DO THE DIFFERENT PHASES OF THE MENSTRUAL CYCLE INFLUENCE MAXIMAL STRENGTH CHARACTERISTICS IN FEMALE TEAM SPORT ATHLETES?

A Thesis submitted by

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ABSTRACT

The relationship between the menstrual cycle and various markers of health is complex and variable, influenced by the ever-changing associated hormonal profile. Female athletes have reported negative impacts on daily life and training as a result of their menstrual cycle, such as abdominal and back pain and migraines, which can result in missed training sessions or needing to alter the intensity or volume of their training sessions. It is important to understand how the unique physiology of female athletes influences their ability to perform, and with only 35-37% of sports science research participants being female, it is imperative to increase representation of female athletes in sport science research. This study investigates the effect of menstrual cycle phase on maximal strength in team sport athletes. Eumenorrheic female athletes (N=10, age; 25.3 ± 4.5yrs, weight; 70.2 ± 11.6kg) undertook maximal isometric squat testing three times per week for one complete menstrual cycle after reporting two months of consistent menstrual cycle activity. Absolute and relative maximal strength and rate of force development were analysed at each phase of the menstrual cycle as a group. Data were also assessed individually to identify athletes with similar trends in their strength profile across the menstrual cycle, resulting in three individual groups. As a collective, there were no significant differences in maximal strength characteristics across the menstrual cycle phases tested. There were significant differences ($P<0.05$) in absolute peak force (APF) and relative peak force (RPF) between Menstrual Phase (MP) and Follicular Phase (FP), MP and Luteal Phase (LP), and Ovulation (OV) and LP in Individual Group One with reduced peak force in FP (-10.5% APF, -7.7% RPF), LP (-13.5%, -13%), and OP (-10%, -11.8%) respectively. There were significant differences in Individual Group Two between FP and OP, and FP and LP for APF and RPF with decreased peak force in FP for both comparisons (-12.6%, -12.4% & -15.2%, -18.3%). Perception of how the menstrual cycle affects performance was also evaluated against individual force data. Athletes' perception of their performance only matched to objective data 20% of the time. Considering the menstrual cycle can affect individuals differently, assessing menstrual cycle data collectively may prohibit understanding of how individual athletes are impacted across the various menstrual cycle phases. Thus, assessing data individually or grouping data sets with similar menstrual cycle trends may provide more nuanced information about the influence of menstrual cycle phase on strength characteristics, which could have implications for athletes' training.

CERTIFICATION OF THESIS

I, Kurt Vogel declare that the Master Thesis entitled “Do the Different Phases of the Menstrual Cycle Influence Maximal Strength in Team Sport Athletes?” is not more than 40,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references, and footnotes.

This Thesis is the work of Kurt Vogel except where otherwise acknowledged, with the majority of the contribution to the papers presented as a Thesis by Publication undertaken by the student. The work is original and has not previously been submitted for any other award, except where acknowledged.

Date: 10/09/2023

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Student and supervisors’ signatures of endorsement are held at the University.

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DEDICATION

I would like to dedicate this research to all of those who strive for a greater voice, those that challenge the current systems, those who do not give up and will continue to do more for the generations to come.

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ABBREVIATIONS

Abbreviation	Complete Phrase / Term
LH	Luteinising Hormone
FSH	Follicle Stimulating Hormone
HC	Hormonal Contraceptives/Hormonal Contraception
SJFT	Special Judo Fitness Test
1RM	One repetition maximum
Yo-Yo IET	Yo-Yo Intermittent endurance test
SPSS	Statistical Package for the Social Sciences
SD	Standard Deviation
SE	Standard Error
N	Newtons
N/kg	Newtons per kilogram of bodyweight
µg	Micrograms
mg	Milligrams
MP	Menstruation Phase
FP	Follicular Phase
OP	Ovulatory Phase
LP	Luteal Phase
PM	Premenstrual Phase
APF	Absolute Peak Force
RPF	Relative Peak Force
RFD100	Rate of Force Development at 100ms
RFD200	Rate of Force Development at 200ms
Qty	Quantity

CHAPTER 1: INTRODUCTION

In recent years there has been a dramatic rise in female sport participation and accompanying female professional national leagues in sports such as football, rugby league, rugby, and cricket (Eime et al., 2019; Football Australia, 2020). Although there are known variations between female and male athletes, training protocols in female sport are predominantly underpinned by research undertaken in male athlete populations (Costello et al., 2014; Emmonds et al., 2019). For instance, when exploring performance literature regarding the "female athlete" and the "female sporting environment" compared to research conducted in male athletes over the past ten years, Emmonds et al. (2019) retrieved 196 articles with the search term of "injury" and "rugby" and "female", and 602 articles when "female" was replaced with "male". Furthermore, Costello et al. (2014) reported that only 35-37% of research participants across three major sports science journals (Medicine and Science in Sports and Exercise; British Journal of Sports Medicine; and American Journal of Sports Medicine) are female. This disparity may reflect the fact that, historically, there have been fewer high-performance opportunities for female athletes when compared to male athletes both in Australia and internationally (*Chapter 4 - Elite Participation. About time! Women in sport and recreation in Australia*, 2006; Deaner et al., 2012). In addition to participation numbers, other barriers may exist within female sport that limit the ability to conduct research, such as insufficient training time, lack of resources and equipment, part time or inappropriately qualified sports science and strength and conditioning staff, and limited funding (Emmonds et al., 2019). However, professional female sports are continually gaining momentum and representation at the elite level, with Australian female athletes outnumbering male athletes for the first time at the 2016 Rio Olympic Games, and 45% of overall participants being female (IOC, 2020; Settimi, 2016). Thus, it is important to understand how the unique physiology of female athletes influences their ability to perform, which relies upon representation in sports science research.

The menstrual cycle is a unique and complex female phenomenon controlled by specific hormonal fluctuations, and lasts an average of 28 days, with normal variations between 21 and 35 days (Bull et al., 2019). The menstrual cycle is commonly split into two phases; the follicular and luteal phases, separated by ovulation. The follicular phase starts at the beginning of menstruation (day 1) and ends at day 14. The luteal phase starts from day 14 and ceases on day 28, the day prior to menstruation. Day 14 is typically when ovulation occurs, assuming a 28-day cycle. Four menstrual-related hormones fluctuate across the menstrual cycle; oestrogen, progesterone, luteinising hormone and follicle stimulating hormone (Stricker et al., 2006). The fluctuations of these hormones are key indicators that separate the different phases of the menstrual cycle and are important to consider when evaluating female-related sports science research.

The current studies that have been conducted are variable in regards to research methodology, the population studied, effect-size, menstrual cycle verification and many other factors, which makes it difficult to establish firm conclusions on whether there is any influence of the menstrual cycle on performance (McNulty et al., 2020). For instance, Sarwar et al. (1996) demonstrated that maximal strength of the knee extensor was greater in the follicular phase, whereas a similar study by Miller (2020) showed no difference between menstrual cycle phases in moderately active women. However, in National-level athletes Graja et al. (2020) found a decrease in maximal strength of the knee extensor in the late-luteal phase. Thus, there is little consensus in the literature regarding the influence of menstrual cycle phase on physical performance. Nevertheless, new research and practice has started to focus on potential adaptations of training based off hormonal fluctuations underpinned by physiological theory (Rowan, 2020; Vargas-Molina et al., 2022). These explanations include the enhanced recovery potential of increased oestrogen during the follicular phase which may allow athletes to train at higher volumes (Campbell & Febbraio, 2001), and the increased inflammation leading into premenstrual symptoms during the luteal phase that may impair performance and the ability to recover (Takeda et al., 2015). However, to manipulate an entire teams' schedules based on primary physiology may be difficult in current environments where resources and staff may be limited, particularly when there is limited evidence to suggest such physiological changes influence performance on a group level (Julian et al., 2020).

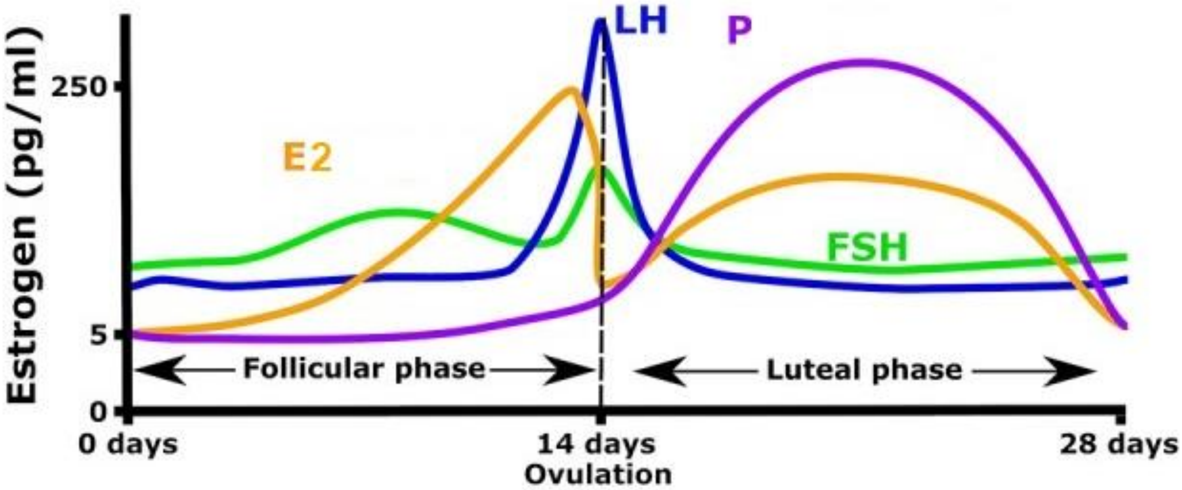
This study represents an additional contribution of literature to the existing body of research and gives greater representation to female athletes in sports science research. Moreover, this study provides further evidence to establish the impact of female physiology on sporting performance, which is key to promoting the best health and performance outcomes for our female athletes. Therefore, the aim of this study was to determine if the different phases of the menstrual cycle are associated with different maximal strength characteristics in female team sport athletes. Based on the theoretical physiology combined with select existing research, it was hypothesised that maximal strength (and associated characteristics) will be lower during the luteal phase.

CHAPTER 2: LITERATURE REVIEW

2.1 The menstrual cycle

In people who menstruate, menstrual-cycle related hormonal fluctuations commence during puberty and occur due to an increase in luteinising hormone and follicle stimulating hormone production which leads to the process of ovulation (in preparation for potential pregnancy) (Thiyagarajan et al., 2020). The start of the menstrual cycle is indicated by day one of menstruation, which refers to a shedding of uterine lining that leads to bleeding in the absence of implantation of an embryo (Thiyagarajan et al., 2020). The average menstrual cycle lasts 28 days, with evidence showing normal variations from 21 to 35 days (Bull et al., 2019); however cycle length can be shorter or longer in those with those with menstrual disorders, such as polycystic ovary syndrome (PCOS) (Fraser et al., 2011; Munro et al., 2022). Within the menstrual cycle there are three distinct phases, characterised by different variations of hormones: the follicular phase, ovulation, and the luteal phase (Figure 1). However, there is substantial fluctuations in different sex hormones within the follicular phase and the luteal phase. Due to these hormonal fluctuations phases are sometimes further broken down into the menstruation (or early follicular) phase and late follicular phase, and the early/mid-luteal and pre-menstrual (or late luteal) phase, respectively. Based on a 28-day cycle, the follicular phase (which contains the menstrual bleed) occurs from Day 1 to Day 14, ovulation occurs 14 days prior to the start of the next menses, and the luteal phase occurs from day 14 to day 28 and ends at the cessation of the next menses. During the follicular phase, oestrogen gradually rises until ovulation (~149 pmol/L to ~671 pmol/L), whilst progesterone remains low (~0.64nmol/L to ~2.54nmol/L)(Stricker et al., 2006). Just prior to ovulation, oestrogen drastically decreases before rising gently and then falling gently over the luteal phase (~313pmol/L to ~496pmol/L to ~327pmol/L)(Stricker et al., 2006). At ovulation, progesterone begins to rise rapidly until the mid-luteal phase, and then decreases at a similar rate by the end of the luteal phase and the start of menses (~13.7nmol/L to ~26.3nmol/L to ~14nmol/L)(Stricker et al., 2006). Luteinising hormone and follicle-stimulating hormone also have varied levels in the menstrual cycle but are specific to ovulation (LH ~5.7 IU/L to ~41.2 IU/L to ~7.9IU/L; FSH ~4.66IU/L to ~12.8

IU/L to 5.6IU/L) (Stricker et al., 2006). The menstrual cycle-related hormonal changes are represented in Figure 1 (Chidi-Ogbolu & Baar, 2018).



Legend: E2 – Oestrogen/Oestradiol, LH – Luteinising Hormone, P – Progesterone, FSH – Follicle Stimulating Hormone

Figure 1: Hormonal fluctuation during a normal menstrual cycle, from Chidi-Ogbolu and Baar (2018)

2.2 Verification of the menstrual cycle

To accurately measure the potential effects of the menstrual cycle on performance, it is important to objectively verify menstrual cycle phase at the time of each test. Most tests used to verify menstrual cycle phase focus on ovulation to differentiate the follicular and luteal phases of the menstrual cycle (Janse et al., 2019). This is an important distinction to ensure anovulation (absence of ovulation) and luteal phase defects are not present, which reflects a different hormonal profile when compared to women with ovulatory cycles (Janse de Jonge, 2003; Janse de Jonge et al., 2019). Characterised by low concentrations of progesterone in the latter phase of the cycle, these disturbances are quite common in regularly menstruating women who exercise (Schliep et al., 2014). For example, recreational runners have been reported to have a high frequency of luteal phase defects (42%), anovulation (12%), and inconsistency between menstrual cycles (De Souza et al., 1998). As such, verification of the menstrual cycle (including evidence of ovulation) allows for the identification of women with a regular cycle and no menstrual cycle disturbances, so that valid conclusions on the effects of the menstrual cycle phases on sporting performance can be drawn.

While the follicular phase can vary in length, the luteal phase is consistently 14 days (Reed & Carr, 2000). Therefore, verification of ovulation occurs 14 days prior to menses. Blood collection is required to confirm that female sex hormone concentrations are indicative of the correct menstrual phase. Past research has taken multiple approaches to verifying the menstrual cycle in regard to the type(s) of collection (e.g., blood analysis, temperature tracking, ovulation predictor kits), timing of collection, and comparison between phases (Allen et al., 2016). This includes comparing early-follicular phase to the late follicular (or pre-ovulation) phase (e.g., Stephenson & Kolka, 1999), comparing early-follicular (e.g., Stachenfeld et al., 1999) or mid-follicular phases to the mid-luteal phase (e.g., Lawrence et al., 2008), comparing five different time points throughout the menstrual cycle (e.g., Lee et al., 2010), or testing weekly then allocating results to the menstrual cycle phase based on the first day of bleeding (e.g., Sarwar et al., 1996). However, some research does not use blood sampling for menstrual cycle phase confirmation (Güler, 2020; Lara et al., 2020; Shakhlina, RRoda, et al., 2016), despite evidence that a single blood samples in each phase (follicular and luteal) can be taken for verification of the menstrual cycle in those with regular cycles (Ahmad et al., 2002). Ahmad et al. (2002) demonstrated that measurements taken between days 6 to 11 after the start of the previous menses for oestrogen, and days 17 to 21 after the start of the previous menses for progesterone, is accurate for menstrual cycle verification. The variability in testing days is utilised to match the length of the women's menstrual cycle (e.g., in women with a consistent 30-day cycle, luteal phase testing should occur between days 19 to 23). These times of collection are consistent with hormone levels where oestrogen and progesterone concentrations, respectively, are at their highest.

The timing of testing within each day is also an important consideration. The variability of oestrogen and progesterone has been reported over a 24-hour period, with variations of oestrogen in the mid-luteal phase as great as 30ng/mL within only three hours (Filicori et al., 1984). Concentrations of oestrogen and progesterone have been shown to be highest in the morning (Bao et al., 2003), therefore consistent diurnal timing of blood sampling is imperative. Furthermore, when training intensities are introduced in physical exercise (aerobic exercise and other sporting activities) that lead to persistent fatigue and persistent soreness (very demanding training or overreaching) then it can result in altered LH secretion and an increase in catecholamine production, negatively impacting gonadotropin-releasing hormone, oestrogen and progesterone (Armstrong & Stuenkel, 2005; Keizer & Rogol, 1990; Le Meur et al., 2013). Further studies demonstrate that acute endurance and resistance training exercise may increase serum oestrogen and testosterone concentrations (Copeland et al., 2002), however the effects are yet to be fully elucidated. Testosterone is another hormone influenced by acute and chronic anaerobic and aerobic exercise, and resistance training (Cook, Crewther, et al., 2021; Enea et al., 2009; Vingren et al., 2010). The interactions between oestrogen, progesterone, and testosterone require consideration, as Bunt (1990) reported that two women can have similar levels of one hormone, but varying levels of another, which may influence physiological responses during exercise such as glycogen utilisation during endurance exercise and physiological responses for regular menstrual cycle function such as delayed puberty, amenorrhea (Bunt, 1990).

2.3 Hormonal contraceptives

The interplay between the menstrual cycle and physical performance can be further confounded by the use of hormonal contraceptives. Hormonal contraceptives are a form of birth control that contain varying combinations and concentrations of synthetic oestrogen and/or progesterone to prevent pregnancy. They are prescribed in multiple forms (Table 2) that change the hormonal profile of females to induce physiological changes that prevent pregnancy and affect the regular menstrual cycle (Rivera et al., 1999). One survey found that out of 430 elite female athletes, 69.8% had previously used hormonal contraceptives, with 49.5% currently using hormonal contraceptives (Martin et al., 2018). It was also found that nearly a third of oral contraceptive (OC) users perceived the ability to predict or manipulate menstruation as a benefit of OC use, whilst in another survey 43.5% of oral contraceptive-using competitive athletes planned to manipulate menstruation (Schaumberg et al., 2013). This is common practice amongst athletes to avoid menstruation of during events such as, holidays, or major sporting competitions (Schaumberg et al., 2018). Moreover, where a coach/team doctor was involved in the decision of prescription of hormonal contraceptives for the athlete, reasons included "in attempt to reduce monthly fluctuations in my performance and fatigue" (Martin et al., 2018). Reasons involved in selecting which type of HC to use included, "higher level of oestrogen", "apparently lowest oestrogen" and "low hormones". It is evident that some athletes currently attempt to manipulate their training and sport through the use of hormonal contraceptives, despite the potential for physical performance being negatively impacted by HC use (Elliott-Sale et al., 2020).

Table 1 Different Types of Hormonal Contraceptives in Australia

Type	Hormones Released	Concentration	Frequency
Oral Contraceptive Pill	Oestradiol combined with Progestogen	20-3000µg 100-3000µg (>30 brands, >20 different variations)	Daily
Mini Pill	Levonorgestrel Norethisterone	30µg 350 µg	Daily
Implants	Etonogestrel (progestin)	68mg	Replaced every 3 years
Injection	Medroxyprogesterone acetate (progestin)	150mg/mL (single dose	Injection every 3 months
Intravaginal Ring	Ethinyl oestradiol (oestrogen) Combined with etonogesterel (progestin)	11.7mg (0.015mg/day) 2.7mg (0.120 mg/day) For 3 weeks	Ring lasts three weeks, remove for one week. Replace.
Hormonal Intrauterine Device	Levonorgestrel (progestogen)	19.5mg 52mg (20µg/24hrs)	
Emergency Contraception (Pill)	Levonorgestrel (progestogen) Ulipristal acetate (progesterone receptor modulator)	1.5mg 30mg	Single use – emergency

Source: National Prescribing Service Medicine Wise,(MedicineWise, 2021; Stewart & Black, 2015) and Family Planning Victoria.(Victoria, 2019)

While the effect of hormonal contraceptive use on exercise performance is an important avenue for future research, this study is focused on athletes with a natural menstrual cycle. Thus, this review of the literature is henceforth focused on research which has investigated the effect of the menstrual cycle on exercise performance in the absence of hormonal contraceptive use.

2.4 The menstrual cycle and sports performance

2.4.1 Athletes perception of menstrual cycle effects on sports performance

Sports performance can be quantified in multiple ways; subjective feedback from coaches, the objective results of an event or sport, and even assessing strength and fitness tests to associate these with performance outcomes (Gabbett et al., 2017). Female athletes have subjectively reported negative impacts on daily life, training and game day performance related to their menstrual cycle (Bruinvels et al., 2016). This includes experiencing symptoms such as abdominal pain, back pain, and migraines which may result in missed training sessions or changing intensity or volume of a training session (Martin et al., 2018).

Armour et al. (2020) surveyed 124 female athletes across both individual and team-based sports and reported that 50% perceived their training to be negatively affected by their menstrual cycle. This number increased to 56.2% who perceived game day to be negatively affected. Notably, 70.9% of athletes in the study reported feeling 'more easily fatigued' during training either just before or during menstruation. Despite the high numbers of athletes affected, 76.3% of participants did not discuss these variations in fatigue with their coach or trainer. This is an important consideration as high volumes of training without sufficient recovery negatively impacts the stress-recovery balance (Jayanthi & Brenner, 2017). Athletes with lower mood and higher acute training loads are associated with increased risk of injury, whilst higher chronic training loads are associated with increased risk of illness (Watson et al., 2017). This suggests a potential link between high training load, fatigue accumulation and overall stress. (Kalkhoven et al., 2020).

In young female athletes (16.5 ± 1.6 years of age) there is preliminary evidence to support the contention that menstrual symptoms increase athlete training load (Cristina-Souza et al., 2019). Cristina-Souza et al. (2019) assessed Training Impulse (TRIMP), training monotony, and training strain across the follicular phase, ovulation, and luteal phase. TRIMP, monotony and strain are three methods to assess intensity and volume of training. Significantly higher values were reported in the follicular phase compared to ovulation for training monotony and strain (both p = 0.03), but not for TRIMP (p = 0.22). Monotony, strain, and TRIMP are methods to monitor training load, yet only monotony and strain were significantly relevant. Additionally, it was reported that menstrual cycle symptoms were elevated in the follicular phase, but training sessions during ovulation were shorter, which may affect the results. While it is interesting to see variation in training load according to menstrual cycle phase, this is a single finding that is inconsistent with the vast majority of research showing that menstrual symptoms typically present in the luteal phase leading into menstruation (Thiyagarajan et al., 2020). However, the study did report between-phase differences in training monotony and strain which needs to be further explored. Nevertheless, rating of perceived exertion values were comparable across menstrual cycle phases, supporting similar outcomes of previous studies on perception (Armour et al., 2020; Gabbett et al., 2017).

In opposition to the majority of literature, Ozbar et al. (2017) surveyed 160 female athletes at a "distinguished" level across football, handball, volleyball, and basketball and found that 75% of athletes felt well (on a scale of very well, well, bad, and very bad) before and during menstruation, despite 55.6% of athletes sometimes experiencing pain during menstruation. The vast majority (91.3%) of athletes in this study believed that menstruation positively effects their performance. The authors also reported that athletes found that exercise positively affected menstrual-related pains in 83.1% of participants.

Collectively, these varying surveys utilised across studies reveal inconsistencies surrounding the perceptions of the menstrual cycle and how it relates to performance. Similar inconsistencies in results of research are seen across studies quantifying physical performance and especially maximal strength.

2.4.2 Physical performance

Studies evaluating the effects of the menstrual cycle on physical performance do not reach a consensus, as illustrated in Table 2. Güler (2020) investigated the effect of the menstrual cycle on the physical performance of 15 amateur volleyball players. Athletes participated in the sit and reach, push up, sit up, vertical jump, and 30m speed tests, with tests being undertaken twice during the menstrual cycle: on day 2 and 23 of the cycle (the early follicular and mid-late luteal phase, respectively). The tests assessed distance for the sit and reach test and vertical jump, the total number of push ups and sit ups, time (in seconds) for the 30m speed test, and anaerobic power was also assessed using vertical jump. This study showed no significant differences between day 2 and 23 for all tests, respectively (27.20 ± 5.41 & 27.87 ± 4.97; 33.73 ± 3.58 & 30.13 ± 4.21; 29.33 ± 9.88 & 23.93 ± 9.24; 31. ± 12.28 & 29 ± 12.13; 4.08 ± 0.69 & 4.14 ± 0.59; 73.77 ± 3.20 & 69.84 ± 3.25). This study was, however, limited by the assessment of menstrual cycle. The inclusion criteria only required regular menstruation (with no clarification on the history of length of this regularity) and not currently taking oral contraceptives. It was not clear as to whether participants taking other forms of hormonal contraceptives were excluded. Furthermore, no blood analysis verification was performed to determine menstrual cycle phase which may compromise the accuracy of the results to ensure anovulation or luteal defects are not present.

Judo athletes reported similar results, with no significant differences found between LP and FP on performance of the Wingate test (Peak power output: 7.11W/kg ± 1.03, 6.48 ± 1.15, respectively) or Special judo fitness test (SJFT) in young female judokas (Number of throws: 25.63 ± 0.74, 24.88 ± 0.99, respectively) (Stefanovsky et al., 2016). The only significant difference noted was the number of throws in the first 15 seconds of the SJFT, with athletes achieving a greater number of throws during the luteal phase (5.88 ± 0.353) compared to the follicular phase (5.38 ± 0.52). Comparable results were also found in a study on female kickboxing athletes, where multiple strength and fitness tests were assessed in the early-follicular phase, mid-follicular phase and the late luteal phase, with no significant differences across any test value (Köse, 2018). Maximal strength and strength endurance were assessed on the bench press exercise, with a 1-repetition maximum (1RM) test used to assess maximal strength (41.20kg ± 6.54, 41.7kg ± 6.40, 41.65kg ± 6.72, respectively) and the maximal number of repetitions completed at 60% of 1RM used to assess strength-endurance (20.88 ± 6.45, 20.55 ± 4.41, 21.15 ± 6.08, respectively). Anaerobic power (Peak power output) was assessed using a Wingate test (554.56W ± 109.00, 556.06W ± 146.18, 555.50W ± 107.29, respectively) and aerobic capacity (Running time in minutes) was assessed using the Bruce Protocol (17.01 ± 2.45, 16.51 ± 2.12, 16.85 ± 1.68, respectively) (Köse, 2018).

In contrast, inconsistent results were reported in a study of nine sub-elite female soccer players who completed a Yo-Yo Intermittent endurance test (Yo-Yo IET), countermovement jump and 3 x 30m sprints at different stages of their menstrual cycle (Julian et al., 2017). Tests were conducted during the early follicular phase and mid luteal phase. This study concluded that there is a potential reduction in maximal endurance performance during the luteal phase of the menstrual cycle, with the total distance covered during the Yo-Yo IET in the follicular phase being 3289 metres compared to only 2822 metres in the luteal phase. Resting heart rate (beats per minute) was also higher (105 ± 12 LP; 97 ± 16 FP) and blood lactate values were lower (6.9 ± 1.9 LP; 8.7 ±2.2 FP) in the luteal phase compared to the follicular phase, which indicate athletes were already in a potentially fatigued state during this phase. The 30m speed test recorded 5m, 10m and 30m split times (in seconds) and reported no significant differences (1.1 ± 0.1 & 1.1 ± 0.1; 1.9 ± 0.1 & 1.9 ± 0.1; 4.7 ± 0.1 & 4.7 ± 0.1, respectively. The countermovement jump also reported no significant differences (29.0cm ± 3.9, 29.6cm ± 3.0, respectively). Interestingly, the opposite result was found in elite female soccer players, where high intensity running distance was greater in the luteal phase (6.64 metres per minute) when compared to the follicular phase (5.9 metres per minute) (Julian et al., 2020). However, it was reported that there were large variations across a total of 76 match observations independent of menstrual cycle stage. It was concluded that the menstrual cycle phase does not influence physical match performance in female soccer players. Given the large discrepancy across studies, it is clear that more research is required before a firm conclusion can be made regarding the influence of menstrual cycle phase on physical performance. A summary of physical performance testing data is listed in Table 2.

Table 2 Physical Performance Testing related to the Menstrual Cycle Research

Study	Population	Age	MC Verified	Sample Size	Performance Test	Frequency of Test	Significant Difference
Burrows and Bird (2005)	Highly training runners	18-40 yrs	LH via saliva	n=10	VO2Max Treadmill	EF, LF, EL, LL; 2 cycles	≠
Cook et al. (2018)	Elite and non-elite athletes	~21 yrs	No	n=22	Peak Power cycle ergometer + PAP	LF, O, ML; 3 cycles	↑ 5-16% ovulation
Dam et al. (2022)	Healthy women	18-35 yrs	POD, FSH, LH, PRO via bloods, LH via urine	n=40	CMJ Handgrip strength Biceps Iso Strength Wingate Test	EF, MF, LF, EL, ML, LL; 1 cycle	↓ 6% CMJ LL compared to MF ↓ 3% Wingate peak power EF compared to ML ↓ 2-5% Wingate average power LL
De Souza et al. (1990)	Well trained runners	~29 yrs	LH via urine	n=8	VO2Max Treadmill 80% Submax Treadmill	EF, ML, 1 cycle	≠
Friden et al. (2003)	Moderately active women	~25.3	LH via urine, FSH, LH, E2, P-4 via bloods	n=10	Handgrip strength Quad isokinetic force	EF, O, ML; 2 cycles	≠
Gordon et al. (2013)	Well training athletes	~20.7 yrs	Day of test via saliva	n=11	KE peak torque isokinetic dynamometer	EF, MF, ML, LL; 1 cycle	↓ peak torque EF compared to ML & LL
Graja et al. (2020)	National-level Handball athletes	~22.5 yrs	POD & PRO via bloods	n=10	Repeated cycle sprint Pre- and post-cycle KE Iso strength	EF, LF, ML, LL, 1 cycle	↓ KE MVC post- in LL ↓ PP & FI in LL compared to LF
Güler (2020)	Amateur volleyballers	~20 yrs	No	n=15	Push up Vertical jump 30m running sprint	EL, LL; 1 cycle	≠
Guo et al. (2005)	Track & field athletes	~18.5 yrs	POD, FSH, LH, PRO via bloods	n=25	500m & 2000m rowing sprint 100m and 200m running sprint	ML, LL; 1 cycle	↓ 500m rowing, 100m and 200m sprint time in ML compared to MF ≠ 2000m rowing
Kishali et al. (2006)	Active basketball, volleyball, judoka	~17.3 yrs	No	n=40	Vertical jump Handgrip strength 20m sprint	EF, MF, LL; 3 cycles	≠
Julian et al. (2017)	Sub-elite soccer	~18.6 yrs	No	n=9	Yo-Yo IET 30m running sprint Countermovement Jump	EF, ML; 1 cycle	↓ Yo-Yo ML compared to EF ≠ 30m Sprint No CMJ
Köse (2018)	Kickboxing	~21	No	n=10	1RM Bench press 60% RM Bench press	EF, MF, LL; 1 cycle	≠
Lara et al. (2020)	Well-trained triathletes	~31.6 yrs	No	n=13	12s Wingate Test	EF, LF, ML; 1 cycle	≠
Study	**Population**	**Age**	**MC Verified**	**Sample Size**	**Performance Test**	**Frequency of Test**	**Significant Difference**
Lebrun et al. (1995)	Trained female athletes	~27.6 yrs	POD, PRO via bloods, oral temp	n=16	VO2Max Treadmill AST Treadmill	FP, LP; 1 cycle	≠

					Endurance Performance Isokinetic KE & KF peak torque		
Middleton and Wenger (2006)	Moderately active women	~24.7 yrs	No	n=6	Repeated cycle sprint	FP, LP; 1 cycle	↑ Power, ↑ VO_2 consumption in LP
Miller (2020)	Moderately active women	~28.6	Oral temp, LH via urine	n=13	KE Iso strength Leg press Elbow flexor Iso	MF, ML; 1 cycle	≠
Phillips et al. (1996)	Rowing	~26.1	LH via urine	n=10	Adductor pollicus isometric strength	3 x week, 1 cycle	10% ↑ follicular phase
Romero-Moraleda et al. (2019)	Triathletes	~31.5	Yes, period tracker, tympanic temp, LH via urine	n=13	1RM half squat	EF, LF, ML; 1 cycle	≠
Rodrigues (2019)	Healthy females	~28	No	n=12	Iso leg press	EF, LF, LL; 1 cycle	↑ force late luteal phase
Sarwar et al. (1996)	Healthy females	~20.7	No	n=10	KN Iso strength Handgrip strength	1 x week, 2 cycles	↑ in follicular phase
Shakhlina, Roda, et al. (2016)	Elite 800m and 1500m runners	17-24 yrs	Oral temp	n=13	PWC170 Cycle 4 x 400m runs	EF, LF, O/EL, ML, LL, 2 cycles	↑ PWC170 in MF & EL ↓ 4 x 400m time in MF, ML
Smekal et al. (2007)	Healthy females	~26.6 yrs	POD, PRO via bloods, body temp	n=19	VO2Max cycle ergometer	MF, ML	≠
Tenan et al. (2016)	Healthy females	~24.7	Oral temp	n=9	KE Iso strength	EF, LF, O, EL, LL; 1 cycle	↓ during ovulation
Tounsi et al. (2018)	High level soccer players	~21.2 yrs	PRO via bloods	n=11	Five-jump test Repeat Sprint Ability Yo-Yo IET	EF,LF,LL; 1 cycle	≠
Tsampoukos et al. (2010)	Highly active athletic females	~20.1 yrs	POD, PRO via bloods	n=14	Repeated treadmill sprint	FP, O, LP; 1 cycle	≠
Vaiksaar et al. (2011)	National (Nat) and recreational (Rec) rowers	~18.4 yrs	POD & PRO via bloods	n=8 (Nat) n=7 (Rec)	VO2Max rowing ergometer	MF, ML, 1 cycle	≠
Wiecek et al. (2016)	Healthy females	~21 yrs	Oral temp, POD & PRO via bloods	n=16	20 sec cycle sprint	EF, ML; 2 cycles	≠

EF – Early follicular, MF – Mid follicular, LF – Late follicular, O – Ovulation, EL – Early luteal, ML – Mid luteal, LL – Late Luteal, POD = Oestradiol, PRO – Progesterone, KE – Knee extensor, Iso – Isometric, PP - Peak power, FI – Fatigue Index, CMJ – Countermovement jump, ≠ - No significant difference

2.4.3 Maximal strength performance

Variations exist in strength parameters within maximal strength testing protocols during different phases of the menstrual cycle, with studies evaluating lower or upper body strength exercises as well as isometric or isotonic type movements. Research from Romero-Moraleda et al. (2019) tested the 1RM of a half squat in 13 resistance-trained female triathletes (with regular menstrual cycles) in the early-follicular, late-follicular, and mid-luteal phases. This study reported no significant differences between phases, with load, force, velocity, and power output all similar in the concentric phase of movement across the three tested menstrual cycle phases. Similar results are demonstrated by Friden et al. (2003)

where handgrip strength and quadriceps isokinetic muscle strength did not significantly change over three phases of the menstrual cycle: early follicular phase, ovulation, and mid-luteal phase. Consistent with these results, it was demonstrated that the quadriceps maximal isometric strength, leg press strength and elbow flexor maximal isometric strength did not change between follicular and luteal phases (Miller, 2020).

Conversely, Phillips et al. (1996) tested maximal isometric strength of the adductor pollicus in trained and untrained females over a 2-month period, testing three days each week. Maximal isometric strength was approximately 10% higher in the follicular phase than the luteal phase, demonstrating a close association with oestrogen concentrations. Data showed that the higher the oestrogen concentration, the stronger the maximal contraction. This is consistent with a study by Sarwar et al. (1996), who demonstrated rising maximal isometric force of the quadriceps as well as handgrip strength from the start of menstruation to ovulation, followed by a sharp decline during the mid-luteal phase. This study is limited by prediction of the menstrual cycle phases, with no blood sampling taken; however depressed force was demonstrated from ovulation to the end of luteal phase. There was also no specification as to whether there were any days to rest or recover between tests which could have implications on the outcomes. Tenan et al. (2016) demonstrated up to a 23% reduction in maximal isometric force during ovulation when compared to the mid luteal phase, and Cristina-Souza et al. (2019) demonstrated an increase in maximal isometric force in the late luteal phase when compared to the mid-follicular phase. However, this study was performed on healthy females and not athletes. On balance, these studies indicate that there may be effects on maximal strength during different phases of the menstrual cycle. However, the inconsistency in previous research findings render it impossible to draw firm conclusions on maximal strength and the influence of the menstrual cycle. This is an exciting avenue for future research, as strength is a key component related to performance in team sports.

CHAPTER 3: METHODS

3.1 Participants

The 10 study participants included female soccer (n = 3) and rugby league athletes (n = 7) who were competing in the highest semi-professional competition in their respective sport (Physical Attributes are presented in Table 3). All participants provided written informed consent to participate, and the study was approved by the USQ Human Ethics Research Committee (H20REA69P1).

Table 3 Physical characteristics of female participants

Variables	Mean ± SD
Age (years)	25.3 ± 4.5yrs
Body Mass (kg)	70.2 ± 11.6kg
Height (cm)	167.6 ± 8.3cm
BMI	24.9 ± 2.87

Inclusion criteria for participants were:

- Be older than 18 years of age;
- Not taking any hormonal contraceptives, or have done for the past three months;
- Have a regular menstrual cycle (between 21 and 35 days) for the past two months;
- Not pregnant, breastfeeding, or have any known reproductive disorders;
- No current injuries and able to complete all team training sessions
- Be able to comprehend English language to a level where participant information and consent forms can be understood, and;
- Compete at highest non-professional level in their sport

3.2 Procedures

3.2.1 Study design

Participants were required to undertake a maximal isometric squat task three (3) times per week using dual force plates (VALD ForceDecks) during their regular weekly training session participation for one complete menstrual cycle. Following each testing session, participants completed a questionnaire with a series of questions to capture their current menstrual cycle status (Appendix 1). Menstrual cycle status was tracked prior to and during the testing window using a mobile app of their choice (examples include Flo, Smartabase, Period Tracker) and data were reported to the investigator. All participants had at least one week of familiarisation with the physical testing protocol.

3.2.2 Maximal isometric squat task

The maximal isometric squat task was chosen rather than dynamic strength tasks as they have high test reliability, are quicker to administer than traditional 1-RM testing (Brady et al., 2020), and will not unduly fatigue the athlete when performing multiple tests per week. The isometric squat task was also chosen instead of the isometric mid-thigh pull as it is quicker to administer and produces significantly higher absolute and relative peak force in female athletes (Brady et al., 2018). This makes the test more practical when integrating it into training (Vogel et al., 2023). During familiarisation participants were informed to adjust the bar height so that it was just below their collar bone. The participant continued to adjust the height on the squat rack (VALD), using a height that placed them approximately into a quarter-squat position and specifically, the position where the participant felt their strongest. This stance was chosen so the athlete was positioned to produce the most force possible. Sessions began with a brief warm up consisting of 10 walking lunges, 10 bodyweight squats, 10 dead bugs, 10 glute bridges and one test effort at an intensity of eight out of ten (8/10) rating of perceived exertion based on the Modified Borg Scale (Wilson & Jones, 1989). The maximal test was performed whilst standing on the force plates and pressing up against the bar as hard as possible for approximately 5 seconds (Figure 2). Strong verbal encouragement was provided to aid motivation. Vocabulary and tone were key considerations to ensure external attentional focus was provided (Halperin et al., 2016). Maximal strength characteristics measured include strength and power measures; absolute peak force (N), relative peak force (N/kg), rate of force development at 100ms and 200ms (N/s). Force data was analysed using VALD ForceDecks software. VALD ForceDecks software sampled data from dual force plates using a sampling rate of 500Hz, with a minimum detection threshold of 40N.

Figure 2 Maximal Isometric Squat Setup; Side and Posterior View

3.2.3 Questionnaire

The questionnaire completed after each testing session involved five questions to capture the current status of the athlete’s menstrual cycle, menstrual cycle symptoms, and their perceptions of test performance. This Questionnaire can be seen in Appendix 1.

3.3 Menstrual cycle phases

Participants performed the testing protocol three times per week to ensure that data were captured across five menstrual cycle phases, including: Menstruation, Follicular, Ovulatory, Luteal, and Premenstrual Phases. Where multiple testing sessions were performed within a select phase, data were averaged so that there was one data point per participant per phase. This method is one method recommended for data analysis in Joyce and Stewart (2019).

Unfortunately, no verification of menstrual cycle via bloods analysis was assessed for this study. Bloods analysis was initially included in the research methods; however, it was deemed too difficult for many participants to attend a pathology lab for blood collection due to work hours and/or distance from a pathology lab. For this reason, verification of the menstrual cycle via bloods analysis was withdrawn from the study. Thus it was assumed that the time from ovulation to the start of menstruation is always 14 days long (Reed & Carr, 2000). Based on the research by Joyce and Stewart (2019) there are certain rules to be followed when analysing the menstrual cycle phase via a calendar counting methods. The following rules were created and are simplified in Table 4:

- Ovulation is Day 1
- The Ovulatory Phase includes one day prior to- and two days after Ovulation
- The Luteal Phase is the day after Ovulatory Phase to the Pre-menstrual phase
- The Pre-menstrual Phase is four (4) days prior to the first day of the Menstruation Phase
- The first day of Menstruation Phase is Day 15
- The Menstruation Phase is five (5) days long
- The Follicular Phase includes days from Day 20 to two days prior to Day 1

Table 4 Rules to assess length of menstrual cycle phases

Menstrual Cycle Phase	Date Range	Length of Cycle
Menstruation	15 - 19	5 Days
Follicular	20 - two days prior to 1	Variable
Ovulatory	1 - 3	4 Days
Luteal	4 - 9	7 Days
Pre-menstrual	10 to 14	4 Days

3.4 Statistical analyses

Due to this individual variability of the menstrual cycle, the quantitative data of this thesis have been split into two types of analyses: collective data and individual data.

Quantitative data (both collective and individual data) were analysed using SPSS (Statistical Package for the Social Sciences). Questionnaires that were completed post-testing were compared against the quantitative analysis of individual data from each session.

3.4.1 Collective data

One-Way Repeated Measures Analysis of Variance (ANOVA) was used to analyse differences between each menstrual cycle phase for the collective cohort. The significance level was set at $P<0.05$.

Results of the strength tests have been expressed as mean, standard deviation (SD). Questionnaire results have been expressed as qualitative data in the results tables.

3.4.2 Individual data

The individual data were assessed for similar patterns between menstrual cycle phases, and then split into respective trending groups based on Absolute Peak force (N). Due to low participant numbers, this was assessed manually. If all five menstrual cycles phases in one participant had similarly positive/negative changes between phases to another participant, they were matched together in a group. These changes were confirmed via Pairwise Samples T-Tests with significance set at $P<0.05$.

Group 1 had three participants with similarly trending data across phases. This was identified by the following trends: FP higher than MP, OP higher than FP and LP, PM higher than LP.

Group 2 had two participants with similarly trending data across phases. This was identified by the following trends: FP high than MP, OP, LP, and PM.

Group 3 comprised a mix of individual results and was not to be assessed as a collective. One participant trended lower in PM than all other phases, one participant trended higher in PM than all other phases, one participant trended lower in OP than all other phases, one participant trended higher in FP than all other phases, one participant had no discernible data pattern across menstrual cycle phases.

3.4.3 Questionnaires

Quantitative data were assessed by analysing the mean and standard deviation of strength characteristics across the different phases of the menstrual cycle for each participant. If a value across a phase of the menstrual cycle was outside of one standard deviation (positive or negative), then it was classified as a change in physical performance.

A "Yes" or "No" value was confirmed if it met the following criteria:

- If there was a change in physical performance and the participant stated "Yes" to the question, "Do you believe these symptoms influence your ability to undertake the testing / training sessions?"
- If there was no change in physical performance and the participant stated "No" to the question, "Do you believe these symptoms influence your ability to undertake the testing / training sessions?"
- A "No" value was confirmed if the participant's answer was in opposition to the first two criteria.

CHAPTER 4: RESULTS

4.1 Collective data

Table 5 Force Characteristics during different phases of the menstrual cycle

Force Characteristic		Phase					$F_{(4,36)}$	p-value
		Menstruation	Follicular	Ovulation	Luteal	Pre		
Absolute Force (N)	M	2277	2178	2234	2191	2252	0.636	0.640
	SD	288	327	375	312	219		
Relative Force (N/kg)	M	33.6	32.5	33.3	32.6	33.1	0.336	0.852
	SD	5.6	5.3	6.0	5.0	5.4		
RFD100 (N/s)	M	1172	1710	1646	1439	1676	1.644	0.185
	SD	745	1210	757	740	897		
RFD200 (N/s)	M	2015	2276	2104	2069	2330	0.376	0.824
	SD	896	1220	959	970	1389		

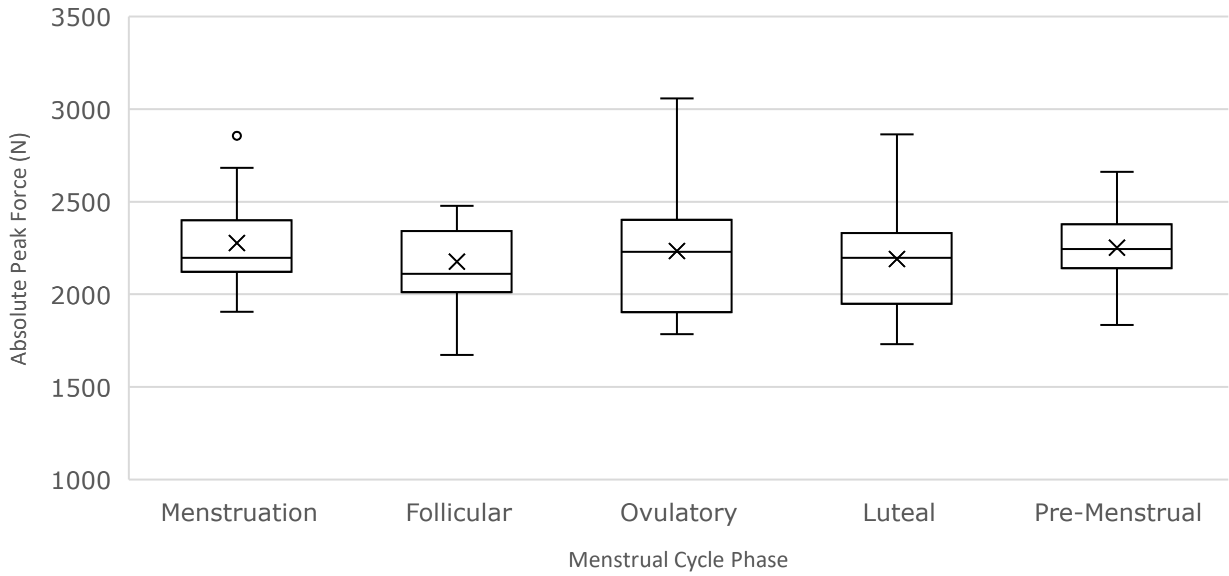


Figure 3 Absolute Peak Force (N) of Isometric Maximal Squat During Different Phases of the Menstrual Cycle

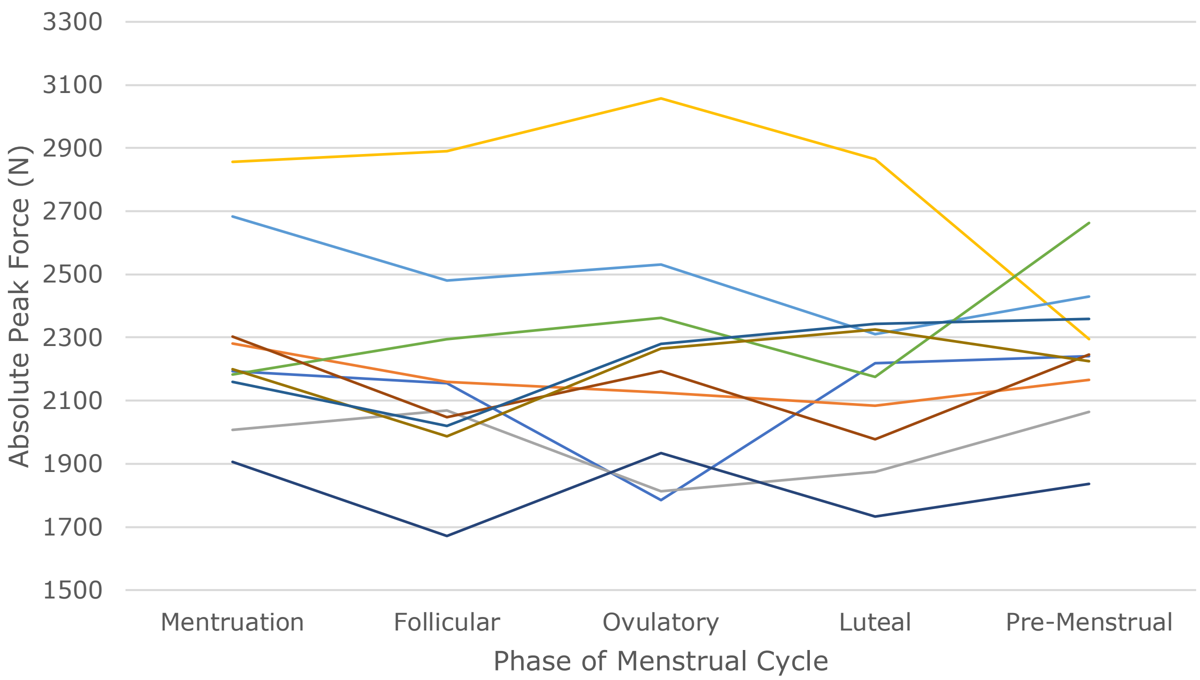


Figure 4 Absolute Peak Force (N) of Isometric Maximal Squat During Different Phases of the Menstrual Cycle for each Participant

There were no significant changes between menstrual cycles for Absolute Peak Force (N), Relative Peak Force (N/kg), and Rate of Force Development at 100m and 200m (N/s) using One-way Repeated ANOVA ($P<0.05$) with F and P-values illustrated in Table 5.

4.2 Individual data

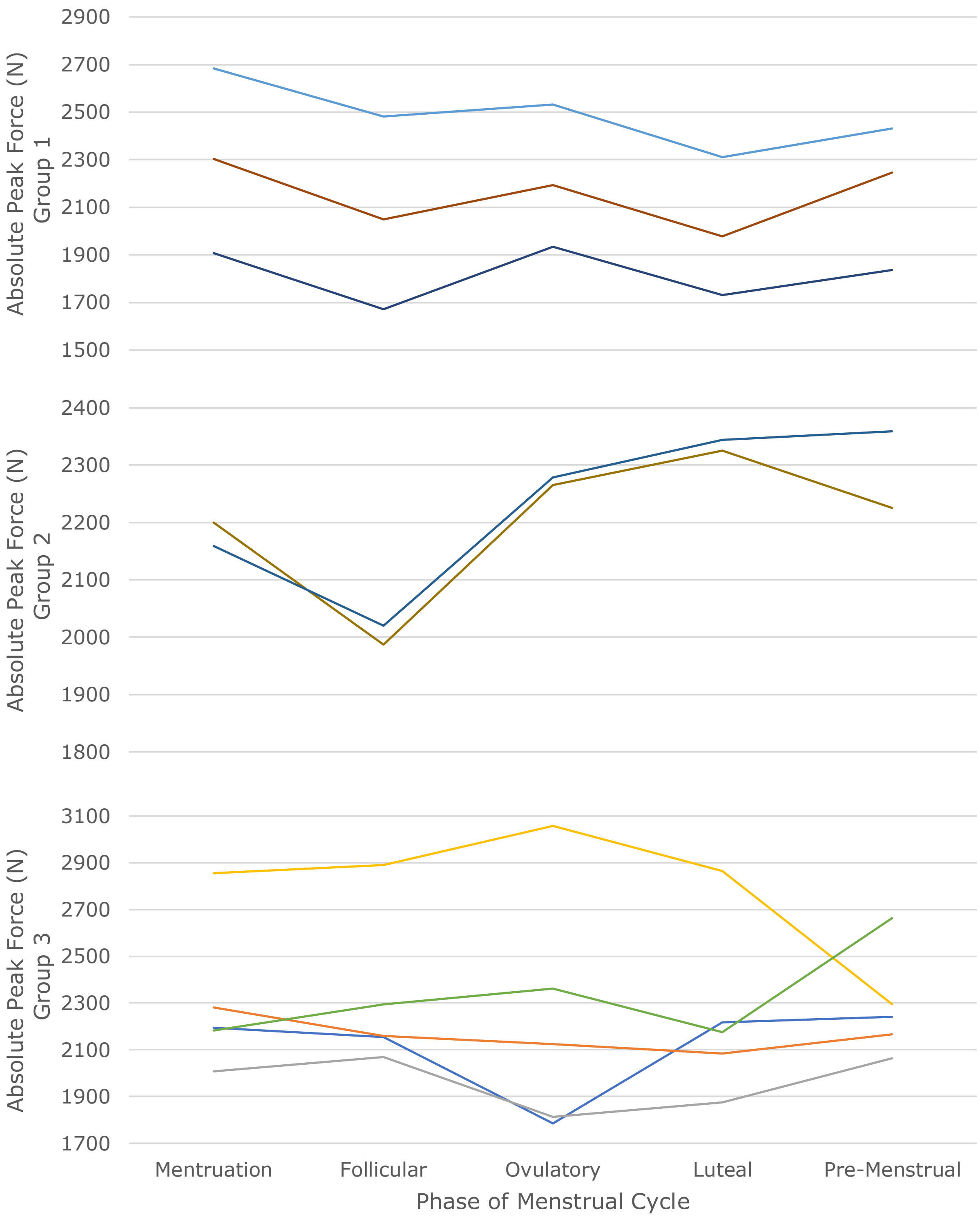


Figure 5 Absolute Peak Force (N) of Isometric Maximal Squat During Different Phases of the Menstrual Cycle for Trending Group One (1), Group Two (2), and Group Three (3)

There were significant changes between OP and LP ($P<0.001$, $P=0.029$) in Group One (1) ($P<0.05$) for APF and RPF, respectively for the two-tailed analyses. MP and FP ($P=0.004$), and MP and LP ($P=0.040$) had significant differences in APF. OP and PM ($P=0.50$) had significant differences in RPF. It is to be noted that there was a significant difference for one-tailed analyses ($P<0.5$) between LP and PM ($P=0.044$).

There were no significant differences between menstrual cycle phases of Group Two (2) for RFD100 ($P<0.05$) for the two-tailed analyses. There were significant differences between MP and OP ($P=0.015$) for the two-tailed analyses ($P<0.05$).

There were significant changes between menstrual cycle phases of Group Two (2) for APF and RPF ($P<0.05$) for the two-tailed analyses. FP and OP ($P=0.023$) and FP and LP ($P=0.014$) were significantly different for APF and RPF, OP and LP ($P=0.022$) was significantly different for APF, and MP and LP ($P=0.11$), and FP and PM ($P=0.033$) were significantly different for RPF. It is to be noted that the LP and PM ($P=0.035$) were significantly different for the one-tailed analysis ($P<0.05$).

There were significant changes between menstrual cycle phases of Group Two (2) for RFD100 and RFD200 ($P<0.05$) for the two-tailed analyses. LP and PM ($P=0.034$) were significantly different for RFD100. MP and LP ($P=0.037$), MP and PM ($P=0.024$), FP and LP ($P=0.014$) and FP and PM ($P=0.038$) were also significantly different in this group.

Table 6 Perception of the Effect of the Menstrual Cycle on Physical Performance vs Statistical Outcomes Post-Data Analysis

Do you believe these symptoms influence your ability to undertake the testing / training sessions?	Qty where changes matched the perception?			
	APF	RPF	RFD100	RFD200
Yes	1	1	3	3
No	9	9	7	7

CHAPTER 5: DISCUSSION AND CONCLUSION

The purpose of this study was to assess whether the different menstrual cycle phases influenced maximal strength in female team sport athletes. The results were assessed as a collective, but throughout the analyses there were trends identified across multiple individuals which led to individual analyses. This is consistent with statements made by Elliott-Sale et al. (2020), recognising it is important for future research to understand individual effects of the menstrual cycle.

Overall, the data suggests no significant differences between the different phases of the menstrual cycle. However, there are significant differences across smaller groups of athletes that had similar changes in maximal strength characteristics between menstrual cycle phases.

5.1 Collective assessments

The results of the study are consistent with a large body of literature as illustrated in Table 2, demonstrating no significant differences between different phases of the menstrual cycle and maximal strength characteristics in team sport participants. Absolute and relative peak force showed no significant changes across the different phases of the menstrual cycle in this participant group; however, it is noted that the standard deviation and standard error was higher during the ovulatory phase. These results are not consistent with the hypothesis that maximal strength characteristics would be lower during the luteal phase.

In the present study, it was concluded the menstrual cycle did not affect maximal strength characteristics. In contrast, a study by Tenan et al. (2016) evaluated the maximal isometric strength of knee extensors across the five phases of the menstrual cycle and found conflicting results with the present study. Tenan et al. (2016) reported a 23% decrease in strength from OP to LP over one cycle. Albeit conflicting results, the study had similar limitations as the present study with low participant numbers ($n<10$). Furthermore, the participants in this study were healthy females whereas the present study were athletes (Tenan et al., 2016). This is an important distinction as female athletes may have differing musculoskeletal morphology (Martusevich & A Karuzin, 2020; Okamoto et al., 2012), strength differences (Degens et al., 2019; Risberg et al., 2018; Unuvar et al., 2023) and hormonal responses to physical stimuli (Cook, Fourie, et al., 2021; Cook et al., 2018; Crewther & Cook, 2018) than healthy non-athletes which can provide different outcomes for research.

Graja et al. (2020) assessed isometric knee extensor strength pre- and post-repeated cycle tests with National-level handball players and found decreased maximal voluntary contraction in late luteal phase (PM) compared to FP and LP. These results are conflicting with the present study findings and Tenan. Both Graja et al. (2020) and Tenan et al. (2016) reported differences in strength between menstrual cycle phases, which is conflicting with the present study findings where there were no significant differences in maximal strength between menstrual cycle phases. However, Graja et al. (2020) reported the decrease in strength in the PM compared to FP and LP, whilst Tenan reported the decrease in strength from OP to LP, demonstrating differences in findings. Graja et al. (2020) did not evaluate ovulation and had low participant numbers (n=10), identical to the present study, however participants were high-performing athletes, and their menstrual cycle was verified via bloods.

One study that evaluated six phases of the menstrual cycle across 40 participants assessed isometric strength, but of the upper arm and handgrip (Dam et al., 2022). The results of this study are consistent with the present study where no significant differences were found in maximal strength characteristics across different phases of the menstrual cycle. However, participants in this prior study were healthy females and not athletes.

Research by Dasa et al. (2021) demonstrated similar findings to the present study. The research evaluated maximal isometric grip strength and one repetition maximum on leg press across 29 participants across soccer, handball and volleyball who played at a high level. The study evaluated the follicular phase and luteal phase and found no significant differences between phases related to performance on the strength tests. The limitation of this study was that it only evaluated two phases, however testing was once per week for six consecutive weeks to ensure there were two tests per phase to compare.

Assessment of rate of force development is limited within research evaluating menstrual cycle and physical performance. A single study (Jaskólska et al., 2004) found the rate of force development was significantly lower from OP to LP, however only in the knee flexors and not the knee extensors. These results are counter to the present study where it was found that rate of force development at 100ms and 200ms showed no significant differences across menstrual cycle phases, however it is noted that standard deviation and standard error is higher in the FP for 100ms, and for the FP and PM phase for 200ms. The higher standard deviation and standard error demonstrates the reliability of the mean and it has been demonstrated that greater familiarisation may be required for rate of force development to establish more meaningful conclusions (Keogh et al., 2020). Additionally, Jaskólska et al. (2004) used a dynamometer to assess maximal voluntary contraction and rate of force development, compared to the present study that used dual force plates. The study also had a relatively small participant group (n=15), similar to the present study but only evaluated the ovulatory and luteal phase, with no comparison to the follicular or menstrual phases.

There are inconsistent methodologies throughout the current body of research. Not all studies evaluate maximal isometric measures or use the same type of performance test.. The present study used a maximal quarter squat test on dual force plates which evaluates a specific key movement position in athletic activities, whereby other maximal isometric measures that were compared to this looked at movements that were isolated to a specific joint. This difference in testing protocols makes it difficult to compare past and present research. There is also limited data on rate of force development related to the menstrual cycle and physical performance, with a single study being used to compare research (Jaskólska et al., 2004). Most studies evaluate only two to four phases of the menstrual cycle (Table 2), compared to the present study which evaluated five due to the relevant hormonal fluctuations between menstrual cycle phases. This is another factor that makes it difficult to compare past and present research. Even the five aforementioned studies (Dam et al., 2022; Dasa et al., 2021; Graja et al., 2020; Jaskólska et al., 2004; Tenan et al., 2016) that have been compared to the present study based on similar aspects of their methodologies each had vastly different limitations, however there were similar limitations in low participant numbers and no menstrual cycle verification outside of self-reporting. Elliott-Sale et al. (2021) discusses the importance of consistent research in this space but acknowledges that there may never be a universal blueprint for direct training and performance for women based off the individuality of, and changes across, the lifespan of the menstrual cycle.

5.2 Individual assessments

As the menstrual cycle may affect people differently, individual assessments were undertaken to determine if there were data patterns across the different phases of the menstrual cycle and if they were similar to other athletes. Three groups were identified; two groups that had similar patterns, and one group with individually mixed results. Significant results that demonstrated strength differences across the menstrual cycle between groups were inconsistent, which makes it difficult to draw conclusions on the effect each menstrual cycle phase has on a group level.

It is difficult to draw conclusions and comparisons on maximal force characteristics such as APF and RPF where there has been only a single study to reference (Jaskólska et al., 2004). There have been studies that have found significant differences between phases of the menstrual cycle and maximal strength (Graja et al., 2020; Phillips et al., 1996; Rodrigues, 2019; Sarwar et al., 1996; Tenan et al., 2016). However, the compared studies used different types of strength testing, had different methodologies for menstrual cycle verification and participant background (athlete, or non-athlete) was not consistent. As an example, Graja et al. (2020) found a decrease in isometric knee extensor force in the PM, Phillips et al. (1996) found an increase in isometric adductor pollicus strength in the FP, Rodrigues (2019) found an increase in isometric leg press force in the PM, Sarwar et al. (1996) found an increase in isometric knee extensor force in the FP, and Tenan et al. (2016) found a decrease in isometric knee extensor strength in the OP. This inconsistency could be due to individual variations as seen in the present study, there were significant differences for APF and RPF between OP and LP for Group One (1), and for FP and OP, and FP and LP for Group Two (2). Conversely, there are also numerous studies which have reported no significant differences between menstrual cycle phases and APF or RPF (De Souza et al., 1990; Friden et al., 2003; Köse, 2018; Miller, 2020; Romero-Moraleda et al., 2019). However, significant results are inconsistent between groups and maximal force characteristics in the present study. Similar inconsistencies are seen across research investigating factors other than strength (e.g., aerobic capacity) (Burrows & Bird, 2005; Julian et al., 2017; Lebrun et al., 1995; Shakhlina, Roda, et al., 2016), potentially due to different methodologies across studies where there are different types of strength tests, types of menstrual cycle verification, cohorts, total cycles, and the phases assessed. The differences across methodologies make it difficult to draw conclusions from the body of research on the menstrual cycle and maximal strength characteristics and provide recommendations to athletes. It is also possible that these prior studies that found no phase-based performance differences at a group level had similar trends to this study, with significant differences observed across phases for individual participants or small groups of participants, which would be missed if only a group level analysis were performed.

The research undertaken by Jaskólska et al. (2004) found results consistent with the present study, with significant differences in RFD occurring during different phases of the menstrual cycle. In the present study, Group Two (2) for RFD100 between LP and PM. Significant differences were also found between MP and OP for RFD200 in Group One (1) and MP and PM, FP and LP, and FP and PM for RFD200 in Group Two (2). Participant 4 in Group 3 also had significant differences with PM compared to all other phases of the menstrual cycle. However, Jaskólska et al. (2004) only evaluated OP and LP, whereas the present study assessed five distinct menstrual cycle phases. The results are not consistent as to whether there is a decrease or increase in RFD across the menstrual cycle. Thus, further research is needed to establish meaningful conclusions on how the different phases of the menstrual cycle influence the maximal strength characteristic of RFD. It may also prove true that the menstrual cycle is so individual that, even with the addition of more research, it may not be possible to provide group-level recommendations about what performance outcomes to expect at each phase.

It is understood that female athletes report negative impacts on daily life, training and game day performance (Bruinvels et al., 2016). One component of this study was to compare these perceptions (qualitative data) against maximal strength characteristics (quantitative data) to determine whether there was alignment between the subjective and objective data. Some participants reported no influence of the MC on testing, however it was found that some of these participants had either lower or higher peak forces or rate of force development whilst menstrual cycle symptoms occurred. This also occurred in the opposite direction, where some participants felt that their symptoms influenced their testing performance when there was no difference in strength characteristics compared to other phases of the menstrual cycle. This has also been noted in research evaluating experiences and perceptions around sport, where some participants will feel stronger, or try harder when experiencing symptoms (Findlay et al., 2020; Martin et al., 2018). had one participant state, "Usually the week before I'm on [my period] I'll not enjoy the gym but I feel strong in the gym." A participant in another study (Martin et al., 2018) stated, "If anything I have to increase it [exercise]. Helps to pass quicker by maybe a day and helps the pain." This is a possible explanation for why reported symptoms do not always match objective data. However, caution should be taken drawing conclusions from these results. Individual variations in perception and data may occur and not represent the wider community of females athletes.

When assessing results individually it is clear there are significant differences between phases of the menstrual cycle; however differences are not always in the same phase of the menstrual cycle. Thus, at a group level the hypotheses was not supported, but there were significant, menstrual cycle phase-based changes at an individual level worthy of consideration. These results provide an insight into why individual assessments need to be considered for female athletes rather than group analyses only.

There are several limitations across the study which were born predominantly from the variable conditions and athlete commitments outside of sport. Conclusions need to be interpreted with caution as participant numbers in this study were limited to 10. Despite over 40 athletes taking part in the study, non-attendance, interrupted sports-seasons, or COVID-19 illness affected data collection and participation. Menstrual cycle verification was ultimately not included in this study for multiple reasons, predominantly participants having conflicts with work schedules and pathology lab opening hours. A further limitation was the inconsistency of the warm-ups performed prior to the strength testing protocol. Due to time constraints where athletes were unable to attend training early enough the warm-ups were shortened so they could participate in training as soon as possible. The shortest warm up involved the participant undertaking the test by gradually increasing intensity over three efforts prior to a maximal effort. This study had to work around the training schedules of coaches rather than having a dedicated time for participation. Variability in the warm up duration and/or intensity, may have affected the outcomes of the strength testing.

Overall, more research is required before we can draw firm conclusions regarding different phases of the menstrual cycle and how they affect maximal strength. Furthermore, it is important to recognise the individual differences between menstruating athletes and as such, future research needs to consider how this can be addressed. It may not be possible to conclude there are menstrual cycle phase-based differences across an entire cohort. As such, it is recommended that practitioners consider individual variations in maximal strength characteristics across different phases of the menstrual cycle for team sport athletes. Drawing conclusions from a body of research that remains inconsistent and contains many methodological flaws is a disservice to the female athlete; this study reflects a contribution to the literature in this space, but is it acknowledged that further, high-quality research is still required to better inform our female athletes' training practices.

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APPENDICES

Appendix 1. Menstrual cycle symptoms questionnaire

Are you currently experiencing menstrual related symptoms?	◯ Yes ◯ No i.e. stomach cramps, headaches, etc.
What symptoms are you experiencing?	
Do you believe these symptoms influence your ability to undertake the testing / training sessions?	◯ Yes ◯ No
How is this influencing the testing / training sessions?	
Are you taking an medication to reduce symptoms?	

Appendix 2. Research outputs

Publication

Vogel, K., Larsen, B., McLellan, C., & Bird, S.P. (2024). Female athletes and the menstrual cycle in team sports: Current state of play and considerations for future research. Sports, 12(1), 4.

Symposium

Vogel, K., Larsen, B., McLellan, C., & Bird, S.P. (2021, Oct 19). Menstrual cycle influences on maximal strength and maximal speed in female soccer players: A work in progress? Centre for Health Research Showcase Symposium. Toowoomba, Queensland.

Vogel, K., Larsen, B., Bird, S.P. & McLellan, C. (2023, July 6). Do the different phases of the menstrual cycle influence maximal strength in female team sport athletes? School of Health and Medical Sciences Student Research Symposium. Toowoomba, Queensland.

Conference Presentation

Vogel, K., Larsen, B., Bird, S.P. & McLellan, C. (2023, Nov 4). Strength expression in female athletes; does the menstrual cycle really matter? International Conference on Applied Strength and Conditioning. Gold Coast, Queensland.

Media

Rope, S., Webber, M., & Sheehan, H. (2022, Mar 13). Research 'gaps' about periods, the pill and female physiology affecting women in sport. ABC News. https://www.abc.net.au/news/2022-03-13/research-gaps-in-sports-science-affecting-women/100865596.