

NEUROMUSCULAR PERFORMANCE AND THE MENSTRUAL CYCLE

by

Shayna Marie Lemke

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Approved for the Department of Health and Human Development

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Approved for the Division of Graduate Education

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ABSTRACT

Women athletes are more likely to tear their anterior cruciate ligament than their male counterparts. The female athlete has a complex system of steroid hormones that are continually changing. These sex hormones that fluctuate throughout each month may influence knee injuries, specifically the anterior cruciate ligament. The increased incidence in women is thought to be multifactorial, a combination of structural, anatomical, or biomechanical factors. The NCAA has reported that 75 percent of anterior cruciate ligament injuries are non-contact in competitive jumping or pivoting sports. In this study, the effects of the menstrual cycle on neuromuscular performance were investigated.

Fifteen healthy females with regular menstrual cycles completed the various tests of this study for three phases of the menstrual cycle. All females were categorized as moderate or vigorous exercisers from an activity questionnaire. This study used a repeated measures experimental design; therefore, each participant served as her own control. The participants completed a series of two tests, including functional balance and fatigability. Each series was completed during three different phases of the menstrual cycle: menstruation, follicular and luteal. The participants used ovulation kits to predict the luteal phase. These phases were then verified through blood tests at each exercise session.

The reaction time and balance test was performed with a BOSU wobble board placed on a force plate. A force platform was utilized to collect center of pressure data from the wobble board. The fatigue test protocol consisted of the participants performing in a pre-fatigue functional test, fatigue protocol and post-fatigue functional ability test. The functional test protocol consisted of two trials of four single-legged hop drills.

It was hypothesized that all of the functional tests would have the greatest neuromuscular performance during the follicular phase of the menstrual cycle, and for all of the tests to have differences between the pre- and post-fatigue trials. However, there were no significant differences in the functional tests over the menstrual cycle. There were differences in fatigue in the forward hop and figure eight tests, but the affect of fatigue on performance did not differ across menstrual cycle phases.

CHAPTER 1

INTRODUCTION

Scope of the Problem

Since the beginning of athletics, about the time of the ancient Romans and Greeks, the sporting arena had been exclusively the place for males, and women were seen as objects of art and beauty. Reasoning for this exclusion was the lack of knowledge, and the misconception that the female body was far more complex and fragile than the male body. Women's monthly menstrual cycles and women's roles to protect and develop unborn children created fear that pounding repetition from running would cause damage to the female organs. It was also believed that women were too easily injured, had weaker hearts and were less able to adapt to heat (Arendt, 1994). These myths were only recently changed when female participation was allowed in the Olympic Games of 1912. Even then it was still believed that women should only participate in non-contact sports and non-endurance events. The women's marathon was added as late as 1984 (Lebrun, 1993). It was not until 1972, with the passage of the Education Amendments of Title IX, that females, both women and girls, dramatically began participating in sports. This increase in female athletes led to a paralleled increase in injuries and research of the female athlete.

Background

The female athlete, during her reproductive years, has continually changing hormone concentrations. These changes occur in every female athlete whether it is the natural endogenous variations in estrogen and progesterone, or the exogenous synthetic hormones of the oral contraceptives (Lebrun, 1993). The fluctuations of hormones cause different effects on the female body. The hormones cause small changes ranging from physical changes to minor changes in motor control and variations in blood pressure, blood volume heart rate and associated premenstrual symptoms, such as weight gain, fluid retention, and mood changes (Lebrun, 2001). Researchers have begun to examine the relationship between hormones and the risk of injury. Recently, researchers have speculated that these particular hormones and associated factors may create opposing physiological effects. Researchers have examined such physiological effects as neuromuscular coordination, manual dexterity, judgment and reaction time. It is also speculated that these opposing effects can lead to injury for the female athlete (Lebrun, 1993).

Injury patterns are similar both in male and female contact sports, with sprains and strains as the most common injuries (Arendt, 1994). However, there are more documented knee injuries occurring in females as compared to males. According to a review of the NCAA Injury Surveillance System (ISS), anterior cruciate ligament (ACL) injuries are shown to be more prevalent knee injuries in women as compared to men. The NCAA reports a knee injury rate of more than one injury for every 10 female athletes per year (NCAA, 2001-02; Toth & Cordasco, 2001). Women have a four to eight fold

increase in ACL tears as compared to their male counterparts (Liu et al. 1997; NCAA, 2001; Slaughterbeck, Liu, Knight, Finerman, Shapiro, 1995; Toth & Cordasco, 2001; Wojtys, Huston, Lindenfeld, Hewett, Greenfield, 1998). Anterior cruciate ligament (ACL) tears have recently become the main focus of many researchers for two reasons: an ACL injury is considered quite serious for an athlete and requires a longer recovery period; and ACL injuries have been increasing in female athletes. Although the incidence of ACL injuries is relatively low compared to other lower extremity injuries, its level of seriousness compared to the more common injuries is much higher (Davis & Ireland, 2001).

Given the potential relationship between the flux in hormone levels and injury in the female athlete, it is important to both examine the specifics of the menstrual cycle and the mechanisms of injury. The menstrual cycle is made up of five phases: menses, follicular, ovulatory, luteal and premenstrual. Each of these phases consists of a different concentration of estrogen, progesterone, lutenizing, and follicular stimulating hormones (Asso, 1983). Neuromuscular performance is a multifactorial term, and describes how our bodies move through space with coordination. If the muscles are not exact in their engagements, these tiny changes may be enough to cause an injury to occur. The physiological properties of skeletal muscle include irritability, contractility, viscosity, extensibility, elasticity, fatigue and stimulation. The central nervous system utilizes the impulses from the different physiological properties, interpreted into a response at the motor structure and produces an action potential at the muscle fibers (Starkey& Ryan, 1996). This then translates into three separate aspects of neuromuscular performance: proprioception, reaction time and balance. Therefore, there is a need to determine the

specific function of each hormone on neuromuscular performance, and to speculate the roles of hormones on an increase in injury in active females. The current study examined a few of the key components of the multifactorial situation of neuromuscular performance involving the active female athlete, including functional balance and fatigue.

Research Question

The research question posed for this study was as follows: *Does the menstrual cycle and its phases influence neuromuscular performance, specifically, functional balance and fatigability?* The purpose of the study was to study is to determine whether neuromuscular performance differs across phases of the menstrual cycle. It is possible that hormones are affecting basic movements and responses and therefore place women's knees in more of a compromising position for the ACL. The fundamental factors of movement examined in this study included balance and fatigability.

Hypotheses

Based on review of current research regarding the female athlete, including the menstrual cycle, the ACL, balance, and fatigability, it may be hypothesized that the menstrual cycle and its phases are affecting neuromuscular performance of the female. Specifically, it was hypothesized that neuromuscular performance is at its greatest capacity when estrogen is high and the progesterone levels are low. For the purpose of this study, the greatest neuromuscular performance was defined as a performance with an increase in speed, coordination, power and balance. The respective phase in which this is

greatest would correlate with the follicular phase of the menstrual cycle. Figure 1.1 illustrates the hypothesis that neuromuscular performance and fatigability are most enhanced during the follicular phase. The higher values in the figure represent a higher neuromuscular performance.

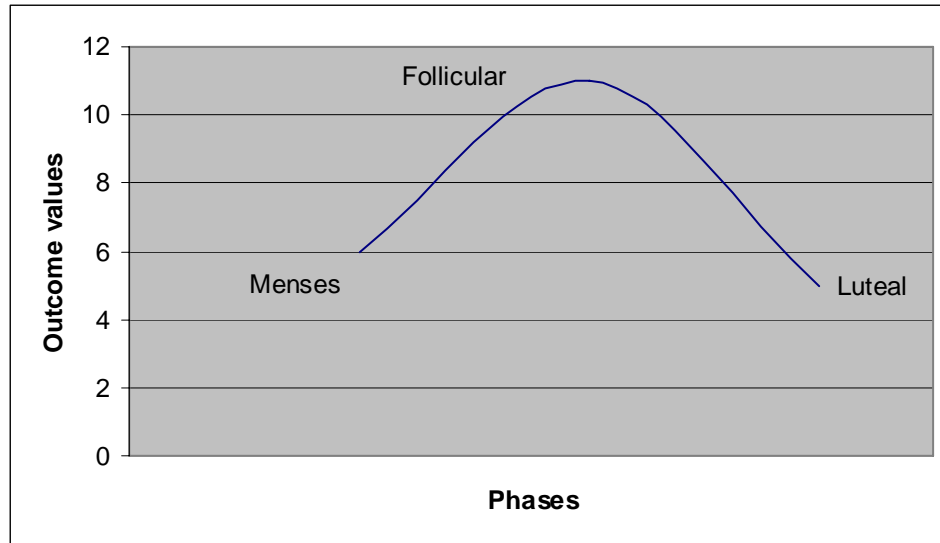


Figure 1.1 Research hypothesis revealing the outcomes for the functional tests during the different phases.

In accordance with this hypothesis is the statistical hypothesis:

$$H_0: \mu_L = \mu_H = \mu_M \text{ and } H_a: \mu_L \neq \mu_H \neq \mu_M;$$

where μ_L is when estrogen and progesterone levels are low (menstrual phase), μ_H when estrogen levels are high and progesterone levels are low (follicular phase), and μ_M is when estrogen levels are lower, but not at its lowest, and progesterone levels are high (luteal phase). The specific hormone levels throughout the menstrual cycle are illustrated in Figure 1.2. Also illustrated in Figure 1.2 are the five phases of the menstrual cycle, the days in which they occur and their corresponding hormone levels. The average days of the phases can be correlated to the hormones graphed in the figure of Table 1.1.

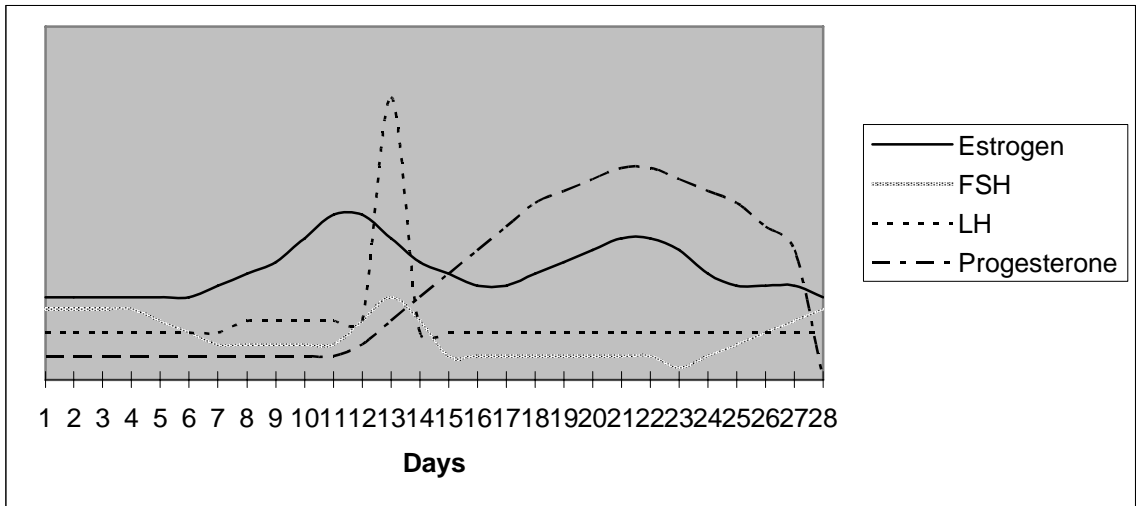


Figure 1.2 Illustrates the hormone levels during the menstrual cycle.

Table 1.1 Average days of menstrual cycle phases.

Days	1-5	6-12	13-15	16-23	24-28	Phase
						Menstrual
						Follicular
						Ovulatory
						Luteal
						Premenstrual

The statistical hypothesis is that all phases of the menstrual cycle have equal effects on neuromuscular performance. The alternative hypothesis is that the effects of the phases on neuromuscular performance are not equal and one phase has more of an effect than the other phases. This study is composed of six measurement outcome values, the dependent variables. The four series of hops are used to determine fatigability and the two variables of center of pressure data were used to measure functional balance. According to the hypothesis of neuromuscular performance being enhanced during the follicular phase, the specific hypotheses for each of the dependent variables are listed in Table 1.2.

Table 1.2. Hypothesized outcomes of performance during the follicular phase for the dependent variables.

Neuromuscular Component	Test	Units	Expected Outcome	
Fatigability (Hops)				
	Forward	(m)	Highest	
	Figure 8	(s)	Lowest	
	Lateral	(s)	Lowest	
	Up/Down	(s)	Lowest	
Functional Balance				
	Range of movement to balance	COP	(mm)	Lowest
	Time to balance	COP	(ms)	Lowest

Abbreviation: Center of pressure (COP).

Assumptions

Given this study involved human subjects and therefore a source of error, the extent of error was minimized through the experimental design. It is assumed that throughout the study all women were truthful and valid in their responses to the questionnaires. It is also assumed that the participants gave maximal efforts when they participated in the different tests of balance and fatigability.

Delimitations

The results of this study can only be applied to moderately or vigorously active females with apparently normal menstrual cycles between the ages of 18 and 30 years and who are not on oral contraceptives. The participants also met medical history criteria including no more than two ankle sprains since high school, no knee surgery, a sense of normal, equal knees, no major lower extremity bone fracture after the age of 15, no spine surgery at any age, and no balance disorders. A menstruation history was also examined and participants were excluded if they had missed a period in the last 6 months, menarched less than one year ago, had a menstrual cycle lasting outside of the range of 26-31 days or a menses range of 4-7 days. The subjects did not represent a random population pool. The subjects were limited to volunteers from Montana State University and the Gallatin County area.

Limitations

This study was limited to women who were not taking oral contraceptives and who were between the ages of 18 and 30 years. Oral contraceptives were not used in this study to ensure natural peaks in the hormonal levels; therefore the results of the study do not apply to women who are taking oral contraceptives. In order to minimize the amount of menstrual cycle variation among individuals participating in the study, the lower age limit was set at 18 years. Young adolescent females have more variation in their menstrual cycles, resulting in inconsistent estrogen and progesterone levels, as compared to the age range of 18-30 years. An upper age limit of 30 years was also set so as to

avoid inconsistency in results, due to suspected damage that estrogen can have on tissues, such as the ACL. This study was also limited to women who were participating in a moderate or vigorous exercise regimen.

Definitions

- Anterior Translation. One bone of the joint sliding forward. In regards to the knee, the ACL keeps the tibia from sliding forward with relation to the femur.
- Balance. The ability to maintain an upright position under a variety of conditions.
- Center of mass. The point in the body about which the whole mass is evenly distributed.
- Center of pressure. The point where the ground reaction force acts on the base of support. A culmination of all the small reaction forces.
- *Estrogen. A steroid hormone, which promotes the development of female secondary sex characteristics.
- Fatigue. A temporary loss of power in response to physical exertion or the continual stimulation of a sensory receptor or motor end organ.
- *Follicle Stimulating Hormone. (FSH) A gonadotropin that stimulates the growth and maturation of graafian follicles in the ovary. It is secreted by the anterior pituitary gland. High levels of estrogen suppress the release of FSH.
- *Follicular Phase. The long phase constituting the first half of the menstrual cycle; as the menstrual flow ceases, the ovarian follicle continues its development started at the end of the previous cycle and increases its production of estrogen.

- Force Platform. A multi-axis force and torque measurement tool.
- Ground Reaction Force. The force supplied by the ground to support the area of body that contacts the environment.
- Isometric. Contraction of the muscle against force without a change in muscle fiber length.
- Isokinetic. Contraction of a muscle at a constant speed/velocity, against force with the change in muscle fibers length.
- Laxity. The combination of joint hypermobility and musculotendinous flexibility.
- *Luteinizing Hormone. (LH) A glycoprotein hormone produced by the anterior pituitary gland. It stimulates the secretion of sex hormones by the ovary. Works with FSH, stimulates the growing follicle in the ovary to secrete estrogen.
- *Luteal Phase. The third phase of the menstrual cycle; the ovarian follicle ruptures and transforms into the corpus luteum, which secretes progesterone.
- *Menstrual Phase. The fourth phase of the menstrual cycle, following the luteal phase and occurring only if fertilization has not taken place. The corpus luteum regresses and is shed through menstruation and growth begins for the ovarian follicle, leading to the follicular phase of the next menstrual cycle.
- Motor Control. The ability to position the body in space.
- Neuromuscular Performance. The ability of the body to move through space with coordination, speed, balance and power.
- *Ovulatory Phase. The second phase of the menstrual cycle; during which the luteinizing hormone surge, the follicle-stimulating hormone surge, and ovulation occur. It is followed by the luteal phase.

- *Progesterone. A hormone secreted by the corpus luteum, placenta, or adrenal cortex.
- Proprioception. The awareness of posture, movement, and changes in equilibrium and the knowledge of position, weight, and resistance of objects in relation to the body.

(* Denotes definitions taken from Mosby's dictionary of medicine, nursing & health professions, 7th edition)

Abbreviations

- NCAA. National Collegiate Athletic Association.
- ACL. Anterior Cruciate Ligament
- ISS. Injury Surveillance System
- PAR-Q. Physical Activity Readiness Questionnaire

CHAPTER TWO

LITERATURE REVIEW

Introduction

With the growing participation of women in athletics, beginning at an early age and into the professional level, researchers have documented an increase in knee injuries among women in sports. The National Collegiate Athletic Association (NCAA) reports a knee injury rate of more than one injury for every 10 female athletes per year (Toth & Cordasco, 2001). Among this incidence of injury, anterior cruciate ligament (ACL) tears are the most common and debilitating injury. The ACL is the primary ligament in the knee with the function of resisting anterior translation and tibial rotation (Starkey, 1996).

Female athletes have a two-to eight-fold higher incidence of ACL injury than male athletes. The majority of ACL injuries in female athletes occur through noncontact mechanisms, most often during the landing of a jump or a cutting maneuver (Toth & Cordasco, 2001). There are many factors that have been studied to explain such an incidence difference between the sexes. These include both intrinsic and extrinsic factors. Intrinsic factors include: ligament size, inherent ligament laxity, collagen tissue, notch dimensions, limb alignment and hormonal factors. Extrinsic factors are composed of the level of skill, level of experience, technique, muscular strength, coordination, the shoe/floor interface, and environmental conditions (Arendt, 1994; Toth & Cordasco, 2001).

The incidence of injuries in female athletes has been examined in many sports. Looking at specific sports, women soccer players are two times more likely to have an ACL injury, and three times more likely through non-contact mechanisms as shown in a study by Arendt, Agel, and Randall (1999). This study also examined basketball for any sex differences related to ACL injuries. In examining female basketball players, it was found that women have an injury rate four times as great as their male counterparts. The basketball statistics are comparable to the NCAA findings based on the Injury Surveillance System (ISS). A 1998-1999 report indicated that the ACL injury rate for women's basketball is seven times higher compared to the men. This report also showed women's gymnastics injury rates are slightly lower (NCAA, 2001).

Mechanism

Due to the prevalence of injuries in females in both contact and non-contact sports, it is necessary to determine the mechanism of action in both scenarios. The ACL is most vulnerable when the tibia is externally rotated and the knee is only slightly flexed, with injury occurring through two main mechanisms: contact and non-contact. The research based upon a contact mechanism for injury focuses on bracing. However, in regards to an injury occurring through non-contact mechanisms, many studies have further analyzed the causative factors with regard to non-contact ACL injuries. The ISS from the NCAA, among other studies (Arendt, 1994; Toth & Cordasco, 2001), reported that 75 percent of ACL injuries are non-contact in competitive jumping or pivoting sports, and the exact mechanism is not known. In studies by Arendt et al. (1999) and Toth and Cordasco (2001), the increased risk was thought to be multifactorial, a

combination of structural, anatomical, and biomechanical factors, rather than one factor solely responsible for the increased rate. Toth and Cordasco (2001) and Arendt (1994) have postulated that some intrinsic and extrinsic factors could increase prevalence of ACL injuries in women. These sex-specific factors are supported by evidence of a lower gender bias in ACL injuries in gymnastics. Gymnastics is a sport that necessitates a strong core and involves a high level of neuromuscular control and balance where men and women are very similar in strength and coordination. Thus, the injury rate is more similar between sexes in this sport possibly because of the more similar sex-specific factors.

Anatomy

One of the intrinsic factors for an increased injury rate in females is anatomy, which encompass many of the intrinsic factors. There are many gender differences in anatomy. Some of these differences include pelvis structure, lower extremity alignment, joint laxity, muscle development, ACL size, and intercondylar notch shape and width. In looking at pelvis structure and lower limb alignment, women usually have wider pelves and a larger hip angle. The hip angle can be defined as the Q angle, or tibiofemoral angle, which describes the relationship between the lines of pull of the muscles from the hip to the knee (Starkey & Ryan 1996). With an increased Q angle, there is an increase of the forces placed on the knee. The increased Q angle typical in women also increases likelihood of hip varus and femoral anteversion, which causes pigeon-toes at the feet and knee valgus (knocked-knees). It is theorized that this increase in Q angle could increase the tilt of the pelvis and therefore allow for hyperextension of the knee when landing

from a jump or in pivoting maneuvers (Toth & Cordasco 2001). Support of this theory is acknowledged in a study by Meister et al. (1999), in which a larger Q angle leads to an increased risk for ACL injuries.

Another dimension of women's ACL injury risk is the intercondylar notch. The intercondylar notch is a deep groove that separates the medial and lateral femoral condyles, and also is the groove through which the ACL passes. Since the ACL passes through the notch, the width and shape of the notch affects the contact sites of the ACL. In an A-shaped notch, the ACL is more likely to be injured when the knee is in flexion due to increased contact with the medial femoral condyle. With the intercondyle notch being a factor in the injury rate, it is reasonable to predict that the size of the ligament is also a factor, although this has not yet been confirmed through research (Toth & Cordasco, 2001).

The increased injury rate could also be due to the laxity of the ACL within the knee joint. This includes both the joint hypermobility and musculotendinous flexibility. Women have been shown to have a greater amount of laxity as compared to men as noted in Toth and Cordasco (2001). Many researchers (Karageanes, Blackcurn & Vangelos, 2000; Toth & Cordasco, 2001) have studied the effects of the menstrual cycle on the ACL, specifically looking at the laxity of the ligament in isolation, but much is still unknown. Karageanes et al. (2000) reported that the adolescent female athlete menstrual cycle phases did not have an effect on laxity.

Endocrine Influences on Injury Susceptibility

The phase lengths of the menstrual cycle changes in women during their reproductive years, and are variant from month to month especially during adolescence. The levels of four different hormones continuously cycle, thereby creating the menstrual cycle. These four hormones include estrogen, progesterone, follicle stimulating hormone (FSH) and luteinizing hormone (LH). The menstrual cycle is made up of five different phases, the menstrual phase (days 1-5), follicular phase (days 6-10), ovulatory phase (days 13-15), the luteal phase (days 16-23) and the premenstrual phase (days 24-28) (Asso, 1983). The menstrual cycle has three phases that are significantly different from each other in regards to the levels of two specific hormones and the duration in which the female spends in the phases. The three significant phases include the menstrual, follicular and luteal phases. The ovulatory and premenstrual phases can be considered transition days into the previously stated three phases. In the first phase, menstruation, both estrogen and progesterone are low. During the follicular phase, estrogen becomes elevated and peaks just prior to ovulation, while progesterone remains low. This leads into the ovulatory phase, when there is a peak in both the luteinizing hormone and follicular stimulating hormones (FSH). At this time the level of progesterone begins to elevate and the increase in estrogen begins to fall from its peak. In the luteal phase, both estrogen and progesterone are elevated, but estrogen is not as elevated as it was during its peak in the follicular phase. Finally in the premenstrual phase all of the hormones begin to return to the low levels for the menstrual phase, except FSH, which increases slightly

for the menstrual phase (Asso, 1983; Gersh & Gersh, 1981; Janse de Jonge Boot, Thom, Ruell & Thompson, 2001).

Fibroblasts

Several researchers (Charlton, Coslett-Charlton & Ciccotti, 1999; Gersh & Gersh, 1981; Janse de Jonge et al., 2001; Toth & Cordasco, 2001) report that reproductive hormones affect the laxity of the ACL, among other ligaments, and also decrease neuromuscular performance, including static and dynamic balance. Specifically, fluctuations in hormone levels have been considered to directly affect the ACL because progesterone and estrogen receptors have been located in the ACL tissue (Liu, Al-Shaikh, Panossian, Finerman & Lane, 1997; Rau et al., 2003; Toth & Cordasco, 2001). These receptors in the ACL affect fibroblast metabolism (Lee et al., 2004; Liu et al., 1997; Wahl, Blandau, & Page, 1977). In affecting the fibroblast metabolism, the ACL structure, composition and mechanical properties are influenced. Researchers have experimentally determined that estrogen decreases fibroblast proliferation and the rate of collagen synthesis, and also has an effect on the growth and development of bone, muscle and connective tissue (Lee et al. 2004; Lee, Smith, Zhang, Hsu, Wang, Luo, 2004; Liu et al. 1997; Rau et al. 2003 and Toth & Cordasco, 2001). Fibroblasts produce collagen, which is the major load-bearing component of the ACL. In a study by Liu et al. (1997), it was found that estrogen not only affected the collagen, but had a significant dose-dependent effect on the fibroblasts of the ACL. Therefore, this decrease in fibroblast proliferation and altered rate of collagen synthesis may be another factor predisposing female athletes to ACL injuries.

Muscle Strength and Fatigue

It is quite evident that muscle performance and mass are considerably different between sexes; however there is no obvious difference present in young children. The differences in muscle performance and mass among males and females are attributed to the specific sex hormones (Davis, Elford, & Jamieson, 1991; Maughan, Harmon, Leiper, Sale, & Delman, 1986). Although it is apparent that sex hormones are causing the physiological differences between sexes, the question researchers are trying to answer is whether one hormone is causing these differences in sizeable amounts, thus causing the dissimilarity in the injury rates between sexes. Researchers are attempting to determine whether females are more vulnerable to injuries due to estrogen levels or if testosterone levels protect males more than females from injuries.

Many researchers have tried to find strength differences in the menstrual phase; however the findings have been equivocal. An enhanced fat metabolism, oxidative stress, muscle mass and contractility are all components of muscle fatigue that are hypothesized to be influenced by estrogen. In a study by Sarwar, Niclos, and Rutherford (1996), quadriceps and handgrip strength were measured over the menstrual cycle phases. These researchers found an increase of 11% in strength during the ovulatory phase as compared to the other phases. Reis, Frick, and Schmidtbleicher (1995) strength trained females according to their menstrual cycle and found that when the athletes weight trained every second day during the follicular phase and once a week during the luteal phase, there were higher strength adaptations as compared to a strengthening program that did not take into account menstrual cycles.

In contrast, other studies (Friden, Hirschberg, & Saartok, 2003; Janse de Jonge et al., 2001; Lebrun & Rumball, 2001; Gur, 1997) have shown there to be no significant differences between the phases in regards to strength. One study performed by Janse de Jonge and colleagues (2001), concluded no change over the menstrual cycle in measuring the maximal isometric quadriceps strength, isokinetic knee flexion and extension, and handgrip strength. This same study also showed there to be no significant difference in fatigue throughout the menstrual cycle.

Research on fatigue has revealed many differences between males and females, and sex hormones are considered to be one of the major influences (Hicks, Kent-Braun & Ditor, 2001; Tiidus et al, 1999; Hatae, 2001; Hakkinen, 1993). These differences may be attributed to estrogen and its effects on metabolism. Estrogen and progesterone have been associated with a variation in blood pressure, blood volume, heart rate, vascular tone, and promoting glycogen uptake. Estrogen contributes to the increase of lipid synthesis, greater protein catabolism, and anabolic effects (Lebrun & Rumball, 2001; Reis et al., 1995). When researching the influences of the sex hormones, there are two main approaches, either studying the affects across the menstrual cycle phases or during a more comparable hormonal period between males and females such as during adolescence and post-menopause. Therefore, to study the effects of estrogen, post-menopausal women were tested with men in studies conducted by the previously mentioned researchers. Again however, when isolating the phases of the menstrual cycle, current research was inconclusive and produced contradicting results. In a study by Cheng, Ditor and Hicks (2003), no sex difference was present in time to fatigue, pattern of fatigue, or recovery in a group of older males and post-menopausal women. However,

the quadriceps muscle was found to be more fatigable during the follicular phase and least fatigable during the luteal phase as seen by Sarwar et al. (1996).

Neuromuscular Performance

One of the aspects which has not been researched, as it pertains to female athletes and their increased risk of ACL injuries, is neuromuscular performance. Neuromuscular performance is a multifactorial term, referring to how our bodies move through space with coordination. The skeletal muscles provide the means through which our bodies are able to perform movements and in the athletic situation the movements must be very precise for cutting, jumping, and pivoting. If the muscles are not exact in their engagements, these minor changes may be enough for an injury to occur. The physiological properties, which make up the skeletal muscle, include irritability, contractility, viscosity, extensibility, elasticity, fatigue, and stimulation. Impulses from all of these different aspects are interpreted at various levels within the central nervous system. Once the impulse is received and interpreted, a response is transmitted to the appropriate motor structure, then producing an action potential for the muscle fibers to respond (Houglum, 2001). Neuromuscular performance is then influenced by three separate aspects: proprioception, reaction time, and balance.

Reaction time and coordinated movements are essential components of neuromuscular performance and therefore are important influences in injury mechanisms. Although it has been examined in research, mostly in the older population and with stroke patients (Berg, Wood-Dauphinee & Williams, 1995; Carter, Khan, Mallinson,

Janssen, Heinonen, Petit, & McKay, 2002; Duncan, Weiner, Chandler & Studenski, 1990), little research is present regarding the female athlete. It has been noted that estrogen affects neuromuscular performance. One study by Jennings, Janowsky, and Orwoll (1998) specifically looked at reaction time and reported that higher levels of estradiol were related to faster reaction times in women. Jennings et al. (1998) reported that progesterone increased fatigue and decreased performance on cognitive tasks and that estrogen may affect complex sequential movements, but not simple, single-response movements. Given such findings, high levels of estrogen and low levels of progesterone should be related to an increase in neuromuscular performance and perhaps resulting in a decrease in injury. This specific composition of hormones is correlated to the follicular phase of the menstrual cycle. This theory is supported through the results of Hampson (1990) who found that an increase in motor speed, coordination and speech articulation occurred during this phase of the menstrual cycle.

Balance is another key component in neuromuscular performance; however there is little research on functional balance, especially in terms of the female athlete. The effects of estrogen on postural balance were studied by Ekblad, Lonnberg, Berg, Odkvist, Ledin, and Hammar (2000). They found no significant difference in balance with estrogen replacement in postmenopausal women. These results were also supported in a study done by Carter et al. (2002). However, two other studies (Hammer, Lindgren, Berg, Moller, & Niklasson, 1996; Naessen, Lindmark, & Larson 1997) concluded that there was a significant increase in balance with estrogen replacement. Numerous other studies (Armstrong, Osborne, Coupland, Macpherson, Basse & Wallace, 1996; Podsiadlo & Richardson, 1991; Hammer et al., 1996; Hill, Bernhardt, McGann, Maltese &

Berkovits, 1996) have researched balance, but not necessarily pertaining to estrogen or the female athlete, but have developed reliable static balance tests. Thus, there is a gap in research pertaining to the female athlete, hormone fluctuations, and neuromuscular performance. The development of a reliable functional balance test is needed.

Conclusion

With the increased number of women in sports, there has also been an increase in the ACL injury rate among women as compared to their male counterparts. Researchers have still not determined the reason why women are more susceptible to this specific injury. As the research narrows, it has been determined that there is not just one specific factor, but a multifactorial situation. Estrogen may be a significant factor, but estrogen affects so many different aspects of the body and finding a precise mechanism is difficult. With respect to neuromuscular performance, the combined effects of estrogen and progesterone may cause the knee to be placed in a compromising position, so as to rely further on the ACL in stabilizing the knee.

As a result of the majority of research being done on balance with the older population and stroke patients, a functional dynamic balance test does not exist for a specific measurement in the athletic population. The authors of a recent study (Hertel, Williams, Olmsted-Kramer, Leidy, & Putukian 2006) examined neuromuscular control and knee laxity in female athletes in three different phases of the menstrual cycle, and determined that there were no significant differences between the follicular, ovulatory and luteal phases. The researchers examined neuromuscular performance through knee flexion and extension peak torque, positional sense, laxity and postural control in a single

leg stance. Even though no significant differences were found in this study, a functional dynamic balance test was not utilized. With neuromuscular performance as the key foundation to any athlete, this is an essential aspect of the multifactorial study of the female and the increased rate of ACL injuries. It is therefore important to look at other aspects of neuromuscular performance including functional balance, fatigue, and how they correlate to the menstrual cycle. These answers are key components of the multifactorial situation involving the female athlete and ACL injuries.

The purpose of the study was to focus more on the basic, fundamental factors of movement relative to the menstrual cycle. In review of the current research, it is possible that hormones are affecting basic movements and responses and therefore placing women's knees in more of a compromising position for the ACL. The current study examined a few of the key components of the multifactorial situation involving the active female athlete, including fatigue and functional balance. It was hypothesized that the menstrual cycle and its phases are affecting neuromuscular performance of the active female. Specifically, it was hypothesized that neuromuscular performance is at its greatest capacity when estrogen is high and the progesterone levels are low. The respective phase would correlate with the follicular phase of the menstrual cycle. The dependent variables of the study are composed of six measurement outcome values. Two of these are used to measure functional balance and four series of hops are used to determine fatigability. With answers to these components of neuromuscular performance, the affects of the menstrual cycle on active females in their injury rates may be better determined.

CHAPTER THREE

METHODOLOGY

Subjects

Twenty-seven healthy, active females volunteered for this study. Volunteers were recruited by flyers distributed around the Montana State University (MSU) campus and Bozeman area. In order to ensure confidentiality, each participant was assigned an identification number and that number was used throughout the study for all data collection. Inclusion requirements for this study included women between the ages of 18 and 30; a menarche more than one year previous; normal menstrual cycle lengths lasting 26 to 31 days; a length of menses between four and seven days; and no use of contraceptive pills or hormone replacement therapy over the past three months. An irregular cycle was defined as a self-reported cycle length with a variation greater than three days. Exclusions were made for ACL injuries or greater than second degree knee and ankle injuries. This study was approved by the Internal Review Board and followed all other procedures recommended by the IRB as instructed, including a signed informed consent form.

Research Design

This study used a repeated measures experimental design; therefore, each participant served as her own control and no separate control group was used. Each participant performed the same protocol in each of the three phases. To prevent an order

effect, an even distribution of females began the protocol in each of the different phases. All of the participants were brought in for a general meeting, in which the study and what was expected of them as participants was described. At this time, informed consent (Appendix A), and a questionnaire including activity levels (Appendix B), health history (Appendix C), and PAR-Q (Appendix D), were filled out. The participants then went through a familiarization period, where they were able to perform all of the tests. Once the participant felt comfortable with the tests, the first meeting time was determined. Upon arrival to the Movement Science Lab (MSL), the participants had their blood drawn and began the neuromuscular performance tests. The testing days were determined on the phases of the menstrual cycle and the presence of ovulation. The participants were tested in the menstrual phase during days 2-4, and then 4-6 days post the end of the menstrual phase for measurement of the follicular phase. Finally, the luteal phase testing occurred 4-6 days post ovulation.

The participants were asked not to do anything out of the ordinary from their average day on the test days. They were also asked to abstain from alcohol and tobacco products within 24 hours of testing. Caffeine intake was to remain consistent with that of their ordinary day, and they were not to eat within two hours of reporting to the lab.

Blood Collection and Analysis

The participants reported to the MSL on the scheduled day and time. All times of the day were consistent for each subject throughout the study, to eliminate any hormone fluctuations dependent upon the time of day. A blood sample was drawn to determine serum estrogen and progesterone levels, with the purpose of confirming that the

estimations of the phases were correct. Upon arrival, the participant sat for ten minutes prior to a standard venipuncture, collected in vacuum tube without additive, clot, centrifuged and stored at negative 80 degrees until analysis. The samples were then sent to Penn State University for radioimmunoassay analysis.

Determination of Menstrual Cycle Phases

In order to determine the luteal phase, an ovulation kit was provided to the participants. Participants were asked to call the researcher when they were ovulating. Upon ovulation, a time was scheduled 4-6 days post ovulation. With the use of the ovulating kit, the luteal phase was determined more accurately, and hormone levels verified through ovulation. If ovulation did not occur during that cycle, then the luteal phase hormones would not be at the desired levels. Ovulation occurs when there is a spike in the luteinizing hormone. The luteinizing hormone secretion is regulated by estrogen, and a short luteal phase is accompanied with a decrease in luteal hormone, follicular stimulating hormone, progesterone and estrogen levels (Asso, 1983; Gersh & Gersh, 1981; Janse de Jonge et al. 2001). If the luteinizing hormone spike does not occur, ovulation will not occur and therefore the hormone levels will be different for that of ovulating and non-ovulating females.

The other phases being measured included the menstrual and follicular phases. The menstrual phase was determined by the presence of the female's period, and the testing date was scheduled once during days 2-4 of the period. The follicular phase was determined by the menstrual phase and participants were scheduled 4-6 days post the end of the female's period. The luteal phase testing was scheduled 4-6 days post ovulation.

These specific days for testing were determined by the research team prior to the onset of the study, through examination of a typical menstrual cycle and the fluctuations of estrogen and progesterone.

Ovulation Detection

All participants were given ovulation kits and instructed in their use. The ovulation kit provided a means of measuring the ovulatory period through which the phases of the menstrual cycle could be determined. This is an important aspect of the study to make sure that specific hormone levels correlated to the determined phase for each participant. The ovulation kits that were used were midstream tests (Early Pregnancy Test) and Ovulite ovulation microscopes (Dynamic Health LLC, Florida).

Dependent Variables

Functional Hop Tests

The design of the functional hop test was partially taken from the protocol developed by Mike Hahn, Assistant Professor at Montana State University and graduate student, Tyler Brown. The protocol consisted of the participants performing a pre-fatigue functional test, fatigue protocol, and post-fatigue functional test. The functional test protocol consisted of two trials of four single-legged hop drills. These functional tests assess the functional performance of the knee joint. The functional test includes three consecutive forward hops, figure eight hops, up/down hops and lateral hops. The dependent variables from this testing included: total distance covered, time taken to complete two consecutive cycles, time taken to complete 20 repetitions up on to and

down off a 20 cm box, and the time taken to complete ten lateral repetitions over a 30 cm gap.

Fatigability

The functional hop tests were performed both pre and post-fatigue. The participants performed the functional hop tests series after a five minute warm up and refamiliarization of the functional hop tests. Then a bicycle ergometer test was utilized to fatigue the leg muscles for a post-fatigue hop test performance. Prior to measurement of the post-fatigue functional test, the participants completed a timed sprint on a stationary bike. The sprint was performed at a resistance of 5.0 kp and the participants were asked to perform 10 repetitions as quickly as possible. Thirty percent of this time was then calculated to be a minimum time achieved post the fatigue protocol. The fatigue protocol consisted of a series of resistances and times over five minutes and 45 seconds (Table 3.1). Upon completion of this, the participants were allowed 30 seconds of 2.5kp resistance and then asked to complete 10 repetitions as quickly as possible at the resistance of 5.0kp. If the minimum fatigue time was not achieved the participants were then asked to repeat another set series of three resistances on the stationary bike. The participants were then allowed water and rest for one minute before beginning the series of functional tests.

Functional Balance and Center of Pressure

This test was performed with a BOSU balance trainer and force platform to determine functional balance in the active female among the menstrual cycle phases both pre and post-fatigue. A BOSU balance trainer is a half ball connected to a hard landing surface. See Figure 3.1 for an illustration. The ball side was placed on the force

platform, and the participants jumped onto the side of the hard surface. The participant was asked to jump onto the BOSU balance trainer when directed by a verbal cue. Tape was placed on the BOSU as a target jump spot to decrease variance in landing areas between participants. Upon the verbal cue, the force platform began collecting data used to calculate the center of pressure. The test concluded when the participant was able to stay in a balanced position for approximately 2 seconds. The participants then removed themselves from the BOSU and repeated this test for ten repetitions.

Table 3.1. The fatigue protocol of resistances and intervals.

	Resistance (kp)	Duration (seconds)	Running Time (min)
Sprint Timed Test	5.0		
Fatigue Protocol	2.5	60	1
	3.0	60	2
	3.5	30	2.5
	3.0	30	3
	3.5	30	3.5
	4.5	15	3.75
	4.0	30	4.25
	5.0	15	4.5
	4.5	30	5
	5.0	15	5.25
	4.5	30	5.75
	2.5	30	6.25
Sprint Timed Test	5.0		
Repeat Series	4.5	30	.5
	5.0	15	.75
	4.5	30	1.25



Figure 3.1. Illustration of the Functional Balance Test.

The data collected from this test included the center of pressure along with the time (milliseconds) and distance (millimeters) it took to get to a common zone of the center of mass, which was defined as the balance point. The center of pressure is defined as all of the forces between the foot and the surface, summed up into one torque vector and a ground reaction force vector. The force platform in combination with the BOSU, allowed for the measurement of the range in which an individual moves from the COP in order to reach a balance point. The primary investigator then used the data from the recording system to determine the range of this zone in millimeters from beginning to end, in addition to the amount of time it also took to reach this same point.

Instrumentation

Force Platform

The force platform (AMTI, Watertown, MA) was used to measure changes in COP after landing on the BOSU board. The data was collected with the use of the force plate recording system. The dependent variables from this testing included: ground reaction force, center of pressure, center of mass, total distance covered and time to

complete balance. The force platform collected measurements at 1000 Hz using the Vicon Workstation (V.4.6, Vicon, Lake Forest, CA).

BOSU Balance Trainer

The BOSU (DW Fitness LLC, Madison, NJ) is a training device to improve balance, and proprioception. In the study it was used as a means of creating an unstable landing area.

Stationary Bicycle

The stationary bicycle used in the current study was a Monark Ergonomic 828E cycle ergometer (Monark Exercise AB, Sweden). The bicycle functioned as a means of a muscle warm up exercise prior to the functional hop tests and had set resistances for the fatigability test.

Data Analysis

Balance Determination.

The analysis that was utilized in order to determine the balance point and therefore, the time to balance was based on preliminary data collection. The center of pressure (COP) data were extracted from a Vicon output file and analyzed in an Excel spreadsheet. In the spreadsheet, the range of movement of the COP upon landing on the BOSU was plotted X (lateral) versus Y (anterior posterior) and X/Y versus time. From these graphs, the balance point could be determined. On the X/Y versus time graph, X and Y were subjectively, visually determined to level off when the graphs leveled off. This balance point was then compared with the X versus Y data in the spreadsheet to

verify a true balance point when there was not more than a ten millimeter difference within five frames (milliseconds). An example of this X/Y versus time graph can be seen in Figure 3.2. The frame (milliseconds) determined to be the balance point was then used to calculate the distance to balance (millimeters). The difference between the maximum and minimum values within the determined frames was calculated to determine the distance covered from the COP until the balance point was reached. This balance point was determined for each of the ten trials and then an average for each phase pre and post-fatigue was computed. These averages were used for the data analysis.

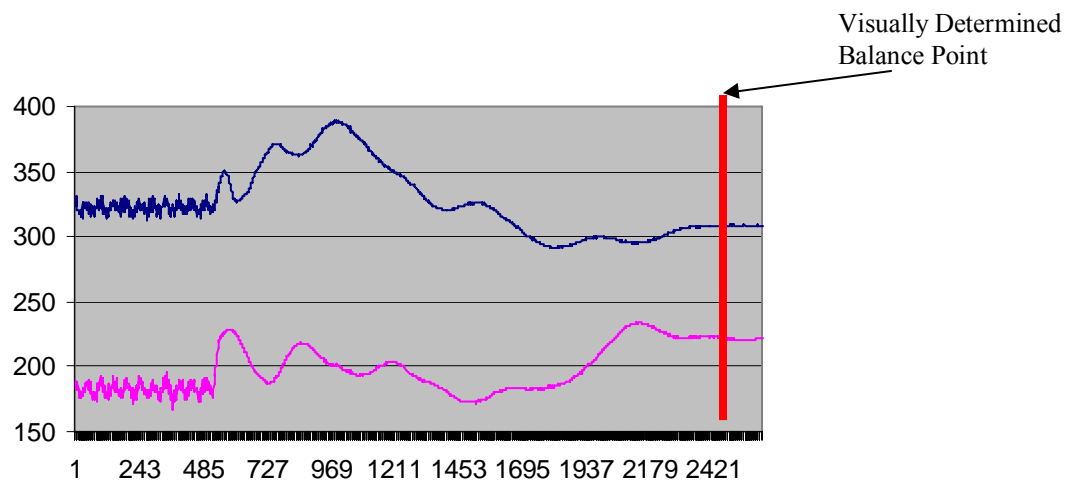


Figure 3.2. The graph is an example for determination of the balance point in each trial.

Statistical Analysis

All data except the hormone levels were analyzed through a general linear model, two-level repeated measures ANOVA. Using SPSS, the main effects of the menstrual cycle phase and pre versus post-fatigue were measured.

A one-sample Kolmogorov-Smirnov Test was utilized to determine the normal distribution of all variables. In the cases where a Mauchly's Test of Sphericity

assumption was violated, the adjustments were made and the Greenhouse-Geisser value was utilized to determine significance. The significance level for this study was set at $\alpha = 0.05$.

CHAPTER FOUR

RESULTS

Participant Characteristics

Twenty-seven healthy, college-age, female participants were enrolled in this investigation. Twelve of the participants did not complete the three phases of testing for various reasons. Five of the twelve had an irregular cycle during testing, including anovulation or an abnormally short luteal phase. Two started birth control during the course of the study, three dropped out, and finally, two were injured outside of the study. These factors contributed to a slight imbalance in the starting phase distribution. Six participants started in the menstrual phase, five in the follicular phase and four in the luteal phase. An even distribution was desired to avoid the confounding influence of a potential order effect. The characteristics of the participants who completed the investigation are detailed in Table 4.1. All fifteen participants reported moderate or vigorous habitual physical activity levels. Activity levels were determined through a questionnaire on duration, frequency, and exercise type (Appendix B). Participants reported compliance regarding the inclusion and exclusion criteria of the study. The inclusion criteria included women between the ages of 18 and 30; a menarche more than one year previous; normal menstrual cycle lengths lasting 26 to 31 days; a length of menses between four and seven days; and no use of contraceptive pills or hormone replacement therapy over the past three months. An irregular cycle was defined as a cycle length with a variation greater than three days. Exclusions were determined

through the responses on a medical history questionnaire. Potential volunteers were excluded from the study if they had more than two ankle sprains since the start of high school, knee surgery, a sense of abnormal or unequal knees, a major lower extremity bone fracture after the age of 15, spine surgery at any age, and any neuromuscular disorder or balance disorder.

Table 4.1. Participant characteristics

	Units	N	Mean	Standard Deviation	Minimum	Maximum
Height	m	15	1.7	9.1	1.5	1.8
Weight	kg	15	67.6	16.0	43.1	108.9
BMI	kg·m ⁻²	15	23.1	3.5	19.1	32.5
Age	yrs	15	22.7	3.2	18	30

Measurement Consistency

There was a moderate to high level of intra-subject consistency for most, but not all variables. The results for each of the functional tests are plotted with the menstrual cycle phases for one of the participants in Figure 4.1. The correlation coefficients were measured by the Pearson correlation for pre and post-fatigue in each of the menstrual cycle phase and given in Table 4.2. The correlation coefficient for the center of pressure measured in millimeters is indicative of a strong relationship. The center of pressure variable measured in milliseconds and sprint time had the least association between the pre and post-fatigue tests.

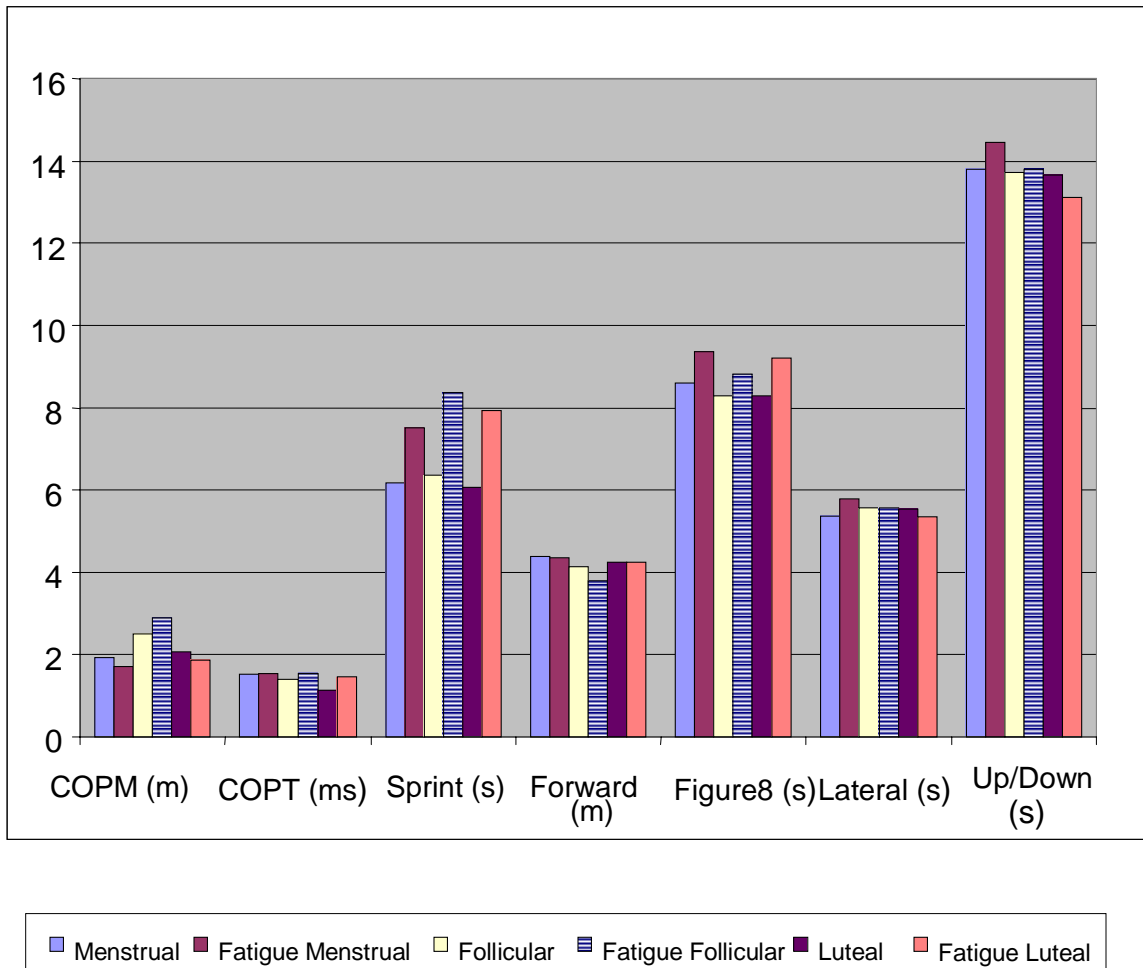


Figure 4.1 Results of the functional tests in each of the three phases for one participant. Abbreviations: Center of pressure-magnitude (COPM), Center of pressure-time (COPT), Meters (m), Milliseconds (ms), Seconds (s).

Table 4.2 Reliability results of the dependent variables.

Variable	Correlation Coefficient	Significance Level
COP(mm)	0.997	0.000
COP(sec)	0.003	0.993
Sprint	0.253	0.384
Forward Hop	0.593	0.026
Figure Eight	0.701	0.005
Lateral Hop	0.631	0.016
Up/Down	0.598	0.024

Hormone Serum Levels

The follicular phase is defined as the presence of high levels of estrogen accompanied with low levels of progesterone. The luteal phase is defined as high levels of progesterone and a moderately high level of estrogen. In the current study, the analysis of serum estrogen and progesterone were measured to validate the phase and correct hormone levels in each phase that the participant was tested. The levels of serum estrogen were found to be significantly different, however they did not fit the reported literature estrogen levels of the different phases. The serum progesterone levels on the other hand were not significantly different, and although slightly higher, followed the reported trend of the menstrual cycle phases. The blood analysis revealed a mean of 105 pg/ml during the luteal phase and 63 pg/ml during the follicular phase. These levels are within the normal ranges of the luteal and follicular phases, where the serum levels range respectively 30-90 pg/ml and 70-300 pg/ml.

Fatigability

The purpose of this protocol was to determine the differences between functional ability hop tests both before and after acute muscular fatigue. If there were differences between the pre- and post-fatigue functional ability hop tests, then fatigue as a component of neuromuscular performance may be affected by the changes of the menstrual cycle. The protocol began with a set five minute warm-up and then a timed sprint on a stationary bike. Following the timed sprint, the pre-fatigue functional tests were performed. During the fatigue protocol, the same timed sprint was again performed and a

30% increase of this time was required to be a minimum time achieved post the fatigue protocol. The fatigue protocol consisted of a series of resistances and times over five minutes and 45 seconds. Increases in sprint time pre- to post-fatigue are given in Table 4.3. There were no differences in fatigability among the phases ($p = 0.289$) or the effect of fatigue on the phases ($p = 0.495$). There were significant differences between the pre-fatigue and post-fatigue trials ($p = .001$) in which fatigue occurred the targeted muscle group. The increase in time to complete the sprint did not differ across the menstrual cycle phases.

Table 4.3 Stationary bike fatigue test for pre- and post-fatigue trials for the three phases of the menstrual cycle.

Test	Phase	Units	N	Pre-fatigue		Post-fatigue	
				Mean	± SD	Mean	± SD
Fatigue	Menstrual	s	15	6.58	± 1.84	8.73	± 2.87
	Follicular		15	6.09	± 0.91	8.54	± 1.33
	Luteal		15	5.89	± 0.77	8.04	± 1.23

The values are the means ± the standard deviation. Abbreviations: Standard deviation (SD), seconds (s).

Neuromuscular Performance

The tests utilized to measure specific components of neuromuscular performance before and after fatigue exercises included functional balance and functional ability hop tests. The functional test protocol consisted of two trials of four single-legged hop drills. The functional test includes three consecutive forward hops, figure eight hops, up/down hops and lateral hops. The dependent variables from this testing included: total distance covered, time taken to complete two consecutive cycles, time taken to complete 20 repetitions up on to and down off a 20 cm box, and the time taken to complete ten lateral

repetitions over a 30 cm gap. The functional balance test consisted of two COP measurements, time to balance in milliseconds (COPT) and balance magnitude in millimeters (COPM). This functional balance test assesses the ability of the lower extremity joints to recover from an uneven landing following a jump.

Functional Hop Tests

No significant differences were detected between the menstrual phases for the functional ability tests as shown through a repeated measures analysis of variance. Additionally, there were no significant differences in the pre- and post-fatigue trials for three of the four functional tests.

The distances presented in Table 4.4, depict the mean distance covered for the forward hop test in all phases pre and post-fatigue. The forward hop test times did not differ among menstrual cycle phases ($p = 0.454$) or for the interaction between phases and the fatigue trials ($p = 0.191$). This test did differ between pre-fatigue and post-fatigue trials ($p = 0.011$). The mean distances for both pre- and post-fatigue trials are plotted in Figure 4.2.

Table 4.4. Mean distance completed during the forward hop test both pre and post fatigue for the three phases of the menstrual cycle.

Test	Phase	Units	N	Pre-fatigue		Post-fatigue *	
Forward Hop	Menstrual	in	15	189.4	± 19.6	185.3	± 22.8
	Follicular		15	193.5	±19.6	184.0	± 23.6
	Luteal		15	189.6	± 19.8	180.2	± 23.8

The values are the means ± the standard deviation. Abbreviations: Standard deviation (SD), inches (in). * $P < 0.05$ compared to pre-fatigue.

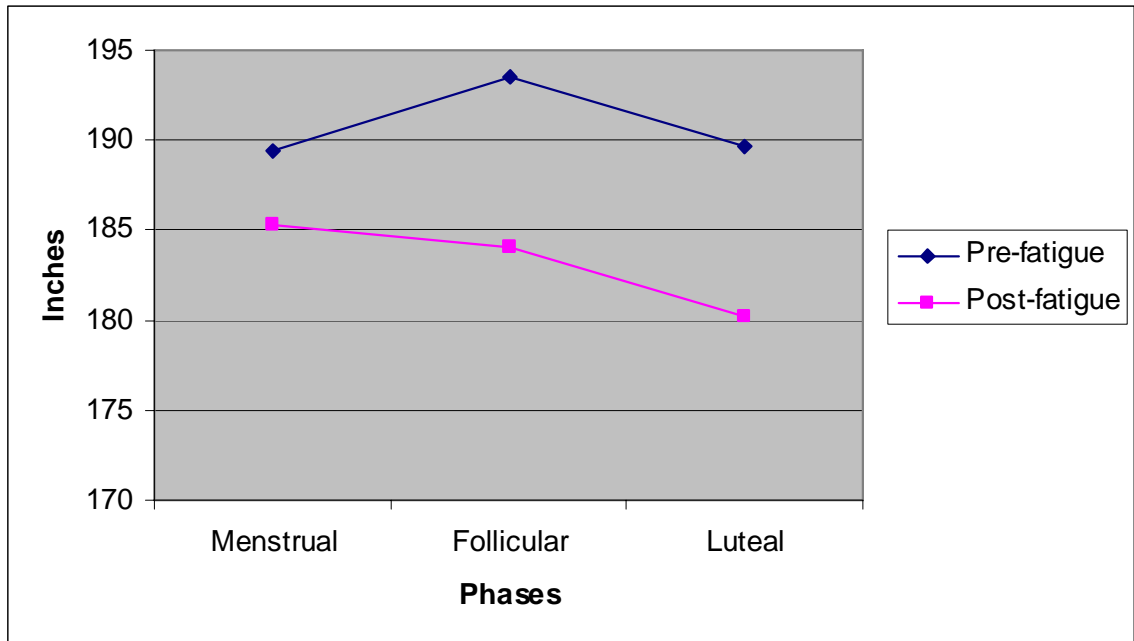


Figure 4.2. Mean distance completed during the forward hop test plotted both pre- and post-fatigue across the three phases of the menstrual cycle.

The figure-eight test did not differ among phases ($p = 0.953$), or the interaction between phases and the fatigue trials ($p = 0.373$), but did differ between the pre and post-fatigue trials ($p = 0.015$). The means of the figure-eight test across the phases are depicted in Table 4.5.

Table 4.5. Mean values of the time taken to complete the figure-eight hop test over the menstrual cycles, both pre and post-fatigue.

Test	Phase	Units	N	Pre-fatigue		Post-fatigue*	
				Mean \pm SD		Mean \pm SD	
Figure 8	Menstrual	s	15	9.05	± 1.32	9.47	± 1.76
	Follicular		15	9.14	± 1.56	9.27	± 1.56
	Luteal		15	9.08	± 1.45	9.40	± 1.60

The values are the means \pm the standard deviation. Abbreviations: Standard deviation (SD), seconds (s). * $P < 0.05$ compared to pre-fatigue.

For the lateral hop test, there was no significant difference among the phases ($p = 0.528$), between the pre and post-fatigue trials ($p = 0.621$) or with the fatigue by phase interaction ($p = 0.389$). The mean values of the lateral hop test are depicted in Table 4.6.

Table 4.6. Mean values of the lateral hop test across the menstrual cycle, both pre and post-fatigue.

Test	Phase	Units	N	Pre-fatigue		Post-fatigue	
				Mean \pm SD		Mean \pm SD	
Lateral	Menstrual	s	15	6.17	± 1.07	6.15	± 1.09
	Follicular		15	5.98	± 0.85	5.99	± 0.96
	Luteal		15	6.05	± 0.75	6.22	± 1.10

The values are the means \pm the standard deviation. Abbreviations: Standard deviation (SD), seconds (s).

The means of the up-down test are given in Table 4.7. There were no differences among the phases ($p = 0.786$), between the pre and post-fatigue trials ($p = 0.338$) or the interaction of fatigue and the phases ($p = 0.999$).

Table 4.7. Mean values of the time taken to complete the up-down test over the menstrual cycle, both pre and post-fatigue.

Test	Phase	Units	N	Pre-fatigue		Post-fatigue	
				Mean \pm SD		Mean \pm SD	
Up/Down	Menstrual	s	15	14.79	± 1.91	15.11	± 2.75
	Follicular		15	14.80	± 2.88	15.10	± 3.82
	Luteal		15	14.51	± 1.70	14.81	± 2.24

The values are the means \pm the standard deviation. Abbreviations: Standard deviation (SD), seconds (s).

Functional BalanceCenter of Pressure (COP)

One outlier was removed from the data set for the functional balance test since her results were greater than two standard deviations from the mean. The COP data were measured in both millimeters and milliseconds to time of balance. The pre-fatigue and post-fatigue COP mean values in millimeters and milliseconds are given in Table 4.8 and 4.9 respectively. There were no differences ($p = 0.429$) in COP range of movement to balance among the phases. Pre-fatigue and post-fatigue trials were not found to be significantly different ($p = 0.419$). The mean ranges of movement for the pre- and post-fatigue trials are plotted against the menstrual cycle phases in Figure 4.3. There were no fatigue by phase effects ($p = 0.205$).

Table 4.8. COPM mean ranges of movement for pre- and post-fatigue trials for the three phases of the menstrual cycle.

Test	Phase	Units	N	Pre-fatigue		Post-fatigue	
				Mean \pm SD		Mean \pm SD	
Balance COPM	Menstrual	mm	14	192.85	± 26.72	181.01	± 26.95
	Follicular		14	204.27	± 52.39	208.51	± 63.07
	Luteal		14	202.64	± 50.45	197.78	± 48.91

The values are the means \pm the standard deviation. Abbreviations: Standard deviation (SD), millimeters (mm) center of pressure measured in millimeters (COPM).

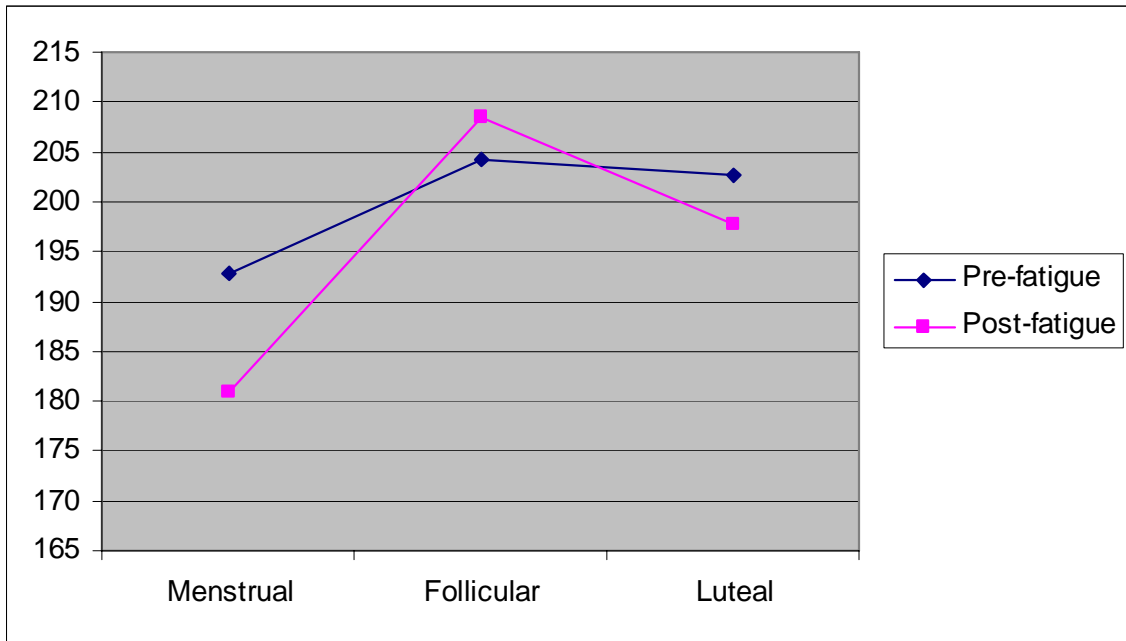


Figure 4.3. The mean ranges of movement for the pre- and post-fatigue trials are plotted against the menstrual cycle phases.

There were no differences of the COP “time to balance” among the phases ($p = 0.586$) or between pre-fatigue and post-fatigue trials ($p = 0.133$). The effect of fatigue on the phases was not significant ($p = 0.395$). The means of the COP tests for each of the menstrual phases can be found in Table 4.9.

Table 4.9 COPT mean times to balance for pre- and post-fatigue trials for the three phases of the menstrual cycle.

Test	Phase	Units	N	Pre-fatigue		Post-fatigue	
				Mean	SD	Mean	SD
Balance COPT	Menstrual	ms	14	1785.16	± 370.81	1615.60	± 389.11
	Follicular		14	1633.26	± 312.36	1558.13	± 340.81
	Luteal		14	1614.03	± 446.05	1570.80	± 334.28

The values are the means ± the standard deviation. Abbreviations: Standard deviation (SD), milliseconds (ms), center of pressure measured in time (COPT).

Summary

There were no differences among the phases for all of the functional balance and functional hop tests. However, there were significant differences between the pre and post-fatigue trials for the forward hop and figure eight functional hop tests. The respective p-values, degrees of freedom and F-values for all of the tests, are specified in Table 4.10.

Table 4.10. Statistical values for the functional tests among the menstrual cycle phases and between fatigue trials.

Variable	Source	p-value	df	F-value
Sprint	Fatigue	0.000	1	95.97
	Phase	0.289	2	1.26
	Fatigue*Phase	0.495	2	0.72
Forward Hop	Fatigue	0.011	1	8.68
	Phase	0.454	2	0.78
	Fatigue*Phase	0.191	2	1.80
Figure Eight	Fatigue	0.015	1	7.71
	Phase	0.953	2	0.02
	Fatigue*Phase	0.373	2	1.00
Lateral Hop	Fatigue	0.621	1	0.26
	Phase	0.528	2	0.60
	Fatigue*Phase	0.389	2	0.92
Up/Down	Fatigue	0.338	1	0.99
	Phase	0.786	2	0.21
	Fatigue*Phase	0.999	2	0.00
COP(mm)	Fatigue	0.419	1	0.70
	Phase	0.429	2	0.85
	Fatigue* Phase	0.205	2	1.72
COP(sec)	Fatigue	0.133	1	2.58
	Phase	0.586	2	0.54
	Fatigue*Phase	0.395	2	0.93

CHAPTER FIVE

DISCUSSION

Introduction

The purpose of this study was to determine if the menstrual cycle influences neuromuscular performance of active females. Neuromuscular performance was measured through a series of balance and hopping tests. A functional balance test was measured using a force plate and calculating the COP in both millimeters and milliseconds to the point of balance. The other functional tests consisted of a series of single leg hops, with performance measured in distance and time to completion. It was hypothesized that high levels of estrogen and low levels of progesterone would provide the female athlete with the greatest performance capacity (Charlton et al., 1999; Gersh & Gersh, 1981; Janse de Jonge et al., 2001 and Toth & Cordasco, 2001). This respective phase would be the follicular phase of the menstrual cycle (Asso, 1983; Gersh & Gersh, 1981 and Janse de Jonge et al., 2001).

The second variable of this study was to determine if there were significant differences between pre- and post-fatigue functional balance and hopping tests. To measure fatigability performance in active females, a stationary bicycle fatigue test was performed. The functional tests were then performed and measured pre- and post-fatigue. It was hypothesized that the post-fatigue functional tests would be significantly worse than the pre-fatigue tests and there would be significantly greater differences between pre- and post-fatigue results during the follicular phase of the menstrual cycle.

In regards to the hypotheses, there were no significant differences in the functional tests over the menstrual cycle. There were differences in fatigue in the forward hop and figure eight tests, but the affect of fatigue on performance did not differ across menstrual cycle phases. These results are consistent with a similar study (Hertel et al., 2006), where neuromuscular performance and knee laxity were not found to change across the menstrual cycle. The Hertel study measured strength, joint position sense, postural control and knee laxity during three stages of the menstrual cycle and found no significant differences.

Menstrual Cycle Phases

One factor noted during the study was that some of the participants had shorter luteal phases (6-9 days) than the 13-15 days noted in the literature (Asso, 1983; Gersh & Gersh, 1981; Janse de Jonge et al., 2001). It was also noted that five of the twenty-seven participants were removed from the study due to irregular phases (anovulation and >3 day variation) during the study. The reason for recruiting participants with normal menstrual cycles was for consistency in hormone levels during the menstrual cycle phases. However, it was noted in this study that although many of the females continued with normal cycles (length in days between menses) the luteal phase was much shorter than reported in literature. The females that had short luteal phases and as a result a shorter menstrual cycle (>3 days) were removed from the study. This information led to further investigation in research to determine the causes and effects of the shorter luteal phases.

Keizer and Rogol (1990) stated that there are more alterations of the menstrual cycle in active females as compared to the sedentary female population. Therefore, it is difficult to identify underlying parameters of physical exercise from other factors. Considering that physical exercise could lead to shortening of the luteal phase and/or amenorrhea, active females could be experiencing altered menstrual cycles. It was noted by Cree (1998) that although the luteal phases in active females may be shorter, the menstrual cycles may appear to be normal on the basis of the length of the cycle between menses being consistent. A menstrual cycle with a shorter luteal phase may cause the next menstrual cycle to have lower progesterone and lead to abnormal luteinizing hormone levels during the ovulatory phase, creating an earlier follicular phase. With an earlier, longer follicular phase and a shorter luteal phase, an end result is what appears to be a normal menstrual cycle. This produces a concern with the hormone levels throughout the cycle and specific phases. A shorter luteal phase is typically accompanied by a decrease in luteinizing hormone, follicle stimulating hormone and estrogen levels. It is possible that a decreased luteinizing hormone secretion during the luteal phase could compromise the corpus luteum function (Beitins, McArthur, Turnbull, Skrinar, & Bullen, 1991).

The luteal hormone secretion is regulated by progesterone, and a short luteal phase is accompanied with a decrease in luteal hormone, follicular stimulating hormone and estrogen levels. Therefore, if active females are more likely to have shorter luteal phases, then the accompanying hormone changes may also be present. These hormone irregularities make it difficult to compare active females with consistent hormone levels throughout the menstrual cycle phases. Without consistency of hormones in active

females, there cannot be a set phase length since variations may occur without the occurrence of anovulation or the most extreme disturbance of the menstrual cycle, amenorrhea (DeSouza, Miller, Loucks, Luciano, Pescatello, 2006).

Hormone Serum Levels

The levels of serum estrogen were found to be significantly different, however did not fit the reported literature estrogen levels of the different phases. The serum progesterone levels on the other hand were not significantly different, and although slightly higher, followed the reported trend of the menstrual cycle phases. There are two possible explanations for this discrepancy. First, during the follicular phase, estrogen peaks just prior to ovulation and this is the only time in which the estrogen levels are higher than the luteal phase. However, the reported range of the luteal phase infers that the estrogen levels can be significantly greater than the peak of the follicular phase. Therefore, it is possible that even though the subjects were being tested during the follicular phase, the estrogen levels were not as high as predicted because testing may have occurred prior to the estrogen peak of the follicular phase. Secondly, as previously stated, it was noted that many of the participants continued with normal cycles (length in days between menses) yet the luteal phase was much shorter than reported in literature. These shorter luteal phases could be characteristic of lower progesterone and estrogen levels. A shorter luteal phase is typically accompanied by a decrease in luteinizing hormone, follicle stimulating hormone progesterone and estrogen levels. Therefore, the serum analyses of a lower estrogen level during the follicular phase is characteristic of a shorter luteal phase the previous month, which then causes a repeat during the following

month and a continuous cycle. The shorter luteal phases were seen consistently with the participants of the current study, but the progesterone levels were higher than normal for the menstruation and follicular phases, which is not consistent with the shorter luteal phase cycle.

Fatigability

When isolating the phases of the menstrual cycle, current research is inconclusive and contradictory. Many researchers (Friden, Hirschberg & Saartok, 2003; Gur, 1997; Janse de Jonge et al., 2001; Lebrun & Rumball, 2001) have shown there to be no significant differences in fatigue among the menstrual cycle phases. However, other researchers have found fatigue differences between sexes (Hakkinen, 1993; Hatae, 2001; Hicks, Kent-Braun & Ditor, 2001; Tiidus et al, 1999). The fatigue differences may be associated with the physiological effects of estrogen and progesterone as previously discussed. The current study however did not find differences among the menstrual cycle phases. It was hypothesized in this study that performance would be the greatest during the follicular phase, based upon the hormone levels. This hypothesis included fatigability, and it was hypothesized that active females would be more resistant to fatigue during the follicular phase.

Fatigue effects were only found in two of the functional ability tests, the forward hop and figure-eight but there was not a phase effect. Rationale for these differences may be that these two functional tests were more accurate measures of the targeted fatigued muscle group and therefore remained fatigued longer. Despite pilot testing, it is also a possibility that the fatigue effects did not persist for the desired duration. Both the

forward hop and the figure-eight tests were the first of the four functional ability tests. In having moderate to vigorous exercisers, it is also possible that height and weight differences influenced the outcomes of these tests. The fatigue protocol was standard with resistances for each participant and although a 30% increase in time was required, the fatigue results may have been different dependent upon the pre-existing muscle mass of the individual. A better comparison would have been an individualized, size dependent fatigue protocol for each participant, followed with analysis of specific differences within in the individual and not overall comparison of outcomes.

Functional Hop Tests

There were no significant differences found between the hop tests and the menstrual cycle phases, however there were some significant differences between the hop tests and the pre- and post-fatigue trials. This is not consistent with results from a study conducted by Jennings, Janowsky, and Orwoll (1998) in which they specifically looked at reaction time, and they reported that higher levels of estradiol were related to faster reaction times in women. Jennings et al. (1998) reported that progesterone increased fatigue and decreased performance on cognitive tasks, and that estrogen may affect complex sequential movements, but not simple, single-response movements. Their results were consistent with the hypothesis of the current study that performance would be greatest during the follicular phase. The hypothesis was also supported through the results of a study (Hampson 1990), where it was found that an increase in motor speed, coordination and speech articulation occurred during the follicular phase of the menstrual cycle. However, the results of the current study are contrary to the results of these other

studies. In the current study, there were no significant differences noted between neuromuscular performances throughout the course of the menstrual cycle. However, these results are consistent with a similar study, which examined neuromuscular performance and knee laxity in female athletes (Hertel et al, 2006) in which they found no significant differences among the menstrual phases.

The results of the current study may have been skewed by the possible variations in hormone levels of the active females. Since active females are more likely to have alterations in their menstrual cycles compared to the sedentary population, the consistency of the hormone levels may not be able to be determined simply through the presence of ovulation (Jasienska, Ziolkiewicz, Thune, Lipson, & Ellison, 2006). It is possible that although the menstrual cycles of the participants appeared to be normal (<3 days variation) and with ovulation; the luteal phases were found to be shorter and therefore may have altered luteinizing hormone secretion, follicular stimulating hormone and estrogen levels. These changes in hormones levels may have caused enough variation in the menstrual phases, the same hormone levels were not being compared between individuals for the corresponding phase.

Functional Balance and Center of Pressure

Much research has been completed on the differences between males and females in terms of balance. However, current research has only examined static balance and has not measured functional balance, especially in regard to the active female. The effect of estrogen on postural balance was studied by Ekblad and colleagues (2000). They found no significant difference in balance with estrogen replacement in postmenopausal

women. Contrary to this study, other researchers report significant differences in postural balance with estrogen replacement (Hammer et al., 1996; Naessen et al., 1997). The effects of neuromuscular performance in active females were examined and no significant differences in dynamic balance over the course of the menstrual cycle were found. These results are similar to the findings of the current study. In the current study, there were no significant differences found in functional balance over three phases of the menstrual cycle.

Two limitations of the current study design were the subjective measurement of the point of balance and a non-controlled BOSU balance trainer pressure. In determining the point of balance, the center of pressure (COP) data were extracted from the Vicon output file and analyzed in an excel spreadsheet. In the excel spreadsheet, the COP position data were plotted X versus Y and X/Y versus time. From these graphs, the balance point was determined. On the X/Y versus time graph, X and Y were subjectively determined to flatten out to identify the point of balance. This balance point was then compared with the X versus Y graph to verify a balance point. This balance point was determined for each of the ten trials and then an average for each phase pre and post-fatigue was computed. Even though the measurements of this test were set up to be as objective as possible, there were some subjective means of determining the point of balance. A better means of determining the point of balance may be necessary for this functional balance test to be effective in detecting menstrual phase effects.

An additional limitation of this study was the BOSU balance trainer pressure. The pressure of the BOSU was not measured prior to the initiation of the study therefore; the pressure could not be compared throughout the study. The BOSU may have lost

some pressure throughout the course of the study and could have had some effects on the COP measurements.

An additional limitation of this study includes size differences. It was noted that there were significant size differences between the subjects with a difference of 65.8kg in weight between the minimum and maximum and a difference of 0.3m in height. The variation in measurement outcomes from these tests had high standard deviations for some of the menstrual cycle phases. It is possible that if the measurement outcomes were corrected for size differences, a smaller change in overall outcome may have been recognized.

Summary

Given the research regarding the female athlete, including the menstrual cycle, the ACL, balance, and fatigability, it was hypothesized for this study that the menstrual cycle and its phases would affect neuromuscular performance in females. Specifically, it was hypothesized that performance would be the best during the follicular phase, based upon the levels of the hormones, when estrogen is high and the progesterone levels are low.

The statistical hypothesis of the study stated with the null hypothesis, that neuromuscular performance would not be different across phases of the menstrual cycle. The alternative hypothesis stated that the effects of the phases on neuromuscular performance are not equal and one phase has more of an effect than the other phases. This study was composed of six measurement outcome values, the dependent variables. Two of these were used to measure functional balance and four series of hop tests were used to determine functional ability. According to the hypothesis of neuromuscular

performance being enhanced during the follicular phase, the specific hypotheses for each of the dependent variables are listed in Table 5.1. Therefore, respective of the significant differences of the dependent variable, the current study is in support of the null hypothesis.

Table 5.1 The expected and actual results of each neuromuscular component in respect to the hypotheses of the study.

Neuromuscular Component	Test	Units	Expected Outcome	Actual Outcome
Functional Balance				
	COPM	(mm)	Lowest	No Change
	COPT	(ms)	Lowest	No Change
Fatigability (Hops)				
	Forward	(m)	Highest	No Change
	Figure 8	(s)	Lowest	No Change
	Lateral	(s)	Lowest	No Change
	Up/Down	(s)	Lowest	No Change

Abbreviations: Center of pressure-magnitude (COPM), center of pressure-time (COPT), millimeters (m), milliseconds (ms), seconds (s).

CHAPTER SIX

CONCLUSION

Introduction

The primary purpose of this study was to compare neuromuscular performance against three phases of the menstrual cycle. This study also examined the effects of fatigability on the functional tests and the menstrual cycle phases. The functional tests utilized consisted of a series of functional balance and single leg hop tests: forward, figure-eight, lateral and up/down. The functional balance test was performed on a force plate, with the participant jumping from one force plate and landing on a BOSU balance trainer, which was placed on the other force plate. A fatigue test was also performed on a stationary bike through a series of sprints. Fatigue was classified as a 30% decrease in sprint time performed at a set resistance.

Menstrual Cycle Phases

The conclusions of this study are that there were no significant differences among the phases of the menstrual cycle for the functional tests. However, it was also noted that the hormone levels of active females may not be as consistent as previously suspected. Alterations in the menstrual cycle with exercise could change the results of the current study. Due to these alterations, a daily comparison of exercise, diet and hormone levels among active females would be the best means for an accurate comparison and understanding of active females. This problem arises with women appearing to have

normal menstrual cycles, although the phases may alter in length but the length between menses not altering. A study with this type of design would take a lot of time and money to complete, but it may be the only way to compare active females with similar hormone levels.

Hormone Serum Levels

Although, the hypotheses of the current study should be switched to a higher neuromuscular performance seen during the luteal phase rather than the follicular phase, neither phase was determined to be statistically significant in the affects on neuromuscular performance. However, it is possible that the current research is misleading in discussing the proper estrogen levels during the menstrual cycle phases. However, it must also be noted that with the presence of the shorter luteal phases in athletes occurring with lower levels of estrogen may be damaging to the corpus luteum (Beitins, McArthur, Turnbull, Skrinar & Bullen; 1991).

Fatigability

The fatigue test was developed in this current study to determine if active females are more resistant to fatigue during phases of the menstrual cycle. If fatigue resistance is present, it could then be hypothesized that this would be correlated with a decreased risk of injury. It is also possible that the different hormone levels could have altered influences in the fatigued state. Although there were significant differences in the forward hop and figure-eight tests of functional ability, the current study did not show any differences among the menstrual cycle phases.

Functional Hop Tests

An additional component of functional balance within this study was a series of functional hop tests. It was hypothesized that all of the functional tests would have the greatest performance during the follicular phase of the menstrual cycle, and for all of the tests to have differences between the pre- and post-fatigue trials. The forward hop and figure-eight tests had decreased performance following the fatigue protocol. No differences among menstrual cycle phases were measured for all of the functional tests.

Center of Pressure

With a lack of research in functional balance, this study aimed to determine the effects of the menstrual cycle on functional balance in the active female. Two functional balance components were employed during the study. Balance on landing was measured using a force plate and a BOSU balance trainer. The current study did not find any differences of functional balance among the menstrual cycle phases. It was also determined that there were no differences of functional balance with pre- and post-fatigue testing.

Hypotheses

Given the research regarding the female athlete, including the menstrual cycle, the ACL, balance, and fatigability, it was hypothesized for this study that the menstrual cycle and its phases would affect neuromuscular performance in females. Specifically, it was hypothesized that performance would be the best during the follicular phase, based upon the levels of the hormones. The null hypothesis stated that all phases of the menstrual

cycle have equal effects on neuromuscular performance. In respect of the significant differences of the dependent variable, the current study is in support of the null hypothesis.

Summary

The researchers of this study found no significant differences with neuromuscular performance among the menstrual cycle phases. Although it was determined that the majority of the participants of the study did not have the literature typical menstrual cycles, however still have normal menstrual cycles by definition. This is most likely attributed to the activity levels of the participants, as they were all moderate to vigorous exercisers. Nonetheless, this study among others has determined that there are no correlations to the menstrual cycle when it pertains to neuromuscular performance and possibly the incidence of ACL injuries. Therefore, it is possible that neuromuscular training may be the multifactorial variable that is causing the increased incidence of ACL injuries among female athletes. More research is needed to determine if neuromuscular training in active females can improve injury rates.

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APPENDICES

APPENDIX A

SUBJECT CONSENT FORM

SUBJECT CONSENT FORM FOR PARTICIPATION IN HUMAN RESEARCH**MONTANA STATE UNIVERSITY**

Study Title: *Does the menstrual cycle and its phases, influence neuromuscular performance consequently affecting the integrity of the ACL, and predisposing women to an increased incidence?*

Investigators: Shayna Lemke, Mary Miles, Ph.D.
Department of Health and Human Development
101 Hosaeus PEC
Phone: 994-3395, lemke@montana.edu
Phone: 994-6678, mmiles@montana.edu

You are being asked to participate in a study investigating the effects of the menstrual cycle on neuromuscular performance. The goal of the study is to focus more on the fundamental factors of movement relative to the menstrual cycle. The fundamental factors of movement include reaction time, balance and fatigability. It is possible that hormones are effecting basic movements and responses and therefore placing women's knees in more of a compromising position for the anterior cruciate ligament (ACL), the most commonly injured structure within the knee. This study could be used to determine the extent to which neuromuscular control may influence knee injury.

Based on review of current research surrounding the female athlete, including the menstrual cycle, the ACL, balance, fatigability, and reaction time, it may be hypothesized that the menstrual cycle and its phases are affecting the female athlete resulting in an increased incidence of ACL injuries. You will be tested in the Montana State University Movement Science Laboratory in Romney Gymnasium.

The purpose of this study is to determine whether neuromuscular performance is being affected by the menstrual cycle. If neuromuscular performance is found to be one of the factors of the increased incidences of ACL tears, then it can be focused on to help prevent knee injuries in women. Once the factor is determined, and then preventative measures can be incorporated in the active females' lives.

If you agree to participate in this study you will do the following things:

1. Chart your menstrual cycle and use the thermometer to determine your ovulation phase.
2. Attend a familiarization session where you will be explained the exercises, have time to try them and also read and sign this document. You will also fill out a physical activity readiness questionnaire, health history questionnaire and physical activity questionnaire that include questions regarding your menstrual cycle and injuries that you have experienced.
3. Have blood collected on three occasions to determine which phase of the menstrual cycle you are in. We will use this information to determine if the estimation of the phase was correct.

4. Report to the Movement Science Laboratory (MSL) on the MSU campus for measurements. Baseline and follow up measurements during the three specific phases. You will be asked to report to the lab during three phases of the menstrual cycle. The blood draw and exercises will be performed every time that you report to the MSL.
5. Each time you come to the lab, you will perform a warm up session, consisting of five minutes of cycling plus two sets of three maximal vertical jumps.
6. Each time you come to the lab, you will perform an exercise using a BOSU ball balance trainer. A BOSU ball is a half ball connected to a hard landing surface. The ball side will be placed on the force plate, and you will jump onto the hard surface side. Landing zones will be taped on the hard side to ensure landing in the middle of the BOSU ball. You will then be asked to start from one platform and jump to the next onto the BOSU ball. This is an exercise that is regularly used as a rehabilitation technique to improve balance. You will be asked to perform this exercise 10 times.
7. Each time you come to the lab, you will perform a series of jump and running tests, these include: figure eight, box jumps, lateral jumps and forward hops. Time and distance will be recorded, respective to the exercise. This exercise will be repeated again later during the session.
8. Each time you come to the lab, you will perform an exercise using a stationary bike. You will warm up for 5 minutes before performing a series of bicycle sprints. This exercise is used to test your time to fatigue. Prior to initializing the sprints, you will perform 10 repetitions at a resistance of 4.0 kpm as fast as you can. 3 minutes of rest and then 3 minutes of warm up again prior to starting the sprint protocol will then follow this. The sprints will be performed at various lengths of time ranging from 15 seconds to 60 seconds; these sprints will also vary in resistance. Following the sprint protocol you will be asked to perform again the 10 repetitions at the 4.0kpm resistance. You may then be asked to perform a few more sprints, followed by the 10 repetitions again, dependent upon your fatigue percentage. This fatigue may be uncomfortable for a short while, but should recover within a few minutes to an hour.
9. Each time you come to the lab, you will then perform the series of jump and running tests again as described in #6.
10. You will complete a physical activity questionnaire about the exercise you typically perform in a week's time.

Sometimes there are side effects from having blood drawn or doing certain activities. These side effects are often called risks, and for this project, the risks are:

1. Approximately 10ml of blood (2 teaspoons) will be removed by putting a needle in your vein. This is the standard medical method used to obtain blood for tests. There is momentary pain at the time the needle is inserted into the vein, but other discomfort should be minimal. In about 10% of the cases there

is a small amount of bleeding under the skin, which will produce a bruise. The risk of infection is less than 1 in 1,000.

2. After performing the resistance exercise and BOSU jumps, you will experience fatigue but this feeling should subside within a couple of days. The risk of serious injury (such as a strain or sprain) from the exercises is small in healthy subjects who have no musculoskeletal problems or have not had surgery to their leg.
3. The bicycle test may cause extreme fatigue immediately following the exercise. The testing also involves a chance of precipitating a cardiac event. However, the possibility of such an event is very slight since you are in good physical condition with no known symptoms of heart disease, and the test will be administered by trained personnel (Certified Athletic Trainer).

Confidentiality: The data and personal information obtained from this study will be regarded as privileged and confidential. A code number will identify the data that we collect from you, and all data will be kept in locked offices in the Movement Science Laboratory or in Dr. Miles' office. The information obtained in this study may be published in scientific journals, but your identity will not be revealed. They will not be released except upon your written request/consent. If during the study you decide to cease your participation, your name will be removed from our study records, and we will not contact you again regarding this study. You will not be penalized in any way.

Freedom of Consent: You may withdraw consent in writing, by telephone, or in person with the investigator (Mary Miles at 406-994-6678 or Shayna Lemke at 994-3395) and discontinue participation in the study at any time and without prejudice. Participation is completely voluntary.

In the event your participation in this research results in injury to you, medical treatment consisting of basic first aid and assistance in getting to Bozeman Deaconess Hospital or Student Health Services will be available, but there is no compensation for such injury available. Further information about this treatment may be obtained by calling Mary Miles at 994-6678.

You are encouraged to express any questions, doubts or concerns regarding this study. The investigator will attempt to answer all questions to the best of her ability. The investigator fully intends to conduct the study with your best interest, safety and comfort in mind. *The Chairman of the Human Subjects Committee, Mark Quinn can answer additional questions about the rights of human subjects at 406-994-5721.*

STATEMENT OF AUTHORIZATION

AUTHORIZATION: I have read the above and understand the discomforts, inconvenience and risk of this study. I, _____
(PRINT YOUR NAME), agree to participate in this research. I understand that I may later refuse to participate, and that I may withdraw from the study at any time. I have received a copy of this consent from for my own records.

Signed: _____ Date: _____
Subject's Signature

Witness: _____ Date: _____
(If other than the investigator)

Investigator: _____ Date: _____
Shayna Lemke

APPENDIX B

SUBJECT ACTIVITY QUESTIONNAIRE

ID # _____

Physical Activity

In this section we would like to ask you about your current physical activity and exercise habits that you perform at least once a week. Please answer as accurately as possible.

Do you work out for at least 30 minutes three times a week? Yes No

How would you classify those three workouts? Light Moderate Vigorous

How many times a week do you engage in vigorous physical activity long enough to work up a sweat? _____(times per week)

I have read, understood, and completed this questionnaire. Any questions I had were answered to my full satisfaction.

Signature: _____

Date: _____

Witness: _____

Date: _____

APPENDIX C

HEALTH HISTORY QUESTIONNAIRE

ID # _____

Health History for Women

The study that you are planning on participating in, is examining the affects of the menstrual cycle on neuromuscular performance. Neuromuscular performance looks at three different aspects of your everyday life, including reaction time, balance and fatigue. Neuromuscular performance allows you to move your body through space in a controlled manner. Since this study is looking at the menstrual cycle, it is important that we fully understand your cycle and the associated hormones, and also any other factors that might affect neuromuscular performance. The following questions will help us determine whether you can participate in this study. Please read the questions carefully and answer each one honestly.

YES NO

___	___	Do you have any current or recent medical problems? If yes, explain.
___	___	Have you ever broken a bone? Which one(s)/When? _____
___	___	Have you ever had a cast or brace? Where/Why/When? _____
___	___	How many times have you had a sprained ankle? _____
___	___	Have you ever had a knee injury? _____
___	___	Have you ever had arthritis?
___	___	Do you get painful or swollen joints not due to an injury?
___	___	Have you ever had surgery? Date(s)/Operation(s)? _____
___	___	Do you have menstrual periods once a month?
___	___	Do you have trouble with heavy bleeding during a period?
___	___	Are menstrual cramps severe enough to interfere with your daily routine?
___	___	What medication, if any, do you take for them? _____
___	___	Are you on "Birth Control Pills"?
___	___	Since you started having periods, what is the longest time you have gone without having a period? _____
___	___	What date was the first day of your last menstrual period? _____
___	___	How many days does a menstrual period last for you? _____
___	___	Do you have asthma?
___	___	Do you regularly consume more than 2 alcoholic beverages per day?
___	___	In the last six months, have you smoked or chewed tobacco?

APPENDIX D

PHYSICAL ACTIVITY READINESS QUESTIONNAIRE

ID # _____

QuestionnairePAR-Q - Physical Activity Readiness Questionnaire

Regular Physical activity is fun and healthy, however, some people should check with their doctors before they start becoming much more physically active. If you are planning on participating in the Neuromuscular Performance and the Menstrual Cycle study, please answer the following questions. These questions will help us determine whether you can safely and actively participate in this study without physician approval. Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly.

- | Yes | No | |
|-----|-----|---|
| ___ | ___ | Has your doctor ever told you that you have a heart condition and that you should only do physical activity recommended by your doctor? |
| ___ | ___ | Do you feel pain in your chest when you do physical activity? |
| ___ | ___ | In the past month, have you had chest pain when you were not doing physical activity? |
| ___ | ___ | Do you lose your balance because of dizziness or do you ever lose consciousness? |
| ___ | ___ | Do you have a bone or joint problem that could be made worse by your participation in this study? |
| ___ | ___ | Is your doctor currently prescribing drugs for your blood pressure or heart condition? |
| ___ | ___ | Have you ever passed out during exercise? |
| ___ | ___ | Have you ever had to stop exercise because of dizziness, chest pain or an irregular heartbeat? |
| ___ | ___ | Have you ever had a blood sugar problem? |
| ___ | ___ | Do you know of any other reason that you should not do physical activity? |

If you answered YES to one or more questions:

Talk with your doctor by phone or in person BEFORE you agree to participate in this study or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which question you answered YES to. You may be able to safely participate in this study.

If you answered NO to all of the questions:

You can be reasonably sure that you can safely participate in this study.

APPENDIX E

INSTITUTIONAL REVIEW BOARD APPROVAL FORM



INSTITUTIONAL REVIEW BOARD

For the Protection of Human Subjects

960 Technology Blvd. Room 127
 c/o Veterinary Molecular Biology
 Montana State University
 Bozeman, MT 59718
 Telephone: 406-994-6783
 FAX: 406-994-4303
 E-mail: cherylj@montana.edu

Chair: Mark Quinn
 406-994-5721
 mquinn@montana.edu
Administrator:
 Cheryl Johnson
 406-994-6783
 cherylj@montana.edu

MEMORANDUM

.....

TO: Shayna Lemke

FROM: Mark Quinn *Mark Quinn*
 Chair, Institutional Review Board for the Protection of Human Subjects

DATE: August 18, 2005

SUBJECT: *The Effects of the Menstrual Cycle on Neuromuscular Performance*

The above proposal was discussed by the Institutional Review Board at its meeting on August 18, 2005. The Board had the following concerns and questions about the proposal.

1. There is an inconsistency in the number of blood draws being performed on the subjects. In the proposal you indicated two blood draws. On the consent form three blood draws were described. The Committee requested clarification.
2. Under Section VII, F. 2. Are facilities/equipment adequate to handle possible adverse effects? The statement "Yes, a telephone is accessible if an emergency call is to be made" is perhaps not a comforting statement for the participants should something adverse happen. The Committee felt that you should change the wording to indicate that a health care provider will be contacted. Will basic first aid be administered? Will there be trained CPR or other medical personnel available on site during the study? If so, that should be listed.
3. The Committee was unfamiliar with the term "BOSU ball" and felt it should be described in the proposal and the consent form since participants may not know what a BOSU ball is.
4. There were a number of typographical errors throughout the proposal and consent form and those need to be corrected.

Once the above clarifications have been received, the Board or the Board Chair will complete the review of the proposal.



INSTITUTIONAL REVIEW BOARD

For the Protection of Human Subjects

960 Technology Blvd. Room 127
 c/o Veterinary Molecular Biology
 Montana State University
 Bozeman, MT 59718
 Telephone: 406-994-6783
 FAX: 406-994-4303
 E-mail: cherylj@montana.edu

Chair: Mark Quinn
 406-994-5721
 mquinn@montana.edu

Administrator:
 Cheryl Johnson
 406-994-6783
 cherylj@montana.edu

MEMORANDUM

.....

TO: Shayna Lemke

FROM: Mark Quinn, Ph.D. *Mark Quinn Ph.D.*
 Chair, Institutional Review Board for the Protection of Human Subjects

DATE: September 16, 2005

SUBJECT: *The effects of the menstrual cycle on neuromuscular performance* [SL091605]

Thank you for submitting the revisions and clarifications requested by the Institutional Review Board. This proposal is now approved for a period of one-year.

Please keep track of the number of subjects who participate in the study and of any unexpected or adverse consequences of the research. If there are any adverse consequences, please report them to the committee as soon as possible. If there are serious adverse consequences, please suspend the research until the situation has been reviewed by the Institutional Review Board.

Any changes in the human subjects aspects of the research should be approved by the committee before they are implemented.

It is the investigator's responsibility to inform subjects about the risks and benefits of the research. Although the subject's signing of the consent form, documents this process, you, as the investigator should be sure that the subject understands it. Please remember that subjects should receive a copy of the consent form and that you should keep a signed copy for your records.

In one year, you will be sent a questionnaire asking for information about the progress of the research. The information that you provide will be used to determine whether the committee will give continuing approval for another year. If the research is still in progress in 5 years, a complete new application will be required.

APPENDIX F

HUMAN SUBJECTS CERTIFICATION



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Human Participant Protections Education for Research Teams

Completion Certificate

This is to certify that

shayna lemke

has completed the **Human Participants Protection Education for Research Teams** online course, sponsored by the National Institutes of Health (NIH), on 01/31/2005.

This course included the following:

- key historical events and current issues that impact guidelines and legislation on human participant protection in research.
- ethical principles and guidelines that should assist in resolving the ethical issues inherent in the conduct of research with human participants.
- the use of key ethical principles and federal regulations to protect human participants at various stages in the research process.
- a description of guidelines for the protection of special populations in research.
- a definition of informed consent and components necessary for a valid consent.
- a description of the role of the IRB in the research process.
- the roles, responsibilities, and interactions of federal agencies, institutions, and researchers in conducting research with human participants.

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