SE			1.0			2.1
Athletes		18.6	20.0	1.4	20.4	28.1	7.7
		16.7	20.5	3.8	14.5	19.1	4.6
		18.7	28.5	9.8	15.9	29.5	13.6
		15.6	19.4	3.8	15.9	27.1	11.2
		13.7	20.6	6.9	14.5	23.6	9.1
Combined	M	16.7	21.8	4.4 ±	16.2	25.5	8.8 ±
	SE			1.4			1.6

[a] Values reported as mg/100ml.

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