The Impact of the Menstrual Cycle on Female Performance in Athletics

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Abstract

Female hormones, key to preparing a woman's body for childbirth, work in a magnificent, cyclical manner. It can be expected that these hormones, with the role of preparing a woman's body to conceive a child and deliver a life safely into the world, would have a large impact on the health of the female, especially when it comes to athletics.

Numerous studies conducted to understand the full extent of the effect of reproductive hormones on the female body have shown that these hormones influence not only menstruation, but also various physiological and psychological elements. Such effects can certainly impact athletic performance.

The Impact of the Menstrual Cycle on Female Performance in Athletics

Introduction

As an athlete, the key to continuing to improve performance, especially in endurance events, is to work alongside your body rather than against it. For women who compete in athletics, the fluctuation of hormones that occurs throughout each month is a factor that must not be overlooked. Many studies have been conducted to investigate the full scope of how the peaks and valleys of hormone levels in the body impact health. The reproductive hormones involved with the menstrual cycle not only impact the fertility of a woman, but also have a role to play in other physiological factors in a woman's well-being.

The analysis of many studies has shown that the variations in hormone levels, whether due to a natural cycle or an abnormal cycle, affect a female's athletic performance. Along with promoting sex characteristics, reproductive hormones play a role in the physiological functioning of the female body to a great extent. To get an accurate picture of how female athletics are impacted, it is necessary to look at the health-related and skills-related fitness components in regard to the cycle. Factors that impact performance, including injury risk, recovery, and nutrition should also be addressed. In addition, the effects of abnormal cycles must be analyzed as well. Abnormal cycles, including amenorrhea (the absence of the period), are present in the female athlete triad. Rather than ignore the natural fluctuation of reproductive hormones, embracing physiological changes that occur throughout the month can be the difference between first and second in high level female athletics (Tornberg et al., 2017).

Understanding the Menstrual Cycle

Understanding what normal fluctuations of reproductive hormone levels look like in a healthy female is crucial before digging into the effects these fluctuations would have on an athlete. Normal menstrual cycles, defined as the time from the first day of menstrual bleeding (menses) until the first day of menses of the next cycle, last between 25 and 30 days (Reed & Carr, 2018). Menstrual bleeding is the sloughing off of the uterine lining in order to rid the body of the unfertilized egg that had been released from the ovaries in the previous cycle. Deviations in cycle timelines are more common around menarche, the first period of a female's reproductive life, and menopause, the last period of a female's reproductive life (Reed & Carr, 2018).

The Follicular Phase

The menstrual cycle can be broken up into two phases which describe the changes occurring in a woman's body. The follicular phase begins with menses and lasts until ovulation. The main event of this phase, as the name describes, is the development of the ovarian follicles in folliculogenesis. As gonadotropin releasing hormone (GnRH) from the hypothalamus increases, follicle stimulating hormone (FSH) from the pituitary gland elevates during the beginning of the cycle, accompanied by a decrease in estrogen and progesterone. During the first 4 days of menses, certain follicles are recruited from non-proliferating follicles when FSH enters the ovaries. From day 5 through 7, one of the recruited follicles is selected to ovulate while the others undergo atresia, or degeneration. The selected follicle then promotes its own growth and dominates over the others by day 8 (Reed & Carr, 2018). As this follicle grows, the levels of estrogen increase. As the estrogen levels rise, the FSH will drop in response. During the first ten days, luteinizing hormone remains at a steady low level due to inhibition from low estrogen

levels. However, as the maturing follicle produces a surge of estrogen, it stimulates the release of luteinizing hormone (Reed & Carr, 2018). About 34-36 hours after the onset of the surge in luteinizing hormone, ovulation occurs in the mature follicle (Reed & Carr, 2018). The oocyte, or egg, is released from the ovary and luteinizing hormone, GnRH, and estrogen all decrease. The FSH has a small spike around ovulation as well, thought to assist in freeing the oocyte from the

begins after ovulation, normally around day 14 of the menstrual cycle. The follicle that is left over is termed a corpus luteum, hence the luteal phase. This follicle stimulates declining estrogen levels to rise and then drop slightly, progesterone levels (which had been low the whole time) to rise, and inhibin levels that were not present to increase. Inhibin suppresses the release of FSH while progesterone suppresses the release of GnRH. Progesterone stimulates the growth of the uterine or endometrial lining to prepare the egg for implantation in the case of fertilization (Reed & Carr, 2018). If a pregnancy occurred, human chorionic gonadotropin would sustain the corpus luteum. However, without fertilization the corpus luteum continues to degenerate and the release of progesterone, estrogen, and inhibin decrease; this in turn allows GnRH to increase, stimulating FSH (Reed & Carr, 2018). The decrease in progesterone leads to shedding of the uterine lining, also called the endometrial lining, and marks the beginning of the next cycle (Reed & Carr, 2018).

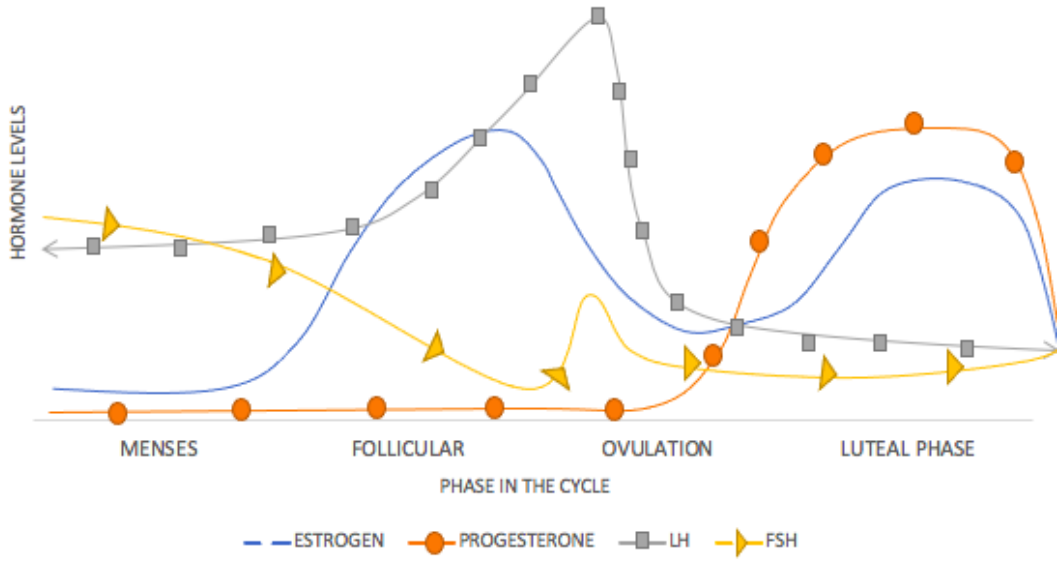
Hormone Fluctuations throughout the Cycle

Noting the individual fluctuation of each hormone throughout the cycle will aid in the understanding of the affects each phase of the cycle has on the female body. Starting with GnRH, a gradual rise all the way until ovulation, around halfway through the cycle, is seen with a gradual decline following. Luteinizing hormone remains low until a sharp peak right before

ovulation and then a sharp decline afterwards. Follicle stimulating hormone (FSH) is high at the beginning of the cycle during menses but then has a slow decline throughout the rest of the follicular phase with a small increase and then decrease around ovulation before declining a bit more through the luteal phase. Near the end of the luteal phase, FSH begins its steady incline leading into the next cycle (Draper et al., 2018). Progesterone levels are very low in the follicular phase. An increase is seen with the corpus luteum and then a decline as the corpus luteum fully degenerates. Lastly, estrogen is very low during menses but then begins to rise until ovulation where it then declines a bit. The corpus luteum spikes another rise in the levels of estrogen in the luteal phase. Estrogen levels decline largely once the corpus luteum degenerates and menses begins (Draper et al., 2018). All of these fluctuations occur in about 28 days, 12 times a year (see Figure 1).

Figure 1

The Menstrual Cycle



Note. The graph is based off the average expected hormone levels of a healthy, eumenorrheic female, providing a visual of the hormone levels in reference to each other throughout the cycle. The symbols do not indicate exact data points but are for differentiation purposes only. Adapted from "The normal menstrual cycle and the control of ovulation," by B. G. Reed, & B. R. Carr, 2018, *Endotext*. CC-BY-NC-ND.

How the Menstrual Cycle Impacts the Female Body

With knowledge of what is occurring with hormone levels at each point in the month, diving into the specifics of how the female body must adapt to continue to perform at a high level in athletics is more feasible. These areas include the most direct factor of premenstrual syndrome (PMS), sports performance as analyzed through health-related fitness and skills-related fitness, and other areas that affect exercises, such as recovery in between sessions.

Premenstrual Syndrome (PMS)

Premenstrual Syndrome is a term often used as a joke to describe irrational behavior in women. However, the slew of symptoms that are associated with PMS should not be taken lightly. Data has shown that 80-95% of females experience recurrent symptoms of PMS, with 5% experiencing symptoms so severe that their daily lives are disrupted (Bharati, 2016). Another study showed a prevalence of 23-31% of reproductive-aged women experiencing symptoms that caused daily life disruption (Direkvand-Moghadam et al., 2014). The Journal of Clinical and Diagnostic Research considers PMS to involve a group of emotional symptoms that may or may not be accompanied with physical symptoms, related to a woman's reproductive cycle and occurring during the luteal phase up to the time of menstruation (Direkvand-Moghadam et al., 2014). Although 17 different symptoms may be categorized under PMS, Freeman (2011) found that using only 6 core symptoms discriminated, just as effectively, whether a woman was experiencing PMS. These symptoms include anxiety/tension, mood swings, aches, appetite/food cravings, cramps, and a decreased interest in activities. Abnormal functioning of the hypothalamic-pituitary-adrenal axis (HPA) leading to flawed adrenal hormone secretion, nutritional defects, and environmental factors have been identified as the main causes of PMS (Direkvand-Moghadam et al., 2014). An additional factor, noted by Bharati (2016), indicates that the rise in ovarian steroid hormones during the menstrual cycle unmasks a calcium deficiency that is otherwise hidden in the rest of the cycle.

PMS is one of the clearest impacts of the menstrual cycle on female athletics. This slew of symptoms is something many females will experience for up to 7 days, every single month. Czajkowska et al. (2015) found that 42.4% of the 75 female athlete subjects aged 16 to 22 years

old had symptoms that were diagnosed as PMS. Having anxiety, mood swings, aches, food cravings, cramps, and a decreased interest in activities understandably effects how the female athlete is feeling during training and competition. These symptoms mimic feeling sick and not much like your normal self. While there are many painkillers and hormonal supplements on the market to manage these symptoms, a study in the Journal of Caring Sciences showed that yoga proves to be an effective form of alleviation from PMS symptoms due to its stress reduction in increasing parasympathetic activity and moderate degree of exercise and toning to the body (Bharati, 2016). It also found calcium supplementation to be of benefit, but not quite as impactful as yoga. Although PMS is definitely not desirable when it comes to athletics, females can take action to mitigate their symptoms.

Measurements of Fitness

While PMS encompasses very obvious symptoms of fluctuations in the menstrual cycle that would affect athletic performance, many wonder whether areas of fitness are truly subjected to the hormonal variances seen throughout each month.

Health-Related Fitness

Health-related fitness involves the components of muscular strength, muscular endurance, cardiovascular endurance, flexibility, and body composition. These components are commonly used to track the progress of athletes or clients following a program. They are also used to identify the health status of an individual, with different tests in each area used to stratify people according to their results.

Muscular Strength. This area of health-related fitness denotes the quantity of force a muscle is able to produce. This can be tested in many different ways, commonly through a 1

repetition maximum (1RM) in the bench press or the back squat. It is interesting to note that estrogen has been found to promote the proliferation and differentiation of skeletal myoblasts, the cells that build muscle, while also influencing the release of growth hormone, insulin-like growth factor-1, and insulin, all of which correlate to muscle mass (Sakamaki-Sunaga et al., 2016). Sakamaki-Sunaga et al. found that training at different frequencies under the same conditions dependent on the current phase of a subject's menstrual cycle did not have an effect on the outcome of a 12- week resistance training program. Another study showed that muscle strength as tested through a Smith machine half-squat remained consistent throughout the different phases of the menstrual cycle for 13 resistance-trained women (Romero-Moraleda et al., 2019).

However, some studies have shown a difference in muscular strength throughout the cycle. For example, Pallavi et al. (2017) tested the muscular strength of 100 healthy females ages 18-24 years old with normal menstrual cycles between 26-32 days long consistent over at least 6 months. Subjects were tested through use of a handgrip dynamometer and Mosso's ergograph during their menstrual phase (classified as phase 1), follicular phase (phase 2), and luteal phase (phase 3). The results showed significantly higher, forceful, and less fatigable muscle contractions during phase 2, the follicular phase, compared to the other two phases tested. In another study, found in the European Journal of Applied Physiology, 9 eumenorrheic females performed a maximal isometric force (MVC) with knee extension throughout their cycle (Tenan et al., 2016). The results showed that strength was significantly lower during the mid-luteal phase compared to the rest of the cycle, where the output seemed to stabilize. While these two studies show a difference throughout the cycle, a systematic review in the Journal of Science and

Medicine in Sport found there to be no variations in MVC or explosive strength throughout the cycle, commenting on the poor quality of most studies that have investigated this topic (Blagrove et al., 2020). Thus, while a female's muscular strength could potentially see variations throughout her cycle, the chances of not seeing any variations are just as great. Results of these studies seem to be very inconclusive, showing the need for further research. What we do know is that while female hormones can often be viewed as the enemy to athletics, estrogen has a clear role in aiding muscle growth (Sakamaki-Sunaga et al., 2016).

Muscular Endurance. Although this area of health-related fitness can get confused with muscular strength, this component focuses on the muscle's ability to exert force continuously without fatiguing. A common test used to measure this is the YMCA-bench press or the push up test. With both, a set amount of weight is used, and repetitions are performed until failure. One study showed that muscle contractions, through use of a handgrip dynamometer, showed lower fatigue rate percentage during the follicular phase compared to the luteal and menstrual phases (Pallavi et al., 2017). This would indicate that the mid-follicular phase would be best for performance in muscular endurance. The study in the European Journal of Applied Physiology mentioned earlier tested tremors during muscular endurance in addition to the MVC previously discussed (Tenan et al., 2016). It was noted that the highest initial tremors were recorded during the mid-luteal phase, but the highest tremors overall were found during the early follicular phase, corresponding with menstruation. However, the researchers expressed that these changes would be negligible in most tasks except for those involving fine motor skills, such as archery, sewing, knitting, or baiting a fishhook. In addition, a study by Fridén et al. (2003) tested muscular endurance with knee extension throughout the different phases of the cycle and noted no

significant difference between phases. While Pallavi et al.'s (2017) study used 100 subjects, which is significantly more than the nine Tenan et al. (2016) or ten Fridén et al. (2003) used, there was no method to which the researcher's verified that subjects were in the phase of the menstrual cycle for which the data was recorded. Fridén et al.'s (2003) study hormonally verified menstrual phase status through blood sampling while Tenan et al. (2016) used basal body temperature to verify menstrual cycle phase. In addition, Pallavi et al.'s (2017) study only tested hand grip strength while the other two studies focused on knee extension, a much more athletically involved movement. Therefore, sifting through all the research shows that muscular endurance is most likely not affected by the menstrual cycle.

Cardiovascular Endurance. This component of health-related fitness encompasses the ability of the heart and lungs to function together in order to provide the necessary oxygen and nutrients for the body during a sustained effort. For endurance athletes, knowing if this piece of health-related fitness is affected by the menstrual cycle is a high priority. A study in the International Journal of Environmental Research and Public Health tested 21 endurance-trained eumenorrheic women with an interval running protocol during three different phases of the cycle defined as the early-follicular phase, late-follicular phase, and mid-luteal phase (Rael et al., 2021). The study analyzed factors such as oxygen consumption, carbon dioxide production, respiratory exchange ratio, breathing frequency, energy expenditure, relative perceived exertion and perceived readiness. Surprisingly, no statistically significant differences were noted in these areas between the three phases. However, there were variations seen in heart rate and breathing frequency, which may indicate that heart rate-based training could be optimal for females. De Jonge (2003) noted that most research declares no changes over the female cycle for maximal

oxygen consumption (VO_{2max}), and females competing in strength-specific and intense anaerobic/aerobic sports do not need to adjust for their menstrual cycle. However, the article also noted that prolonged endurance activity may see a difference depending on the phase of the menstrual cycle. When exercise took place in hot, humid conditions, there was a decrease in time to exhaustion during the mid-luteal phase, a time when resting core temperature is elevated. Therefore, while athletes cannot normally control the environment of their performance, they can utilize this knowledge in training. If it is hot and humid during a workout, coaches should not be surprised by a greater decrease in performance with their females compared to their males, given that some of the females may be in their mid-luteal phase. Female athletes themselves can better understand the fluctuations they see and give grace to themselves.

Flexibility. This area of fitness involves the ability to move each joint through the appropriate range of motion. This component of health-related fitness may not be as significant for most team sport or endurance athletes. However, for gymnasts, acrobats, and dancers, variations in this area would be critical. One study used 20 subjects between the ages of 18 and 35, who practice gymnastics in fitness centers (Melegario et al., 2006). Flexibility was tested through eight different movements using goniometers in the three phases of the menstrual cycle. For these subjects, no significant differences were noted between the phases in regard to degrees of motion. Melegario et al. discussed that while other studies show the increase of the hormone relaxin on the 12^{th} day and 20^{th} day of the cycle to be associated with a decrease in soft tissue tension, the present study results did not agree, as seen in the lack of variation in flexibility of the subjects. Another study examined 20 elite female soccer players over two consecutive menstrual cycles (Campa et al., 2021). The sit and reach test was used to assess flexibility. This study did

show a difference in flexibility throughout the cycle, with a decrease in range of motion occurring during the early follicular phase. Based on these studies, athletes whose sports do not focus on flexibility may experience some variation throughout their cycle but athletes whose sports are centered around flexibility may not experience much difference.

Body Composition. This last component of health-related fitness compares the amount of fat mass an individual has to their non-fat mass, including muscle, bone, and organs. Many athletic teams track body composition in order to follow any changes the athlete may be experiencing. If an athlete is tested at a certain point in their cycle one semester, and then retested the next semester at a different point in their cycle, it is important for the examiner to know whether this will cause inaccurate data. While most research agrees that women experience fluctuations in body mass during their cycle due to fluid retention, or bloating, throughout the cycle, this does not indicate the body composition would also be affected (Hicks et al., 2017). The study by Campa et al. (2021) on elite soccer players mentioned with flexibility found that during the early follicular phase (the time of menstruation), fluid accumulation was increased, as tested through bioelectrical impedance. The author noted that this change did not affect performance of the countermovement jump or 20-meter sprint that was also tested. A study in the International Journal of Exercise Science examined the use of different technology to compare body composition between the follicular and luteal phases of the cycle (Hicks et al., 2017). A Dual energy x-ray absorptiometry, BOD POD, and bioelectrical impedance analysis were all used. All subjects reported feeling more bloated during menses which corresponded with variations in extracellular water throughout the cycle. However, body composition remained consistent through both phases for all three pieces of equipment. Therefore, although athletes

will notice bloating during their period, results from body composition tests can be considered accurate at any point throughout the cycle.

Table 1

Summary of Health-Related Fitness Throughout the Cycle

	Menstruation	Mid-Follicular	Ovulation	Mid-Luteal
Muscular Strength	Unaffected	Unaffected	Unaffected	Unaffected
Muscular Endurance	Unaffected	Unaffected	Unaffected	Unaffected
Cardiovascular Endurance	Unaffected	Unaffected	Unaffected	May be inhibited during prolonged activity in hot/humid environment
Flexibility	Unaffected	May be Enhanced	May be Enhanced	May be Enhanced
Body Composition	Bloating may be noted	Unaffected	Unaffected	Unaffected

Skills-Related Fitness

Skills-related fitness involves six components that are necessary for an individual to have for many different team sports and involve an integration of motor skills and movement patterns. The six components include agility, balance, coordination, power, reaction time, and speed. Individuals who are considered highly athletic would normally excel in a majority of these categories.

Agility. This component of skills-related fitness is defined as the ability to change direction and body position in response to a stimulus. The importance of this factor can be seen in a soccer game when an athlete must quickly change directions to get around their opponent with the ball. There are many different fitness drills that are used to test agility, such as the hexagon agility test, the quick feet test, and the t-test. A 2018 study of females aged 20-24 years

old examined side-step ability throughout the cycle (Sawai et al.). The study found that agility was decreased during the menstrual phase compared to the follicular and ovulatory phases, negatively correlating to fluid retention in the calves. This study also mentioned another study that tested agility performance throughout the cycle, noting the best performance during the first couple post menstruation days and the worst performance occurring on the days leading up to the period and the first couple days of the period (Lebrun, 1993). Therefore, female athletes may find that their performance on agility drills may decline slightly on the days leading up to their menstruation and even for a couple days of their menstruation.

Balance. This involves the ability to control or stabilize the body against movement. Any sport that requires landing on one foot is going to require great balance. This can be seen in obvious ways such as the balance beam and in more inconspicuous ways, such as landing safely on one foot after jumping over a hurdle. The study that tested side-step ability on 13 females aged 20-24 years old also tested static balance throughout the cycle (Sawai et al., 2018). The results showed that total locus length, a factor used to denote how far from a point of perfect balance a subject is, increased significantly during menstruation compared to the other phases of the cycle. Researchers attributed this decrease in performance to the menstrual bleeding itself. All the other factors analyzed in regard to balance were not affected throughout the phases of the cycle. The researchers noted a different study that also analyzed balance throughout the cycle and found a decrease in ability during the menstrual, early luteal, and late-luteal phases in comparison to the follicular phase (Hayashi et al., 2004). This study hypothesized that the increase in estrogen and progesterone during this time is the cause due to the effects these hormones can have on the central nervous system in regard to posture control. Therefore,

although some components of balance have been found to decrease during the time of menstruation, the skill does not seem to be affected completely. Athletes performing during their period may need to allow some grace for their body.

Coordination. This factor is defined as the ability to integrate use of the senses and body parts during movement. In athletics, actions such as soccer ball juggling and basketball dribbling all require great coordination. While there does not seem to be a great amount of valid research in this area of question, there is a study found in Brain and Cognition that investigates the effects of sex hormonal changes throughout the menstrual cycle on functional cerebral asymmetries, which refers to differences in activity seen in the hemispheres of the brain, particularly in fine motor coordination (Bayer & Hausmann, 2012). The results showed that there was a reduction in the degree of dominant hand manual asymmetries during the luteal phase while during the menstrual phase, the asymmetries were reversed in direction, giving the non-dominant hand a slight advantage. While these findings are highly specific to neurological research in brain use and fine motor skills, it is important for female athletes to understand that they may feel different throughout their cycle. The way they approach certain skills may require variance.

Power. Not to be confused with muscular strength, this component of fitness is the ability to exert force *quickly,* combining both speed and muscular strength. The study by Romero-Moraleda et al. (2019) that researched muscular strength variations throughout the cycle through use of a 1RM half squat on a Smith Machine also investigated power output throughout the cycle. The researchers used software associated with an encoder to calculate the mean and peak power output from the product of the force and bar velocity. While small variations in these measurements were noted, no statistical differences were noted during the different phases of the

cycle. Therefore, power output is most likely not affected due to the fluctuations of hormones throughout the menstrual cycle.

Reaction Time. This skill-related component of fitness is described as the ability to respond quickly to a certain stimulus. This is extremely important in following position changes by opponents during play, reacting to the sound of the gun during a race, and making quick decisions throughout a game. Kumar et al. (2013) examined auditory and visual reaction times of 30 eumenorrheic women aged 18-25 years old throughout the menstrual cycle. Results showed that both auditory and visual reaction times were increased during the luteal phase compared to the follicular phase. Another study found that reaction times were longer when hormone levels were low (menstrual and early follicular phase) and shorter when hormone levels were higher (preovulatory and mid luteal phase) (Simić & Ravlić, 2013). These observations also correlated with the rise in body temperature that is found when hormone levels are higher. The researchers noted that other studies demonstrated a higher level of estrogen associated with "shorter movement time in performing reaction time tasks" (Simić & Ravlić, 2013, p.104). While the study was analyzing this in regard to how variations in speed of the central nervous system should be taken into account when conducting neuropsychological studies on women, the same rings true for athletics. Rather than try to ignore these fluctuations, understanding how these fluctuations may influence performance may ease frustrations that athletes may experience.

Speed. This last component of skills-related fitness is defined as the ability to move your body quickly; this is something that is required in almost all anaerobic athletics. A study by Wiecek et al. (2016) found that the results of a 20 second maximal cycling test did not fluctuate depending on whether the 16 female subjects were in their mid-follicular phase or mid-luteal phase. It is interesting to note that this study only tested subjects at two different points in the cycle. This misses the potential for finding other fluctuations at other stages, such as surrounding the time of menstruation. Another study tested 8 females with two repetitions of a 30 second sprint on a non-motorized treadmill with 2 minutes rest in between repetitions. These methods were followed during the early follicular phase, the days just prior to ovulation, and the mid luteal phase (Tsampoukos et al., 2010). Similar to the first study, no significant difference was noticed throughout the different phases of the cycle. Therefore, female athletes should not worry about any shifts in their speed performance from hormonal fluctuations from the menstrual cycle.

Table 2

Summary of Skill-Related Fitness throughout the Cycle

	Menstruation	Mid-Follicular	Ovulation	Luteal
Agility	May be inhibited	May be enhanced	Unaffected	May be inhibited
Balance	May be inhibited	Unaffected	Unaffected	May be inhibited
Coordination	May notice variation	Unaffected	Unaffected	May notice variation
Power	Unaffected	Unaffected	Unaffected	Unaffected
Reaction Time	May be inhibited	Unaffected	May be inhibited	Normal in middle; May be inhibited in second half
Speed	Unaffected	Unaffected	Unaffected	Unaffected

Other Factors Impacting Performance

While the different components of health- and skill-related fitness breakdown the different areas of an athletic performance, every athlete knows that there are factors outside of the game or competition that also play a role in performance. Injury risk, recovery time required between practices, and the utilization of different nutrients all play a role in athletic performance. To grasp the full impact of the menstrual cycle on female athletes, these areas must also be discussed.

Injury Risk

Injury prevention is just as crucial of a component to athletics as skill development is. Understanding the role hormonal fluctuations play in level of injury risk on a given day can and should lead to modified training to combat the risk. Chidi-Ogbolu (2019) notes how estrogen improves muscle mass and strength as well as increases the collagen content of connective tissues. The author specifies that while bone and muscle function are improved with an increase in estrogen, tendons and ligaments decrease in stiffness, and thus lead to increased laxity. Sadly, it has been found that women are 2-8 times more likely than men to rupture their ACL (Chidi-Ogbolu, 2019). The article also mentions a study, among multiple others, that found increased knee laxity during the time of ovulation compared to the other phases of the cycle, observing an increased from 4.7 ± 0.8 mm in the follicular phase to 5.3 ± 0.7 mm in the ovulatory phase. Beynnon et al. (2006) found agreeing results, noting that the risk of an ACL injury was found to increase during the preovulatory phase for alpine skiers. While many studies seem to agree the knee ligament laxity is increased during the preovulatory phase, there are other studies that disagree and claim that knee laxity is not affected by fluctuations of female hormones (Shafiei et

al., 2016). Despite the conflicting research, female athletes should be implementing knee strengthening exercises into their routines to err on the side of caution.

One may wonder why there is an increase in tendon and ligament laxity, but there was not a clear increase in overall flexibility throughout the cycle. Looking at the role of the hormone relaxin, researchers have seen a clear connection between increased levels and a decrease in stiffness of soft tissue (Dehghan et al., 2014). Why was there not a variation in flexibility among gymnasts? Research shows that the ACL has estrogen and relaxin receptors, leading to a more pliable state of the ligament when the receptors are full. Tendons are affected similarly. However, when examining skeletal muscle, the effect is different. Relaxin has been found to aid in decreasing inflammation; it hasn't been found that muscle length is affected by the hormone. Thus, gymnasts who are constantly working on flexibility might not notice a difference throughout the cycle while athletes who don't work on flexibility may experience a larger disparity in ROM due to the decrease in tendon and ligament stiffness when hormones are high.

In addition, a study in the Orthopaedic Journal of Sports Medicine analyzed the width of the tibiofibular syndesmosis, muscle activity, and movement abnormalities during drop landing in 28 young women throughout their menstrual cycles (Okazaki et al., 2017). During the luteal phase, the width of the tibiofibular syndesmosis, hip internal rotation, and knee valgus was greatest. Ankle adduction and eversion was also greatest during this time compared to the follicular and menstrual phases. The study also showed lower gluteus maximus activation prior to landing compared to the other phases. Thus, the results of the study support that female athletes may experience fluctuations in their strength, stability, and ankle laxity throughout their cycle, with injury risk increasing during the luteal phase. Ultimately, it seems that when estrogen

and progesterone are higher than normal, such as during ovulation and the middle of the luteal phase, female athletes may experience an increase in laxity at both the knees and ankles. In application, performing stability strengthening exercises routinely to build up the muscles in the hips and around these joints can increase prevention of injury due to increased disposition at certain times in the cycle.

Although it may seem that women have the short end of the stick with ligament laxity, Chidi-Ogbolu (2019) discusses how the decrease in tendon stiffness proves to be of benefit in reducing risk of muscle injury, noting that women suffer 54% fewer muscle strains than men and are at a lower risk for rupturing their Achilles. In fact, the authors state that women who use oral contraceptives experience a decrease in collagen synthesis since they are experiencing steady levels of estrogen rather than a rise and fall. Women using oral contraceptives have also been found to have greater muscle damage and an increase of delayed onset muscle soreness (DOMS) following exercise. In postmenopausal women, those who use estrogen replacement therapy, which provides a daily rise in estrogen, may have increased tendon collagen synthesis. Therefore, eumenorrheic women experiencing a cyclical rise and fall of estrogen experience a beneficial increase in tendon collagen synthesis and muscle recovery.

Recovery

Being able to hit workouts hard multiple times a week is all dependent on how well an athlete can recover. Optimal recovery equals optimal training. One study in Biomedical Human Kinetics studied the recovery of 8 female runners after a 90-minute running bout at 70% VO_{2max} on a treadmill during their mid-follicular phase and their mid-luteal phase (Hackney et al., 2019). The researchers' outcome measures were the concentrations of blood creatine kinase (CK) and

interleukin-6 (IL-6) at different time intervals following the exercise bout. Biomarker CK is used as a depiction of the level of muscle damage while IL-6 is correspondent to inflammation. The results showed that the biomarker levels remained elevated for longer during the mid-follicular phase, prior to the rise in estrogen before ovulation. When hormone levels are low, female athletes may need to focus on recovery even more or allow for more time in between hard efforts. Koikawa et al. (2020) looked into how sleep may be altered throughout the cycle. Based on the 45 female athletes tested, results showed that sleep was most negatively affected during the time of menstruation, with increased time to fall asleep and less time in deep sleep. Therefore, female athletes may need to be even more diligent in healthy sleep habits, such as putting electronics away a couple hours before the desired sleep time and making sure the environment is cold. These adjustments are especially important during their time of menstruation until just prior to ovulation. Furthermore, adjusting training to the needs of the athletes' complete recovery will allow for better quality in the long run.

Nutrient Utilization

Nutrients provide the energy needed to perform at a high level and determining the amounts of each of the macronutrients needed by an athlete could even be considered an art. Each body is different in the combination of proteins, carbohydrates and fats they need to achieve their desired results. It should be expected that the hormone fluctuations throughout the cycle require specific attention in order to optimize energy and performance. While many studies have shown that carbohydrate supplementation during moderately intense exercise improves exercise time to fatigue by 24-32% in men, there are not many studies on how it impacts women (Bailey, 2000). Looking to decrease this gap in research, a study in the Journal of Applied

Physiology analyzed how carbohydrate supplementation affected fatigue rates through the menstrual cycle on 9 moderately trained women (Bailey, 2000). The women cycled at 70% peak oxygen consumption until they reached exhaustion, consuming 0.6 grams of carbohydrates per kilogram of body weight per hour every 30 minutes. The control group consumed a placebo drink. The results showed that despite the phase of the menstrual cycle, carbohydrate supplementation still improved exercise time to fatigue. A different study demonstrated that in a fasted state, endurance performance is better during the follicular phase than the luteal phase (Campbell et al., 2001). When glucose supplementation was used, however, the differences between phases disappeared. Adding to the results of the previous studies, McLay et al. (2007) demonstrated that while the follicular phase may be characterized by lower muscle glycogen levels in comparison to the luteal phase, carbohydrate loading decreased any differences between phases, as demonstrated in the 9 female subjects who cycled for 75 minutes and then performed a 16-km time trail. Therefore, all the research supports that adequate carbohydrate supplementation during endurance exercise can eliminate any performance disparity caused by the menstrual cycle.

Moving on to the metabolism of proteins throughout the cycle, research has shown that amino acid levels may be decreased, and nitrogen utilization increased during the luteal phase (Draper et al., 2018). These differences have been attributed to the increase in progesterone levels and accompanying protein synthesis in order to prepare the uterus for possible pregnancy with endometrial thickening. Understanding this change in protein metabolism throughout the cycle demonstrates that female athletes cannot fuel the same each day of the month and see the same results in performance. Fueling for females requires working with the fluctuations of the

body rather than maintaining a consistent diet, which would work for males. Ultimately, female athletes may benefit from higher protein percentages in their diet during the luteal phase.

Lastly, similar to protein usage, lipid metabolites have been found to be reduced during the luteal phase compared to the follicular phase (Draper et al., 2018). Researchers have explained this through the increase in lipid synthesis during this time. Therefore, while carbohydrate supplementation seems to remain a consistent need throughout the cycle, female athletes may want to pay special attention to a purposeful intake of fats and proteins during the luteal phase.

How the Menstrual Cycle Impacts Athletes Psychologically

Understanding the psychological impact the menstrual cycle has on female athletes is just as important as analyzing the different ways athletes are affected physically. One study of 140 endurance athletes showed that the majority felt that their fitness and performance was the worst during their menstruation and the best during their late follicular phase (Solli et al., 2020). Whether or not performance is truly affected, these athletes feel that it is, showing the need to address the mental side of the female reproductive hormone fluctuations. Armour et al. (2020) reports that out of 124 Australian athletes ages 16-45 years old, 82% claimed to experience period pain and 83% noted pre-menstrual symptoms that contributed to fatigue and perceived decreases in performance in training and competition during their menstruation. Although the female athletes perceive a difference in how they feel throughout their cycle, sadly these differences are not normally taken into account when training is planned. The study on Australian athletes showed that over 75% of the athletes studied reported having no modifications in their assigned training to work with their menstrual cycle as well as having zero

discussion about their cycle with their coaches (Armour et al., 2020). With such a great majority of female athletes noticing the changes in their body due to their menstrual cycle, it is devastating to see the lack of attention given to these changes in athletics.

Female Athlete Triad and RED-S

Although the menstrual cycle can seem like a battle for women each month, there are so many benefits to the rise and fall of estrogen and progesterone, including the previous discussion in regard to injury risk. Learning to work with your body's fluctuations can lead to a boost in performance. Sadly, some female athletes can go months without getting their period. Skipping a monthly menstruation can seem blissful, but it is actually extremely detrimental to both the woman's health and performance.

Defining the Terms

The female athlete triad can be defined as "the interrelationship among energy availability, menstrual function, and bone mineral density existing on spectra of health to disease" (Tenforde et al., 2020, p.76). Energy availability is affected by both low caloric intake and high energy expenditure due to excessive physical activity (De Oliveira et al., 2018). While the term "female athlete triad" has been around for quite a while, the International Olympic Committee recently coined a new term, Relative Energy Deficiency in Sport (RED-S), in 2014 that recognizes the numerous negative health and performance consequences that occur due to low energy availability in athletes, male and female (Tenforde et al., 2020). The female athlete triad is considered to be a more specific version of RED-S.

The Negative Impact of the Triad and RED-S

The prevalence of the triad in athletics is revealed in a study that assessed 40 elite female endurance athletes (Melin et al., 2015). From this group, 60% had menstrual dysfunctions, 45% had impaired bone health, and 23% had all three components of the female athlete triad. While menstrual irregularities have often been brushed off as a side-effect of intense training and high fitness levels, the negative effects are clear. A decrease in fat mass can lead to a change in leptin production, a cytokine produced in white adipose tissue (De Oliveira et al., 2018). Leptin increases the secretion of GnRH, which directly affects the menstrual cycle. With a decrease in leptin and the stress of training, the secretion of GnRH may be interrupted, altering the menstrual cycle and causing an estrogen deficiency (De Oliveira et al., 2018). Estrogen is necessary for maintaining bone mineral density through its prevention of bone resorption and stimulation of osteoblast activity to create more bone. Low levels of estrogen lead to reduced bone mineral density, and thus, increased risk of stress fractures and osteoporosis. Females with menstrual irregularities have been found to have an increase in cardiovascular risk factors as well (Melin et al., 2015). In addition, amenorrhoeic females have been found to have lower neuromuscular performance, lower glucose levels, and higher cortisol levels compared to eumenorrheic females (Tornberg et al., 2017). Therefore, rather than viewing the menstrual cycle as something to get rid of or ignore, female athletes should embrace the hormonal fluctuations of their body, working alongside it rather than against it.

Conclusion

The research displays the undeniable influence of the menstrual cycle in female athletics. Although initial thought may be that these effects are negative, the fluctuation of reproductive

hormones proves to be of great advantage. Bone health, cortisol levels, neuromuscular health and cardiovascular risk can all be impacted negatively through the absence of a normal menstrual cycle. In addition, while females may experience more ACL ruptures than their male counterparts, they do experience fewer muscular injuries.

Premenstrual syndrome is one of the clearest detriments female athletes may face due to their hormone fluctuations. However, this condition can be improved through proper lifestyle modifications, such as stress alleviation and diet adjustments. Research on different fitness components shows to be highly conflicting, demonstrating a great need for further studies for female athletes. Nevertheless, some general conclusions can be made. Many female athletes may see no difference in their muscular strength or muscular endurance; few may notice they are their strongest during their follicular phase and their muscular endurance may be negatively impacted during menstruation. While general cardiovascular endurance may not be affected, female performance in prolonged endurance activities taking place in hot and humid conditions may be affected. There seem to be no significant impacts on flexibility or body composition throughout the cycle. On the skills-related side of fitness, power, coordination and speed show little need for adjustment in application for athletics. Agility, balance, and reaction time may be negatively impacted during the couple days leading up to and the days of menstruation. Research also shows the female athletes may experience ligament laxity fluctuations throughout their cycle. In order to avoid injury, female athletes should implement stability work into their training, regardless of where they are in their cycle. During the follicular phase, greater attention to recovery may also allow female athletes to perform better. Coaches may want to implement heart rate-based training in order to correctly load athletes during each training session, avoiding

overtraining a stressed athlete. Lastly, female athletes can work with their body through adjusting their nutrition each month, incorporating more fats and proteins in during their luteal phase and consistently refueling with carbohydrates during long sessions.

Although the menstrual cycle is often ignored in female athletics, the psychological impact it has on females expresses the need for greater communication in this area. Rather than feel they need to ignore their bodily changes to perform in athletics like their male counterparts, female athletes can actually enhance their training through understanding their cycle, understanding the changes that occur throughout their cycle that are specific to them as an individual, and implementing the necessary adjustments to work alongside their body rather than against. Learning how God made a woman's body to work allows the female athlete to work more efficiently towards reaching their full potential.

References

Armour, M., Parry, K. A., Steel, K., & Smith, C. A. (2020). Australian female athlete perceptions of the challenges associated with training and competing when menstrual symptoms are present. *International Journal of Sports Science & Coaching*, *15*(3), 316–323. https://doi.org/10.1177/1747954120916073

Bailey, S. P., Zacher, C. M., & Mittleman, K. D. (2000). Effect of menstrual cycle phase on carbohydrate supplementation during prolonged exercise to fatigue. *Journal of Applied Physiology*, *88*(2), 690–697. https://doi.org/10.1152/jappl.2000.88.2.690

Bayer, U., & Hausmann, M. (2012). Menstrual cycle-related changes of function cerebral asymmetries in fine motor coordination. *Brain and Cognition*, *79*(1), 34–38. https://doi.org/10.1016/j.bandc.2012.02.003

Beynnon, B. D., Johnson, R. J., Braun, S., Sargent, M., Bernstein, I. M., Skelly, J. M., et al. (2006). The relationship between menstrual cycle phase and anterior cruciate ligament injury: A case-control study of recreational alpine skiers. *American Journal of Sports Medicine*, *34*, 757–764. https://doi.org/10.1177/0363546505282624

Bharati M. (2016). Comparing the effects of yoga & oral calcium administration in alleviating symptoms of premenstrual syndrome in medical undergraduates. *Journal of Caring Sciences*, *5*(3), 179–185. https://doi.org/10.15171/jcs.2016.019

Blagrove, R. C., Bruinvels, G., & Pedlar, C. R. (2020). Variations in strength-related measures during the menstrual cycle in eumenorrheic women: A systematic review and meta-analysis. *Journal of Science and Medicine in Sport*, *23*(12), 1220–1227. https://doi.org/10.1016/j.jsams.2020.04.022

Campa, F., Levi Micheli, M., Pompignoli, M., Cannataro, R., Gulisano, M., Toselli, S., Greco, G., & Coratella, G. (2021). The Influence of menstrual cycle on bioimpedance vector patterns, performance, and flexibility in elite soccer players. *International Journal of Sports Physiology and Performance*, 1–9. https://doi.org/10.1123/ijspp.2021-0135.

Campbell, S. E., Angus, D. J., & Febbraio, M. A. (2001). Glucose kinetics and exercise performance during phases of the menstrual cycle: Effect of glucose ingestion. *American Journal of Physiology-Endocrinology and Metabolism*, *281*(4). https://doi.org/10.1152/ajpendo.2001.281.4.e817

Chidi-Ogbolu, N., & Baar, K. (2019). Effect of estrogen on musculoskeletal performance and injury risk. *Frontiers in Physiology*, *9*. https://doi.org/10.3389/fphys.2018.01834

Czajkowska, M., Drosdzol-Cop, A., Gałązka, I., Naworska, B., & Skrzypulec-Plinta, V. (2015). Menstrual cycle and the prevalence of premenstrual syndrome/premenstrual dysphoric disorder in adolescent athletes. *Journal of Pediatric and Adolescent Gynecology*, *28*(6), 492–498. https://doi.org/10.1016/j.jpag.2015.02.113

Dehghan, F., Haerian, B. S., Muniandy, S., Yusof, A., Dragoo, J. L., & Salleh, N. (2014). The effect of relaxin on the musculoskeletal system. *Scandinavian Journal of Medicine & Science in Sports*, *24*(4), e220–e229. https://doi.org/10.1111/sms.12149

De Jonge, X.A.K.J. (2003). Effects of the menstrual cycle on exercise performance. *Sports Medicine*, 33**,** 833–851. https://doi.org/10.2165/00007256-200333110-00004

De Oliveira, T. A. P., De Oliveira, G. L., Valentin-Silva, J., Dantas, E. H. M., & Filho, J. F. (2018). Female athlete triad in high performance sports: Implications from performance

and women health. *Journal of Physical Education and Sport*, *18*(4), 2428-2439. http://dx.doi.org.ezproxy.liberty.edu/10.7752/jpes.2018.04365

Direkvand-Moghadam, A., Sayehmiri, K., Delpisheh, A., & Kaikhavandi, S. (2014). Epidemiology of premenstrual syndrome (PMS)-a systematic review and meta-analysis study. *Journal of Clinical and Diagnostic Research*, *8*(2), 106–109. https://doi.org/10.7860/JCDR/2014/8024.4021

Draper, C. F., Duisters, K., & Weger, B. (2018). Menstrual cycle rhythmicity: Metabolic patterns in healthy women. *Scientific Reports*, 1–15. https://doi.org/10.1038/s41598-018-32647-0

Freeman, E. W., Halberstadt, S. M., Rickels, K., Legler, J. M., Lin, H., & Sammel, M. D. (2011). Core symptoms that discriminate premenstrual syndrome. *Journal of Women's Health (2002)*, *20*(1), 29–35. https://doi.org/10.1089/jwh.2010.2161

Fridén, C., Hirschberg, A. L., & Saartok, T. (2003). Muscle strength and endurance do not significantly vary across 3 phases of the menstrual cycle in moderately active premenopausal women. *Clinical Journal of Sport Medicine*, *13*(4), 238–241. https://doi.org/10.1097/00042752-200307000-00007

Hackney, A. C., Kallman, A. L., & Eser Ağgön. (2019). Female sex hormones and the recovery from exercise: Menstrual cycle phase affects responses. *Biomedical Human Kinetics*, *11*(1), 87-89. https://doi.org/10.1007/s00421-015-3258-x

Hayashi C, Ikeda M, Aizawa K, Murai F, Mesaki N. (2004). Change in dynamic and static balance ability during menstrual cycle among young women. *The Japanese Journal of Physical Fitness and Sports Medicine*, *53*, 197–203. https://doi.org/10.7600/jspfsm1949.53.197

Hicks, C. S., McLester, C. N., Esmat, T. A., & McLester, J. R. (2017). A comparison of body composition across two phases of the menstrual cycle utilizing dual-energy x-ray absorptiometry, air displacement plethysmography, and bioelectrical impedance analysis. *International Journal of Exercise Science*, *10*(8), 1235–1249. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5786198/

Koikawa, N., Takami, Y., Kawasaki, Y., Kawana, F., Shiroshita, N., Ogasawara, E., & Kasai, T. (2020). Changes in the objective measures of sleep between the initial nights of menses and the nights during the midfollicular phase of the menstrual cycle in collegiate female athletes. *Journal of Clinical Sleep Medicine: Official Publication of the American Academy of Sleep Medicine*, *16*(10), 1745–1751. https://doi.org/10.5664/jcsm.8692

Kumar, S., Mufti, M., & Kisan, R. (2013). Variation of reaction time in different phases of menstrual cycle. *Journal of Clinical and Diagnostic Research : JCDR*, *7*(8), 1604–1605. https://doi.org/10.7860/JCDR/2013/6032.3236

Lebrun C. M. (1993). Effect of the different phases of the menstrual cycle and oral contraceptives on athletic performance. *Sports Medicine (Auckland, N.Z.)*, *16*(6), 400–430. https://doi.org/10.2165/00007256-199316060-00005

McLay, R. T., Thomson, C. D., Williams, S. M., & Rehrer, N. J. (2007). Carbohydrate loading and female endurance athletes: effect of menstrual-cycle phase. *International Journal of Sport Nutrition and Exercise Metabolism*, *17*(2), 189–205. https://doi.org/10.1123/ijsnem.17.2.189

Melegario, S. M., Simão, R., Vale, R. G. S., Batista, L. A., & Novaes, J. S. (2006). A influência do ciclo menstrual na flexibilidade em praticantes de ginástica de academia. *Revista*

Brasileira De Medicina Do Esporte, *12*(3), 125–128. https://doi.org/10.1590/s1517-86922006000300003

Melin, A., Tornberg, Å. B., Skouby, S., Møller, S. S., Sundgot-Borgen, J., Faber, J., Sidelmann, J. J., Aziz, M., & Sjödin, A. (2015). Energy availability and the female athlete triad in elite endurance athletes. *Scandinavian Journal of Medicine & Science in Sports*, *25*(5), 610–622. https://doi.org/10.1111/sms.12261

Okazaki, M., Kaneko, M., Ishida, Y., Murase, N., & Katsumura, T. (2017). Changes in the width of the tibiofibular syndesmosis related to lower extremity joint dynamics and neuromuscular coordination on drop landing during the menstrual cycle. *Orthopaedic Journal of Sports Medicine*, *5*(9), 1-7. https://doi.org/10.1177/2325967117724753

Pallavi, L. C., Souza, U. J. D., & Shivaprakash, G. (2017). Assessment of musculoskeletal strength and levels of fatigue during different phases of menstrual cycle in young adults. *Journal of Clinical & Diagnostic Research*, *11*(2), 11–13. https://doi.org/10.7860/JCDR/2017/24316.9408

Rael, B., Alfaro-Magallanes, V. M., Romero-Parra, N., Castro, E. A., Cupeiro, R., Janse de Jonge, X., Wehrwein, E. A., & Peinado, A. B. (2021). Menstrual cycle phases influence on cardiorespiratory response to exercise in endurance-trained females. *International Journal of Environmental Research and Public Health*, *18*(3), 860. https://doi.org/10.3390/ijerph18030860

Reed, B. G., & Carr, B. R. (2018). The normal menstrual cycle and the control of ovulation. *Endotext*. https://www.ncbi.nlm.nih.gov/books/NBK279054/.

Romero-Moraleda, B., Coso, J. D., Gutiérrez-Hellín, J., Ruiz-Moreno, C., Grgic, J., & Lara, B. (2019). The influence of the menstrual cycle on muscle strength and power performance. *Journal of Human Kinetics*, *68*, 123–133. https://doi.org/10.2478/hukin-2019-0061

Sakamaki-Sunaga, M., Min, S. , Kamemoto, K. , Okamoto, T. & (2016). Effects of menstrual phase–dependent resistance training frequency on muscular hypertrophy and strength. *Journal of Strength and Conditioning Research*, *30*(6), 1727-1734. https://doi.org/10.1519/JSC.0000000000001250.

Sawai, A., Tochigi, Y., Kavaliova, N., Zaboronok, A., Warashina, Y., Mathis, B. J., Mesaki, N., Shiraki, H., & Watanabe, K. (2018). MRI reveals menstrually-related muscle edema that negatively affects athletic agility in young women. *PloS ONE*, *13*(1). https://doi.org/10.1371/journal.pone.0191022

Shafiei, S. E., Peyvandi, S., Kariminasab, M. H., Azar, M. S., Mehdi Daneshpoor, S. M., Khalilian, A., & Aghajantabar, Z. (2016). Knee laxity variations in the menstrual cycle in female athletes referred to the orthopedic clinic. *Asian Journal of Sports Medicine*, *7*(4), 1–4. https://doi.org/10.5812/asjsm.30199

Simić, N., & Ravlić, A. (2013). Changes in basal body temperature and simple reaction times during the menstrual cycle. *Archives of Industrial Hygiene and Toxicology*, *64*(1), 99–106. https://doi.org/10.2478/10004-1254-64-2013-2167

Solli, G. S., Sandbakk, S. B., Noordhof, D. A., Ihalainen, J. K., & Sandbakk, Ø. (2020). Changes in self-reported physical fitness, performance, and side effects across the phases of the

menstrual cycle among competitive endurance athletes. *International Journal of Sports Physiology and Performance*, 1–10. https://doi.org/10.1123/ijspp.2019-0616

Tenan, M., Hackney, A., Griffin, L., Tenan, M. S., & Hackney, A. C. (2016). Maximal force and tremor changes across the menstrual cycle. *European Journal of Applied Physiology*, *116*(1), 153–160. https://doi.org/10.1007/s00421-015-3258-x

Tenforde, A. S., Beauchesne, A. R., Borg-Stein, J., Hollander, K., McInnis, K., Kotler, D., & Ackerman, K. E. (2020). Awareness and comfort treating the female athlete triad and relative energy deficency in sport among healthcare providers. / Bewusstsein über und kenntnisse bei der behandlung der „female athlete triad“ und des relativen energiedefizits im sport. *German Journal of Sports Medicine / Deutsche Zeitschrift Fur Sportmedizin*, *71*(3), 76–80. https://doi.org/10.5960/dzsm.2020.422

Tornberg, Å. B., Melin, A., Koivula, F. M., Johansson, A., Skouby, S., Faber, J., & Sjödin, A. (2017). Reduced neuromuscular performance in amenorrheic elite endurance athletes. *Medicine and Science in Sports and Exercise*, *49*(12), 2478–2485. https://doi.org/10.1249/MSS.0000000000001383

Tsampoukos, A., Peckham, E. A., James, R., & Nevill, M. E. (2010). Effect of menstrual cycle phase on sprinting performance. *European Journal of Applied Physiology*, *109*(4), 659–667. https://doi.org/10.1007/s00421-010-1384-z

Wiecek, M., Szymura, J., Maciejczyk, M., Cempla, J., & Szygula, Z. (2016). Effect of sex and menstrual cycle in women on starting speed, anaerobic endurance and muscle power. *Physiology International*, *103*(1), 127–132. https://doi.org/10.1556/036.103.2016.1.13