The Effect of Menstrual Cycle Phases on Vertical Jump Kinematics and Kinetics in Elite Athletes

Ruaibah Yazani Tengah[1], Ashril Yusof[2], and Abd. Halim Mokhtar[2]
[1]*Universiti Pendidikan Sultan Idris, Malaysia*
[2]*Universiti Malaya, Malaysia*
ruaibah@fsskj.upsi.edu.my

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Abstract: Understanding the effect of menstrual cycle on kinematics and kinetics of exercise performance is important in the sense that menstrual cycle disrupts the hormonal balance of athletes. Changes in hormonal balance might affect exercise performance, and thus might affect longitudinal adaptations which occur from training, and also with biomechanical changes which increase the likelihood of injury. Twelve well trained elite female athletes voluntarily participated in this study. Thirteen kinematic and kinetic variables were measured via force platform during a counter movement jump exercise. Three variables namely peak power ($p = 0.030$), mean power ($p = 0.010$) and peak velocity ($p = 0.016$) were significantly differed ($p < 0.05$) across the three menstrual cycle phases, where a reduction was clearly observed during the menses phase. Based on the results, menses phase was detrimental to exercise performance that requires explosive power component for elite level athletes. Thus, training with aims and goals of developing explosive power adaptation is not recommended to be carried out by elite athletes during their menses, with change of strategy during competition is suggested when a decrease in explosive power output might impair related sports specific performance. As a conclusion, athletes' menstrual cycle process should be monitored closely with training and competition for performance purposes as well as for injury prevention.

1 INTRODUCTION

Sports performance particularly relies a lot on strength and power capabilities of the athletes to sprint faster (Cronin et.al, 2007; Delecluse et.al, 1995), jump higher (Cormie, et.al, 2010), minimize the movement metabolic requirement (Storen, et.al, 2008) and improve other functional capabilities (Harris, et.al, 2000). It is worth to note that a decrease or an increase of muscle performance depends on many factors which include, hormonal, metabolic and neural factor.

Menstrual cycle phase experienced by the female athletes caused continuous changes in hormone concentration (Lebrun & Rumball, 2001) and thus might alter the hormonal stimulus secreted and received during the strength training session, which might affect exercise performance. There have been many studies that have investigated the effect of menstrual cycle on human sports and exercise performance (Di Brezzo Fort, & Brown, 1991; de Jonge, 2003; Petrofsky, et.al, 1976; Sarwar, et.al, 1996; Sung, et.al, 2014; Gil, 2017; Pallavi, et.al, 2017). Certain phases of menstrual cycle have been identified to increase risk of anterior cruciate ligament injury (Abt, Sell, et.al, 2007). This is not surprising as menses is a disruption to hormonal activities (Oosthuyse, & Bosch, 2010) and changes in hormonal function might affect physical activities performance. Female sex hormones fluctuation during the menstrual cycle is reported to have significant effects on the neuromuscular system (Hewett, 2000; Ekenros, et.al, 2017). On the other hand, few studies performed on recreationally trained athletes or non-athletics population indicated that there were no significant differences on the neuromuscular performance during menstrual phases (Di Brezzo, et.al, 1994; Lebrun, et.al, 1995; Bennal, et.al, 2016). At present, little data is available regarding the effect of menstrual cycle on exercise performance in elite athletes. Other findings suggest that hormonal fluctuations due to menstrual cycle phases do not interfere with maximal intensity whole body sprinting and the metabolic responses to such exercise (Tsampoukos, et.al, 2010). Since the finding remains inconclusive, further investigation in this area is needed. In term of team sports especially in relation to match or game based sports such as hockey

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matches, the ability to sustain high intensity intermittent loads is believed to be crucial for the final outcome of the match (Reilly & Borrie, 1992). As mentioned earlier, strength and power will improve functional performance during the games which will contribute towards improving the physical performance of the athletes. Vertical jump exercise is one of the typically used exercises for strength and power training and assessment (Tricoli, et.al, 2005; Hanson, et.al, 2007; Hester, et.al, 2017). A decrease in vertical jump's kinematics and kinetics during training might decrease overall performance adaptation longitudinally. Therefore, the purpose of this study was to identify the differences in vertical jump kinematics and kinetics that might occur between the menses, follicular phase and luteal phase of the menstrual cycle among elite athletes.

2 METHODS

2.1 Experimental Approach to the Problem

Acute randomized within-subjects cross-over design was used in this study, where subjects were asked to attend one familiarization and three testing sessions. The subjects randomly performed the testing session starting at different phases of the menstrual cycle which includes i) Menses (Day 1 – 5); ii) Follicular Phase (Day 6 -13); and, iii) Luteal Phase (Day 15 – to next cycle). This design allowed the subjects to complete testing sessions within one menstrual cycle, and some were allowed to carry over the testing sessions into their next cycle. Two weeks before their first testing session all subjects were asked to attend a familiarization session at the Exercise Physiology Laboratory, National Institute of Sports, Malaysia. During the familiarization session, the subjects were given briefings on exercise and experimental protocols, procedures and exercise techniques.

2.2 Subjects

Twelve well trained elite female intermittent sport athletes voluntarily participated in this study. All subjects were elite athletes ranging from intermittent sport athletes with the national team of Malaysia at the time of the testing. Subjects' selection criteria were, aged between 18-28 years old with a maximum oxygen uptake (O2max) of = 50 ml/kg/min, healthy with no allergies, free of metabolic, cardiovascular or respiratory diseases, nonsmokers and regular menstrual cycles lasting 28 ± 2 days in duration (3 month monitoring of regularity). All subjects were fully informed of the study's purposes and possible risks before signing a consent form. Subjects were also told that they are free to withdraw at any stage of the study without the obligation to give reasons. Prior to commencing the study, approval was obtained from the ethical committee of University of Malaya and National Sports Council, Malaysia.

2.3 Equipment

Counter movement vertical jump was conducted on a force plate (400 Series Performance Force Plate, Fitness Technology, Australia) interfaced with computer software (Ballistic Measurement System, Fitness Technology, Australia) that allowed direct measurements of displacement, force, velocity and power variables. Data sampling rate was set at 200 Hz with filter cut-off frequency rate of 10 Hz. Jump height was estimated using the following equation [(h = t2•g/8]. Where g is the gravitational acceleration estimated at 9.81ms•-1 and is the flight time.

2.4 Procedures

Preliminary Assessments and Familiarization: Subjects' body height and weight were measured after the briefing and their informed consent form were collected. Subjects were then showed the counter movement vertical jump technique, followed by several trials of the jump by each of the subject on the force plate. Improper technique was corrected and the subjects performed several more trials until the researcher was satisfied with the jump technique. Verification of menstrual cycle phase: Menstrual phases of each subject was verified using blood samples to determine the level of estrogen, progesterone, LH and FSH based on method by (Kleiblova, et.al, 2006) along with basal body temperature (BBT) charts (Guermandi, et.al, 2001).

2.4.1 Method

Counter movement vertical jump technique: The counter movement vertical jump ready position was standardized with subjects standing with the feet approximately shoulder width apart and hands on their hips. The jumps began with the subjects lowered down their buttock, bend their knees to quarter-squat position, and later immediately straighten the knee with feet pushing the ground for their take-off. The subjects were then considered had completed one repetition of the jump when they landed with their hands still on their hip within the force plate area with the knee again bend during the landing to absorb impact. The subjects made another jump straight-away until desired repetitions were achieved.

Testing procedures: The subjects were tested randomly at different phases of their menstrual cycle. Method of assessment was replicated as previously described (Hespanhol, et.al, 2006) with all subjects tested at similar time of the day for each testing occasion. During each testing, the subjects performed 4 series of 15 seconds vertical counter-movement jump (CMJ). All subjects started their testing session with a standardized general warm-up and practiced jumping several times until they were comfortable and consistent with it. The subjects performed 4 trials x 15 seconds maximum effort counter movement vertical jumps. The subjects were instructed to jump as high as possible on each of the single repetition, with 10 seconds rest periods were given between each trial. Each testing session ended with cooling down and stretching exercises.

2.5 Data Analysis

The force plate measures all dependent variables of interest at a sampling frequency of 200 Hz. Variables of interest include peak force (N), mean force (N), peak power (W), mean power (W), jump height (m), peak distance (m), min distance (m), peak velocity (m.s-1), min Velocity (m.s-1), jump repetition, impulse at 100 (ms), 200 (ms) and 300 (ms) were calculated for each set of the jumps involved via the BMS software data analysis program. The variables of interest in this study have been proven to be stable within and between sessions (i.e. typical CV < 5% and ICC~0.95).

2.6 Statistical Analysis

All data from variables of interest during the three phases of menstrual cycle were analyzed using a general linear model one way repeated measure (ANOVA). A one sample Kolomogorov Smirnov test was utilized to determine the normal distribution of all variable. In the cases where a Mauchly's test of sphericity assumption was violated, the Greenhouse-Geisser value was utilized to determine significance. Further analyses using paired sample t test were used to identify relative changes between menses versus luteal phase and follicular phase versus menses. The significance level of this study was set as $p < 0.05$.

3 RESULTS

3.1 Counter Movement Jump (CMJ)

Mean values (± SD) for thirteen selected kinematic and kinetic components for CMJ performance during different phases of the menstrual cycle are presented in Table 1. Significant differences ($p < 0.05$) were found in peak power, mean power and peak velocity output between the three phases based on one way repeated measure (ANOVA), while paired simple t test indicated that the significant difference were actually originated from the differences between luteal phase and menses phase.

Table 1: Mean ± SD of counter movement jump performance during menstrual cycle phases. (Average of 4 trials x 15s counter movement jump).

Variable (n=12)	Luteal Phase	Menses	Follicular Phase	P value
	Mean ± SD	Mean ± SD	Mean ± SD	
Peak Force (Newton)	1154.55 ± 114.79	1130.98 ± 130.20	1114.26 ± 102.08	0.4388
Mean Force (Newton)	863.41 ± 66.27	845.01 ± 69.12	841.10 ± 56.35	0.2027
Peak Power (Watts)	**2880.88 ± 375.46***	**1952.30 ± 135.64**	**2069.25 ± 216.99**	**0.0304**
Mean Power (Watts)	**1087.24 ± 168.78***	**987.05 ± 91.81**	**1009.22 ± 98.37**	**0.0096**
Jump Hight (m)	0.23 ± 0.02	0.22 ± 0.02	0.22 ± 0.03	0.0781
Peak Distance (m)	1.28 ± 1.55	0.50 ± 0.48	0.91 ± 0.87	0.1893
Min Distance (m)	0.14 ± 2.66	-1.38 ± 0.65	0.38 ± 0.82	0.2037
Peak Velocity ($m.s^{-1}$)	**2.39 ± 0.25***	**2.19. ± 0.14**	**2.31 ± 0.16**	**0.0160**
Min Velocity ($m.s^{-1}$)	-1.33 ± 0.25	-1.23 ± 0.37	-1.37 ± 0.19	0.4292
Jump Repetition	15.66 ± 0.9	15.62 ± 0.70	15.52 ± 1.3	0.7713
Impulse at 100 (ms)	95.92 ± 10.29	93.12 ± 9.20	92.08 ± 7.0	0.2200
Impulse at 200 (ms)	196.14 ± 21.98	191.02 ± 22.20	186.80 ± 21.31	0.2284
Impulse at 300 (ms)	285.96 ± 29.83	279.05 ± 29.13	273.62 ± 32.12	0.2378

*denotes significant difference between Luteal Phase vs Menses: $p < 0.05$

3.2 Peak power (W)

The analysis of variance for the peak power (W) is shown in Table 1. The peak power (W) varied significantly between the phases in the menstrual cycle [F (2, 11) = 4.112, $p < 0.05$]. Pairwise comparison showed that relative peak power (W) responses were affected during M -LP than FP –M.

3.3 Mean power (W)

The analysis of variance for the mean power (W) is shown in Table 1. Mean power (W) was significantly differed in three phases of menstrual cycle [F (2, 11) = 5.784, $p < 0.05$]. Relative change of mean power slightly decreased before menses (M – LP) compared to after menses (FP – M).

3.4 Peak velocity (m.s-1)

The analysis of variance for the peak velocity (m.s-1) is shown in Table 1. Peak velocity (m.s 1) was found to be significantly differed between the phases of the menstrual cycle [F (2, 11) = 5.020, $p < 0.05$]. Relative change of peak velocity (m.s-1) was significantly higher during LP – M then FP – M.

3.5 Estrogen / Progesterone Ratio

Mean values (± SD) of serum estrogen and progesterone levels in the different phases of the menstrual cycle for the 12 subjects are presented in Table 2. Estrogen levels were low in the menses phase and increased as expected in the luteal phase and follicular phase. Progesterone levels increased in the luteal phase compared to other phases.

Table 2: Mean values (± SD) of serum estrogen and progesterone levels in the different phases of the menstrual cycle.

Hormone	Luteal phase	Menses	Follicular phase
Estrogen (pmol/I)	405.08 ± 232.27*	158.58 ± 43.89	255.50 ± 118.08
Progesterone (nmol/I)	3.86 ± 2.7*	1.94 ± 0.5	2.46 ± 0.8
E/P Ratio	104.94	81.74	103.86

*denotes significant at luteal when compare with menses with $p < 0.05$.
E=Estrogen; P= Progesterone.

3.6 Estrogen (pmol/I)

The estrogen level was significantly differed between the phases of menstrual cycle, F (2, 22) = 7.246, $p < 0.05$].The estrogen level during luteal phase (405.08 ± 232.27 pmol/I) was higher compared to menses (158.58 ± 43.89 pmol/I) and follicular phase (255.50 ± 118.08 pmol/I).

3.7 Progesterone (nmol/I)

The Progesterone level was significantly differed between the phases of menstrual cycle, [F (2, 22) = 4.366, $p < 0.05$].The progesterone level during luteal phase (3.86 ± 2.7 nmol/I) was higher compared to menses (1.94 ± 0.5 nmol/I) and follicular phase (2.46 ± 0.8 nmol/I).

4 DISCUSSION

The main aim of this study is to investigate how some selected kinematics and kinetics were affected by menstrual cycle phases, when performing acute explosive anaerobic type activities such as the counter movement jump among well trained elite athletes. The most important finding is that significant differences in peak power (W), mean power (W) and peak velocity (m.s-1) between the three menstrual cycle phases. Other variables measured such as peak force (N), mean force (N), jump height (m), peak distance (m), min distance (m), min velocity (m.s-1), jump repetition, impulse at 100 (ms), impulse at 200 (ms) and impulse at 300 (ms) did not show any difference during the menstrual cycle phases, which confirmed what have been found by previous studies (Friden, et.al, 2003).

Before further discussions are made on the key findings of this study, several factors that might influence the results obtained should also be noted. First limiting factor that may affect the results of this study is the timing of each testing with regards to the day of the menstrual cycle phases. De Jonge (2003), recommended that testing should be conducted on the same day (i.e., 3rd day of LP, M and FP). However in our study it was difficult to gather the subjects to be tested on similar timing each of their menstrual cycle phases. Thus, this might have some minor impact on the results obtained, due to fluctuations in hormone levels within each day of the menstrual phases (Bambaeichi, et.al, 2004).). Although it was difficult to gather elite athletes at one specific menses timing, all subjects were tested at similar time of the day, to ensure minimal differences in the circadian variations.

The second factor is the pulsatile secretion of estrogen and progesterone. In order to minimize inaccuracy that might be caused by higher secretion due to exercise or time of the day, all subjects were tested within the same time of the day as indicated earlier. All testing's were conducted at rest condition. It has been reported that while the level of estrogen might be similar between subjects, the progesterone level might fluctuate and vary between subjects, and thus may influence the physical exercise performance (Bunt, 1990; de Jonge, 2003). Based on observation made on both hormones secreted in this study (Table 2), fluctuations on the estrogen and progesterone ratio during each testing period existed. Therefore this result suggested that the changes in female steroid hormones during the menstrual cycle may affect the mechanical properties of human muscle and tendon. A previous study had also found that muscle fiber recruitment / motor unit activations were negatively affected across menstrual cycle phase (Bambaeichi, et.al, 2004).

The main findings of this study were reduction in peak power, mean power and peak velocity during the menses phase, and these findings are in agreement with a number of previous studies (Friden, et.al, 2003; Nicolay, et. al, 2007; Wojtys, et.al, 1998). However, none of these cited studies used well-trained high performance athletes as subjects. Thus, the present study has shown that the well trained athletes also reacted similarly as the untrained subjects in this matter. Training status has previously been shown to have an impact on power production ability and utilization of muscle activities during explosive or non-explosive anaerobic type of exercise or movement (Pick & Becque, 2000) but this might exclude female athletes with menses, in which their training status might not made them 'immune' towards the effect of menstrual cycle on performance. It could be suggested that, during training or competition, athletes with menses should shift their game play from relying more on power based movement into skills or movement that requires less of this, in order to maintain their typical performance. This kind of change of strategy or skills used might minimize the negative effect assaulted with menstrual cycle experienced by the trained athletes. However, this is far from definite and further studies are on the way to elucidate this.

Soares, et.al, (2011) suggested that the behaviour of the muscles in women presents different characteristics during different phases of the menstrual cycle, in particular, at the end of the luteal phase. Findings of their study also supported what have been found previously, that different neuromuscular patterns were utilized when performing jump sequence during different phase of menses, as luteal phase has higher estrogen level compared to during early follicular phase, which has lower level of estrogen (Dedrick, et.al, 2008). Our results also suggested that estrogen and progesterone levels decreased during the menses phase in which the reduction in peak power, mean power, and peak velocity were observed.

Another explanation that may be considered for the reduction in peak power, mean power and peak velocity is pre-menstrual syndrome (PMS). PMS is characterized by cyclical physical and mood disturbance during the luteal phase, where severity of the symptoms (i.e., pain) gradually increases during the luteal phase and disappears a few days after onset of menses (Friden, et.al, 2003). Giacomoni, et.al, (2000) proposed that although there were no significant differences in maximal anaerobic performance during different menstrual cycle phases, results of their study suggested that the presence or absence of premenstrual or menstrual syndrome symptoms may have an effect, possibly through an action on the stretch shortening cycle of tendons and ligaments. Research has provided strong evidence that PMS symptoms are the result of an abnormal response to normal levels of estrogen and progesterone (Schmidt, et.al, 1998).

SCIENCE AND TECHNOLOGY PUBLICATIONS

4.1 Practical Applications

Results of this study indicate the need of some considerations to be taken when managing strength and power training for female elite athletes especially during their menses. While the findings of this study is far from definite, coaches and athletes alike should take into consideration to properly monitor female elite athletes that need to perform explosive power type of movement during training and competition. Changes of strategies especially in sports with explosive type of movement might be required in order to ensure continuity of desirable peak performance during competition. Training sessions with an emphasis and goal on peak power output should be adjourned to another day to ensure maximum adaptations can take place longitudinally. A proper monitoring system for female athletes menstrual cycle process should also be a part of conditioning training plans, should include both performance related reasons and injury preventions. However, the results obtained in this study still need to be investigated further, especially by performing longitudinal research and taking into accounts other factors involved such as muscle activation, firing rate and many more before firm conclusion can be elucidated.

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