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The effects of menstrual cycle phase on the development of peak torque under isokinetic conditions

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Abstract.
BACKGROUND: There are alterations in strength in relation to menstrual cycle phase but little data attributing these responses to female sex hormone levels using a pseudo-menstrual cycle group as control.
OBJECTIVE: Examining the effects of menstrual cycle phase on the development of peak torque across a range of isokinetic speeds.
METHOD: 17 well trained females, 11 formed the non-oral contraceptive group (n-OC) (age 20.7 ± 1.4 yrs, mass 59.2 ± 6.9 kg, height 166.8 ± 7.1 cm) and 6 the oral contraceptive control group (OC) (age 20.3 ± 0.5 yrs, mass 60.5 ± 4.2 kg, height 164.8 ± 4.8 cm). Concentric strength of the knee flexors and extensors (60–240°/s) was assessed, corresponding to menstruation (MEN), mid-follicular (mFOL), mid-luteal (mLUT) and pre-menstrual (pMEN).
RESULTS: For n-OC significant decreases in peak torque production of the extensors at 120°/s ($P = 0.0207$) (MEN) and of the flexors at 60°/s ($P = 0.0116$) (MEN) and 120°/s ($P = 0.0282$) (MEN) were observed compared to pMEN. No significant differences were observed across any menstrual cycle phase and peak torque for the OC group ($p > 0.05$). Significant positive correlations were observed (mLUT) between peak torque and oestrogen at 60°/s ($P = 0.040$) and 120°/s ($P = 0.031$).
CONCLUSIONS: There are significant fluctuations in peak torque of the knee extensors in response to phases of the menstrual cycle associated with variances in the female sex hormones. The findings have implications for the planning of strength training in female athletes.

Keywords: Peak torque, menstruation, oestrogen, force production

1. Introduction

A primary facet of athletic performance assessment, rehabilitation, general health and fitness is the development and maintenance of muscular strength. Indeed, it is widely recognised that in athletic groups the evaluation of skeletal muscle strength is being frequently used as an index of performance, to compare individuals and to monitor the physiological responses to training [6,12,35]. Given the increasing numbers of women participating, both in recreational and performance-based sport, it is apparent that more women are undertaking strength-based assessments [17]. However, previous studies have revealed that there are significant decrements in athletic performance during the menstrual cycle [2,8,33,34]. Furthermore, the menstrual cycle has been shown to be associated with fluctuations

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in metabolism, thermoregulation, muscle contractile responses, endurance and an increased risk of in injury [4,5,7,18,19,27,29,31], all as a result of the circadian variations in oestrogen and progesterone. The majority of these studies have focused on the menstrual, follicular and luteal phases with little data relating to the pre-menstrual phase. However, studies that have addressed the pre-menstrual phase have indicated that there is an increased risk of injury during this period [23,25].

Specifically, previous work has suggested that the alterations in physical capacities are a consequence of fluctuations in the female sex steroid hormones which affect both metabolic pathways and the functioning of autonomic nervous system [9,11]. Interestingly, there would appear to be a consensus that there are non-significant changes in physiological or metabolic responses in women who were taking oral-contraceptives which contain a combination of oestrogen and progesterone. The association between menstrual cycle phase and muscular strength is though less clear. A number of studies have suggested that there is no association between skeletal muscle strength and the phases of the menstrual cycle [8,9,16,21]. Conversely a number of studies have demonstrated that there is such an association. Within those studies showing an association a disparity exists. With some showing increased strength and reduced fatigability mid cycle [29] compared to other suggesting that the peak association occurs mid-follicular [27] or even mid-luteal [14]. Conflicts in these findings have been attributed both to the choice of exercise modality and the ability to accurately predict the timings of the phases of the menstrual cycle. Furthermore, despite the obvious associations between the phases of the menstrual cycle and the concentrations of the female sex hormones, it is surprising that a number of studies have not recorded hormonal responses. Therefore, the purpose of this study was to examine the effects of menstrual cycle phase on the development of peak torque across a range of isokinetic speeds whilst monitoring hormonal responses.

2. Methods

2.1. Participants

Following local institutional ethical approval 17 well trained female participants agreed to participate, of which 11 formed the non-oral contraceptive group (n-OC) (age 20.7 ± 1.4 yrs, mass 59.2 ± 6.9 kg, height 166.8 ± 7.1 cm) and prior to participating reported a regular menstrual cycle (28.6 ± 2.4 days). The remaining 6 participants formed the oral contraceptive control group (OC) (age 20.3 ± 0.5 yrs, mass 60.5 ± 4.2 kg, height 164.8 ± 4.8 cm) and had been taking monophasic oral contraceptives for at least three months prior to testing.

2.2. Study design

The participants reported to the laboratory on five separate occasions for the determination of functional muscular strength of the knee extensors and flexor. All tests were conducted at the same time of day so as to minimise diurnal variations, with all strength-based assessments taking place between the hours of 14:00–17:00. The first visit was completed prior to establishing the menstrual pattern of the n-OC group and was used as a familiarisation condition in order to allow the participants to get used to both the protocol and the surroundings in which they were to complete the trials. The remaining visits corresponded to menstruation (MEN), mid-follicular (mFOL), mid-luteal (mLUT) and immediately pre-menstrual (pMEN). All trials were completed using a pre-calibrated isokinetic dynamometer (Humac, Norm, USA), with the dynamometer sampling data at 100 Hz.

2.3. Functional tests

For each participant the dynamometer was configured according to the manufacturer's specifications. The position of the participant was stabilised using both a pelvic strap and two over the shoulder support straps so as to reduce mechanical assistance from other body parts. The dynamometer chair was moved in order to align the lateral femoral epicondyle with the axis of rotation of the dynamometer arm. The leg being tested was secured with a strap across the lower thigh and the dynamometer arm was secured to the ankle in the angle between the shin and foot. The contra lateral leg was placed behind a brace, again to limit movement and participants were instructed to use the handles in order to generate maximum force. In order to reduce variability within the torque data, limb weight and moment acting on the dynamometer arm were corrected for gravity during each visit to the laboratory [13]. Each trial commenced with the participant completing a prescribed warm-up which consisted of 4 concentric extensions/flexions at 60°/s, followed by a 30 s recovery period.

Table 1
Torque production (nM) of the knee extensors and flexors during the phases of the menstrual cycle for n-OC group

Speed	MEN	mFOL	mLUT	pMEN
Extensors				
60°/s	110.7 ± 25.23	116.8 ± 23.63	116.8 ± 22.49	116.2 ± 22.34
120°/s	94.96 ± 18.49*	95.26 ± 21.50	97.73 ± 18.19	96.61 ± 18.88
180°/s	78.3 ± 14.09	78.05 ± 17.51	79.78 ± 15.25	82.81 ± 16
240°/s	65.76 ± 11.85	64.75 ± 13.32	66.2 ± 13.64	68.29 ± 12.45
Flexors				
60°/s	64.09 ± 18.61*	70 ± 16.27	71.09 ± 15.94	73.18 ± 20.03
120°/s	59.18 ± 14.91*	60.18 ± 14.8	62 ± 11.69	64.45 ± 13.28
180°/s	50.91 ± 13.55	52.64 ± 12.7	54.45 ± 9.86	54.09 ± 9.37
240°/s	43.82 ± 11.5	45.82 ± 10.39	47.09 ± 7.98	47.18 ± 8.98

*Indicates a significant difference ($p < 0.05$).

Maximum isokinetic torque of the knee extensors and flexors was measured using reciprocal concentric contractions at four speeds which corresponded to 60°/s, 120°/s, 180°/s and 240°/s, with five repetitions completed at each speed. The trials were completed in incremental order of speed with each set of 5 repetitions separated by a passive recovery of 180 s.

2.4. *Establishment of menstrual patterns*

Once the participants had been selected they were instructed to provide a diary of menstrual patterns for two cycles. Testing was completed according to the following time frames MEN days 1–3, mFOL days 9–11, mLUT days 19–20 and pMEN days 27–28, where necessary exact dates were adjusted in order to match the individually reported cycle lengths. The phase of the menstrual cycle where each participant commenced their functional tests was randomised so as to minimise experimental bias due to familiarity with the dynamometer. For the OC group their functional tests were aligned with menstrual cycle phases described previously and were subsequently defined as pseudo-menstrual cycle phases.

2.5. *Hormone measurements*

Duplicate, and in a few cases, triplicate saliva samples were taken before testing on the day of the test and stored frozen at −20°C until analysed. 17-β-oestradiol and progesterone concentrations were measured using standard enzymatic assay kits (Salimetrics, LLC., Pennsylvania. USA). All samples were analysed in duplicate and compared with standard curves and a quality control sample. For the purpose of statistical analysis readings that lay below the lower threshold of sensitivity (0.1 pg·ml^{-1} for oestradiol and 5 pg·ml^{-1} for progesterone) were deemed equal to the lowest standard tested (1 pg·ml^{-1} and 10 pg·ml^{-1} respectively). Correlation between salivary and plasma concentrations using these kits were $r = 0.80$ for oestradiol and $r = 0.87$ for progesterone.

2.6. *Data analysis*

All data are presented as mean ± SD. The primary outcome measure from the functional tests was the peak torque for both the extensors and flexors expressed as Nm. For each dynamometer speed the initial peak torque score for extension was removed from all subsequent data analysis as this was shown to be significantly lower than the subsequent four repetitions across all speeds and conditions. A Friedman repeated measures analysis of variance (ANOVA) was used to test the null hypothesis that menstrual cycle phases (MEN, mFOL, mLUT and pMEN) had no effect on peak torque for knee extensors and flexors at 60°/s, 120°/s, 180°/s and 240°/s. The responses of salivary oestrogen and progesterone were determined in relation to menstrual cycle phases using a Friedman repeated measures ANOVA. Given that these hormones show fluctuating patterns of response throughout the menstrual cycle the data are also expressed as the ratio of progesterone to oestrogen. Additionally, to account for any learning effect within the trials the data was re-ordered according to trial order as opposed to menstrual cycle phase. For all repeated measures tests Dunn's post-hoc test was performed. For all statistical analyses, the alpha level was set at $P < 0.05$, with all statistical analyses completed using SPSS version 16 (SPSS, Chicago, IL, USA).

3. Results

The peak torque results for the n-OC group are presented in Table 1, with the results for the OC group presented in Table 2.

Table 2
Torque production (nM) of the knee extensors and flexors during the pseudo phases of the menstrual cycle for OC group

Speed	MEN	mFOL	mLUT	pMEN
Extensors				
60°/s	110.7 ± 25.23	116.8 ± 23.63	116.8 ± 22.49	116.2 ± 22.34
120°/s	94.96 ± 18.49	95.26 ± 21.50	97.73 ± 18.19	96.61 ± 18.88
180°/s	78.3 ± 14.09	78.05 ± 17.51	79.78 ± 15.25	82.81 ± 16
240°/s	65.76 ± 11.85	64.75 ± 13.32	66.2 ± 13.64	68.29 ± 12.45
Flexors				
60°/s	73 ± 4.20	71.5 ± 10.15	62.83 ± 10.44	72.5 ± 8.57
120°/s	64.83 ± 4.79	62.17 ± 7.33	57.33 ± 9.50	63.17 ± 8.28
180°/s	58.17 ± 7.78	54.67 ± 7.94	51.33 ± 10.69	57.5 ± 11.54
240°/s	50.17 ± 7.44	49.17 ± 7.11	44.0 ± 4.71	49.17 ± 8.93

*Indicates a significant difference ($p < 0.05$).

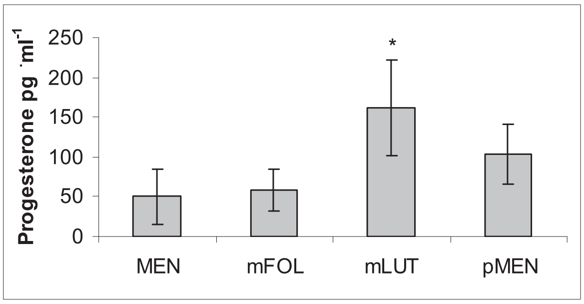

Fig. 1. Mean ± SD progesterone concentration recorded for the non-OC group across the four stages of the menstrual cycle where MEN = menstruation, mFOL = mid folicular, mLUT = mid luteal and pMEN = pre menstruation. Where * denotes a significant difference between mLUT and mFOL ($p < 0.05$).

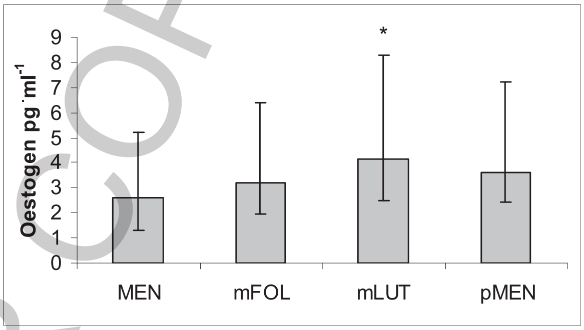

Fig. 2. Mean ± SD oestrogen concentration recorded for the non-OC group across the four stages of the menstrual cycle where MEN = menstruation, mFOL = mid folicular, mLUT = mid luteal and pMEN = pre menstruation. Where * shows a significant difference between mLUT and MEN ($p < 0.05$).

The data in Tables 1 and 2 indicate that there was a significant reduction in peak torque production of the extensors at 120°/s for MEN ($P = 0.0207$) compared to mLUT and for the flexors within MEN for both 60°/s ($P = 0.0183$) and 120°/s ($P = 0.0216$) when compared to pMEN, while there was no significant changes for peak torque within the OC group across the pseudo phases of the menstrual cycle ($p > 0.05$). The data revealed that there was a non-significant difference for peak torque of either the flexors or extensors between the OC and n-OC groups ($p > 0.05$).

Both progesterone and oestrogen displayed typical responses in relation to the phases of the menstrual cycle, with progesterone concentrations shown to be significantly higher during m-LUT compared to both MEN and m-FOL ($P = 0.0010$), as highlighted in Fig. 1. Oestrogen showed a similar response pattern as shown in Fig. 2, displaying significantly lower levels during MEN compared to mLUT ($P = 0.0207$). When the progesterone to oestrogen ratio (P-E) was calculated a significant difference was observed between mLUT and mFOL ($P = 0.001$) as displayed in Fig. 3. Significant positive correlations $r = 0.644$ and $r = 0.687$ were observed between progesterone (pg·ml^{-1}) and PT (°/s) during mLUT at 60°/s ($P = 0.031$) and 120°/s ($P = 0.020$) respectively. Additionally during mLUT correlations were observed between PT and oestrogen at 60°/s $r = 0.612$ ($P = 0.040$) and 120°/s $r = 0.644$ ($P = 0.031$). Significant inverse correlations were observed for pMEN between progesterone and PT at 120°/s $r = -0.590$ ($P = 0.047$) and 180°/s $r = 0.587$ ($P = 0.048$). Within mFOL significant correlations with P-E ratio were observed $r = 0.602$ ($P = 0.043$), $r = 0.798$ ($P = 0.05$) and $r = 0.707$ ($P = 0.017$) for PT of 120, 180 and 240°/s respectively.

4. Discussion

The primary purpose of this study was to evaluate the effects of menstrual cycle phase on the development of peak torque within the flexors and extensors of the knee across a range of contraction speeds. The major finding was that there were significant reductions in peak torque of the knee extensors and flexors at 60°/s and 120°/s during menses (MEN) in compari-

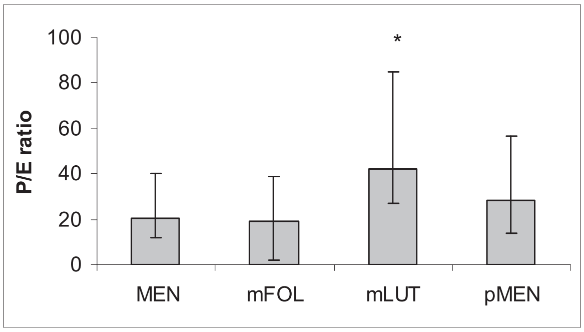

Fig. 3. Mean ± SD progesterone to oestoregn ratio (P-E) concentration recorded for the non-OC group across the four stages of the menstrual cycle where MEN = menstruation, mFOL = mid follicular, mLUT = mid luteal and pMEN = pre menstruation. Where * shows a significant difference between mLUT and mFOL ($p < 0.05$).

son to pMEN and mLUT. These data are in agreement with [4] who showed that peak torque of the flexors was at it's greatest around the time of ovulation. Previous studies have also suggested that during mid-cycle [days 12–18] the quadriceps exhibit increased isometric strength and relaxation times [29]. However, we would contend that some caution should be applied to these data, for unlike this study the authors did not directly determine the menstrual cycle phases but rather used estimates which were tracked back from the reported initial day of bleeding with ovulation being predicted to occur 14-days prior to menstruation.

The data from this study suggests that when oestrogen levels are reduced, as evidenced during the menstrual phase, there was a significant reduction in peak torque of the flexors at 60°/s and 120°/s and 120°/s for the extensors. These results are consistent with the concept of oestrogen having a strength enhancing effect [27]. The finding that there was no effect of menstrual cycle phase on peak torque production at either 180°/s or 240°/s is consistent with findings from previous studies [1,7,15,16,31]. It is well established that at slower velocities of muscle shortening (60, 120 °/s) the development of torque is a function of the amount of tension that can be developed within the recruited muscle fibres [32], whilst at faster velocities (180, 240°/s) the limitation to force generation is the number of muscle fibres that can be recruited, suggesting a neural mediated response [25].

These force generating properties would appear to be magnified in response to varying concentrations of oestrogen. Indeed, it has recently been proposed that skeletal muscle is an oestrogen responsive tissue [22] and that within skeletal muscle α-oestrogen receptors, mRNA and protein levels are sensitive to circulating levels of oestrogens [3]. Coupled with these findings it has previously been demonstrated that myosin is directly affected by oestrogen concentration [22] and that under conditions of reduced oestrogen levels, as experienced during menses, there is a reduction in the number of active myosin heads bound to actin, thereby reducing the force generating capacity of the muscle [24]. These previous findings are corroborated by the significant reduction in oestrogen for MEN when compared to mLUT, the significant positive correlation between PT and oestrogen concentration observed during mLUT and the non-significant associations during MEN, mFOL and pMEN.

There are a number of studies that suggest there is no association between the menstrual cycle and peak torque at either 60°/s [1,16] or 60 and 240°/s [9]. We would, however, assert that in these studies and in a number of other works, pertaining to the effects of menstrual cycle phase on athletic performance, that there was a lack of adequate experimental controls. Indeed, none of these cited studies reported using a control group of participants who had been administered an oral contraceptive pill for regulation of the menstrual cycle, against which the experimental (menstruating) responders could be compared.

Monophasic oral contraceptives, such as those taken by the participants in the OC group, are designed to suppress the level of estradiol and progesterone, thereby inhibiting the secretion of both follicle stimulating hormone (FSH) and luteinizing hormone (LH) (pituitary gonadotropins) [28]. The outcome of OC administration is a consistent, although pharmacologically controlled regulation of the female sex hormones. The implications for outcome orientated research relating to the menstrual cycle is that the administration of OC's can significantly limit both the inter- and intra-variability in the circulating female sex hormones and the inclusion of such a group provides an ecologically sound reference or control group against which to compare the non-OC menstruating participants.

The implications of these findings for female athletes who are undergoing rigorous training are significant, especially where there is a sequential structuring of training load as expressed through training models such as linear-periodisation, non-linear (undulating) periodisation or block training [20,30]. Structured training is based on the manipulation of training load through cycles or phases in order to elicit physiological/metabolic responses. When coach's and trainers are designing these structured schedules they should also take into account the length of their athlete's menstrual cycle as the data from this study suggests that, depending on the phases of the menstrual cycle, there will be alterations in sex steroid levels and significant alterations in the force generating capacity of the muscle. Future works now need to address the actual mechanisms by which oestrogen exerts an influence on muscle contractile properties and the longer terms training responses in relation to menstrual function.

5. Conclusion

Using a pseudo-menstrual cycle group as controls the data suggests that throughout the menstrual cycle there are significant alterations in the concentrations of the sex steroid hormones which are associated with decrements in the force generating capacity of the muscle, where the rate of force development occurs at slower velocities of shortening. The implications of these findings support the notion that skeletal muscle is sensitive to changes in oestrogen concentration and due consideration should be given to these responses when considering planning of training in female athletes.

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