Differences in sleep quality and quantity during the menstrual cycle, and how this relates to subjective energy level and muscular feeling among endurance junior athletes

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ABSTRACT

Women have a circamensal rhythm driven by hormones that induce physical and psychological effects on the female body, that may consequently affect exercise quality, recovery, adaption to exercise and sport performance. The primary objective in this study was to investigate whether sleep quality and sleep duration differs between the phases of the menstrual cycle. The secondary objective was to investigate coinciding effects on muscular feeling and energy level during the menstrual cycle. Objective sleep quality was measured by an impulse radio ultra-wideband pulse Doppler Radar, and a visual analog scale (VAS) was used to measure subjective sleep need, energy level and muscular feeling. All measures were repeated daily in a 61-day period. Results are based on 16 female high-school cross-country athletes with mean age 17.5 (SD ± 0.5) not using hormonal contraceptives. In the follicular phase, 18.8 ± 5.3 % of total sleep time was registered as deep sleep, which was significantly higher than 17.4 ± 4.9 % in the luteal phase (p-value = .02). Furthermore, 55.5 ± 6.4 % of total sleep time was registered as light sleep in the follicular phase, which was lower than 57.0 ± 7.2 % in the luteal phase (p-value = .04). Reduced energy level was found in the follicular phase, with VAS-scores of 60.3 ± 19.0 compared to 55.8 ± 20.0 in the luteal phase (p-value = .04). Higher muscular tenderness was found in the follicular phase with a VAS-score of 55.8 ± 21.6 compared to 63.4 ± 19.8 in the pre-menstrual phase (p-value =.01). These findings indicate an effect of the menstrual cycle on objectively measured sleep quality, with reduced quality in the luteal phase compared to the follicular phase. Reduced energy level and increased muscular tenderness in the follicular phase, compared to the luteal and pre-menstrual phases respectively, coincided with lower sleep quality in the luteal phase. In other words, a delayed negative effect of reduced sleep quality and consequently reduced recovery in the luteal phase leads to lower perceived energy levels and increased muscular tenderness in the subsequent follicular phase.

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Table of contents

1 INTRODUCTION

Female endurance athletes perform large amounts of endurance exercise, which require subsequent recovery to enable positive adaptation and high-level performance in sports. In order to archive this, finding a good balance between training load and recovery is a key factor (1). Recovery is a process which happens relative to time resulting in maintaining an equilibrium by compensating both physical and psychological stress (1). Sleep is known to be an important factor contributing to recovery (2). Therefore, sufficient and high-quality sleep, will have a significant effect on athletic performance (3). Factors that affect sleep will influence the ability to recover after exercise, and some of these factors are gender-related, putting women in a different position than men. Women have a circamensal rhythm driven by sex hormones where blood concentration of hormones varies during the cycle. These hormones might have both physical and psychological effect on the recovery process, and thereby influence the ability to adapt from exercise and thereby affect performance. For this reason, understanding the influence of menstrual cycle on sleep, and the ability to recover after exercise is of high importance among female athletes.

1.1 Sleep

Sleep is a state of lower ability to register what is affecting us, what is happening to us, and consequently respond to this (4), as well as, lessened motoric and sensory functions (5).
Sleep can be measured by looking at the rhythmical electrical activity of the brain, or brain waves, registered by electroencephalography (EEG) (6). During sleep the brain waves go through different cycles, which repeat four to five times during a night (4), consisting of 5 different stages. Stage 1 and 2 are light sleep; stage 3 and 4 are called slow-wave-sleep or deep sleep. The last stage is called rapid eye movement sleep (REM-sleep). Often stages 1-4 are referred to as non-REM (NREM) sleep.

In the everyday regulation of sleep circadian rhythms, body temperature, behavior, daylight and darkness play an important role (6). The circadian rhythm is an internal biological process repeating every 24 hour, and is controlled by nucleus suprachiasmaticus (7). Nucleus suprachiasmaticus controls the endogenous secretion of melatonin (8), which is inhibited by light (6). This means there is lower concentration of melatonin in daytime and higher at night. During the day, concentration of a hormone called adenosine builds up and is known to regulate sleep pressure (9). Sleep pressure can be thought of as the brains need for sleep, which increases during hours awake. Both melatonin and adenosine are hormones that build up during the day, decrease during night, and contribute to the everyday regulation of sleep. The need for sleep will vary among individuals and varies every night, depending on factors like physical and psychological stress, illness and time schedules (3), and is important for e.g. our cognitive function and emotional skills that would be disturbed by lack of sleep (10).

In terms of athletic performance, sufficient high-quality sleep and its relation to recovery has become a topic of interest among scientist (11). For example, previous studies done on sleep and athletic performance, found that sleep deprivation affects performance negatively, and that an increase in sleeping time is positively associated with performance (12). Improved sleep might also lower the risk for getting ill and getting injuries (3). Another study found a significant increase in sleep time and slow-wave-sleep after extreme training load (13). Sleep has a key role in recovery and adaption process among athletes, and the pattern of sleep stages and total sleeping time are changing after metabolic stress (13). In addition, it has been speculated that also the timing of sleep and the length of different sleep phases would be of importance for different performance development.

1.2 Menstruation

When menarche occurs, females experience cyclic variation in sex hormones, which include cyclic variation in concentration of progesterone, estrogen, luteinizing hormone (LH) and follicle stimulating hormone (FSH). One cycle lasts between 25 - 35 days and is normally a vital part of every woman's life from around 13 until around 50 years of age. The menstrual cycle consists of a preovulatory follicular phase, the ovulation and postovulatory luteal phase. The first day of menstruation cycle starts with the first day of menstruation (14). During the menstrual cycle, concentration of the sex hormones varies. These hormones have not only reproductive function, but also function outside the grasp of reproductive organs (14). These changes may affect females physically and psychologically, which again might have effect on the athlete's performance (15), and also the women's recovery in terms of altered sleep and circadian rhythms (14).

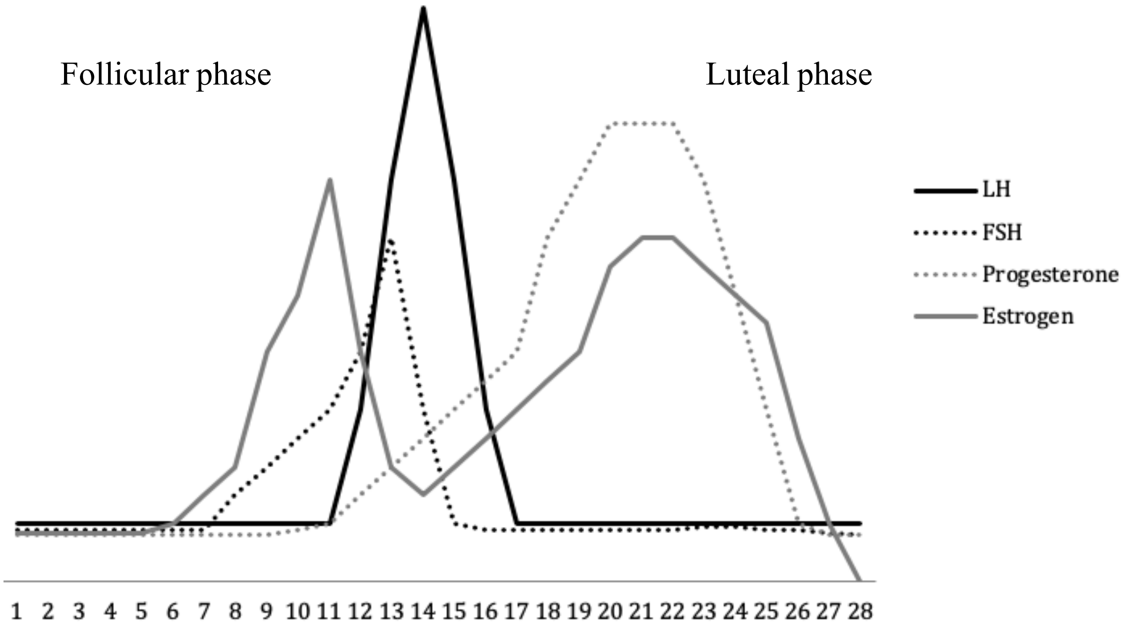

Figure 1: Illustration of theoretical changes in hormonal concentration during the menstrual cycle for normally menstruating women not using hormonal contraceptives, with the follicular phase representing the first 14 days, and the luteal phase representing the following 14 next days in this figure.

Studies showed that the changes in the menstrual cycle and sex hormones might be associated with changes in physiological performance (15, 16). In the luteal phase, the rise in progesterone affects the thermoregulatory center located in hypothalamus, and also body temperature and the metabolic rate varies during the cycle (17). Other research found decreased balance control and muscle strength of the hip, and consequently poorer tennis performance around ovulation among players having a normal and natural menstruation, but could not conclude that menses severely affect performance (16). These findings may indicate a change in both muscle strength and balance control during the cycle, which might have an effect on the athletes' adaptation to exercise and recovery after exercise. In the pre-menstrual phase we see changes like higher storage of water that causes an increase in bodyweight (15), and dysmenorrhea (painful menses due to cramps), which may be unfavorable for performance at a high level (15). The recovery process might also be affected due to menstrual pain and not being able to relax as normal. However, not all studies find an effect of the menstrual cycle on performance (18), or sleep (19). As we can see, many factors during the menstrual cycle might affect athlete's performance and recovery, but more investigation is needed to establish the mechanisms at play.

The menstrual cycle can be manipulated or changed due to different factors. Many females use hormonal contraceptives in years of their reproductive age. There are different reasons for the use of contraceptive e.g. control of bleeding, control of premenstrual and menstrual pain and avoiding pregnancy. Previous research found that competitive athletes consider sport activities and competitions important in deciding whether to manipulate their cycle (20). This might lead to an effect on the athlete's performance and ability to recover, as a result of manipulating the menstrual cycle. Other factors like nutrition and BMI might also affect the menstrual cycle. A different study found delayed menarche and menstrual irregularities, while studying body composition and dietary intake prior to competition among female gymnasts (21). This emphasizes important factors to have in mind when analyzing the menstrual cycle and its effect on recovery and performance.

1.3 Menstruation and sleep

Hormonal changes may lead to an increased risk for sleep disturbances. Previous research found that women had a higher risk of reporting insomnia than men (22) , and that changes in circadian rhythm and sleep were associated with changes in blood concentration of sex hormones during the menstrual cycle (14). A change in circadian rhythm was associated with a progesterone-mediated effect on melatonin, with a delay of melatonin secretion in the luteal phase (23). Changes of melatonin secretion were also seen in travelling women, which were related to increased numbers of females with amenorrhea (15). An increased EEG activity in NREM sleep was seen when the concentration of progesterone and estradiol were high (24), which could be explained by receptors for progesterone and estradiol located in many areas of the brain regulating sleep, including hypothalamus, locus coeruleus, dorsal raphe nucleus and the basal forebrain (14, 25). Also, an interaction between the circadian rhythm and menstrual cycle has been registered in the regulation of REM-sleep (26). Furthermore, the premenstrual days and the first days of menstruation showed to negatively affect self-reported sleep quality (14, 27). These findings indicate that the menstrual cycle is coordinated with circadian rhythms and together this might influence the female athletes' recovery and adaption to exercise.

Today, most research focusing on sleep among elite athletes does not take possible differences across the menstrual cycle into account, even though it is well known that the menstrual cycle affects the circadian rhythm. In the current study, our primary aim is to examine whether sleep quantity and quality differ between the different phases of the normal menstrual cycle among female junior endurance athletes. The secondary objective is to investigate the coinciding effects on the subjective muscular feeling and energy level during the menstrual cycle.

Hypothesis

Based on previous research outlined above, the main hypothesis is that the menstrual cycle affects sleep quality and total sleeping time. More specifically, it is expected that during the luteal phase, due to progesterone-mediated effect on melatonin and also pre-menstrual effects like discomfort and weight gain, that we see a longer total sleeping time consisting of more light sleep, and that this will have a negative effect on reported energy level and muscular feeling.

2 METHODOLOGY

This study was done as part of a larger study focusing on sleep in elite athletes, including a PhD project named "Long-term monitoring of sleep in junior elite athletes: roles of cognitive and physical stress". Thus, the methodology is based on this project.

2.1 Subjects

The participants of the study were female junior athletes from specialized high schools for sports in Trøndelag, in the middle of Norway. Age ranged from 17 to 19 years, and the study lasted 8 consecutive weeks. Athletes not manipulating their menstrual cycle using hormonal contraceptives were defined as having normal menstruation. Initially, 19 participants were included. Among these, 2 were excluded due to use of hormonal contraceptives, and 1 was excluded due to missing data. Results are therefore based on the 16 women defined having normal menstruation.

2.2 Procedure and instruments

Three main types of instruments were used: A menstruation form, the XeThru X4 sleep radar and a stress scale. In the beginning of the study, the participants answered 7 questions related to menstrual issues. 4 different menstrual symptoms were listed, and they answered whether their experienced these or not by answering yes or no. If they had other symptoms, they were asked to describe these. They also answered whether their menstrual symptoms affected their sleep or not. Participants started the study in different phases of the menstrual cycle and have different cyclic length. The menstrual cycle was divided into 4 parts; the follicular, luteal, pre-menstrual and menstrual phase. The menstrual phase was defined by the number of days of menstrual bleeding. The pre-menstrual phase was defined by the 3 last days prior to menstrual bleeding. First and second half of the cycle was defined as respectively follicular and luteal phase. For odd number of days, the luteal phase was given the extra day. To compare the overlapping phases, e.g. menstrual phase and follicular phase, the days in the follicular phase not being in the menstrual phase was compared with the menstrual days.

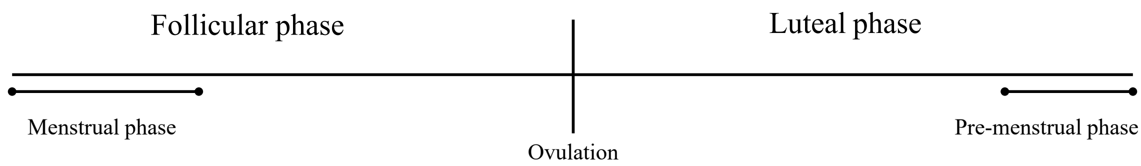

Figure 2. Defined phases of the menstrual cycle.

The menstrual bleeding was used for defining the 4 phases. For subjects having 2 menstrual bleedings during the 8 weeks, the follicular and luteal phase was calculated as well as the pre-menstrual and menstrual phase. For those having only 1 bleeding, pre-menstrual and menstrual phase was calculated. For one subject not having any bleeding during the 8 weeks, no phase was possible to calculate.

Sleep was registered by the sleep monitor Somnofy (VitalThings AS, Tønsberg, Norway). Somnofy houses an impulse radio ultra-wideband pulse Doppler Radar, the XeThru model X4. The sleep monitor registers phase modulation (physiological movements), which allows identification of respiration rates and movement of the body (28). Based on this information algorithms have been constructed to translate these variables into sleep variables (sleep, wake and sleep stages) (28). The parameters that were collected were time in bed, time asleep, time in the different sleep stages, and sleep efficiency. Sleep efficiency was defined as time asleep in percent of total time in bed. Every night, the XeThru X4 sleep radar was used for objective sleep monitoring. The monitoring happened automatically, and the athletes were introduced to place the sleep radar on their bedstand.

Information was gathered every evening about the athlete's subjective energy level, muscular feeling and sleep need, ranked on a visual analogue scale (VAS) from 0 to 100. A VAS-scale is found to be reliable and with high compliance (29). High scores on muscular feeling indicated lower muscle tenderness, high score on energy level indicates lower energy, and high score on sleep need indicates low sleep need. The gathering of information was done by an app linked to the sleep monitor Somnofy. On this app the athletes got information about their sleep last night, and they also got the visual analogue scale to rank their energy level, muscular feeling and sleep need. The energy level, muscular felling and sleep need were to be registered every evening before the athletes went to sleep.

2.3 Statistical analysis

Descriptive analyzes of sleep variables, sleep need, energy level and muscular feeling in the 4 phases of the menstrual cycle was calculated. Mean values and standard deviation (SD) were calculated for each variable in the respectively 4 phases of the menstrual cycle using Statistical Programme for Social Science (SPSS) version 25.0 of IBM corp. located in Armonk, NY (30). For calculating p-value independent t-test was used for the different variables. P-value was set at alpha = 0.05. For measuring the effect size on p-values < 0.05 UNIANOVA and Partial Eta Squared was used.

3 RESULTS

3.1 The sample

Mean age of the 16 females having normal menstruation was 17.5 (SD ± 0.5), and mean duration of the menstrual cycle was calculated being 28.3 days (SD ± 4.6). Altogether 80 days in pre-menstrual phase were registered, 139 days in menstrual phase, 181 days in follicular phase and 187 days in luteal phase. Sleep data was registered in 89.3 % of the defined phases, and subjective sleep need, energy level and muscular feeling were registered in 86.0 % of the defined phases. The participants reported different subjective menstrual symptoms: 50.0 % reported change in mood, 75.0 % had stomach and back pain, 18.8 % had headache, 25.0 % reported tender breasts, 18.8 % reported other issues. 25.0 % reported that their menstrual symptoms affected their sleep.

3.2 The menstrual cycle’s relation to sleep, energy level and muscular feeling

More light sleep was registered in the luteal phase compared to follicular phase as our hypothesis suggested (see Table 1). However, we did not find any significant difference on the variables *time in bed* and *time asleep* in any of the phases of the menstrual cycle.

Table 1.
Mean values± SD for the objective sleep variables and the subjective variables sleep need, energy level and muscular feeling in the 4 phases of the menstrual cycle among female endurance athletes.

Sleep variables	Pre-menstrual	Menstrual	Follicular	Luteal
Time in bed (hours)	9.8 ± 1.2	9.9 ± 1.5	9.8 ± 1.5	9.7 ± 1.5
Time asleep (hours)	8.0 ± 1.0	7.9 ± 1.2	7.9 ± 1.3	7.8 ± 1.2
Time in light sleep (%)	55.6 ± 5.7	54.0 ± 6.9 • ∇	55.5 ± 6.4 # ∇	57.0 ±7.2 • #
Time in deep sleep (%)	17.9 ± 4.6	19.3 ± 5.3 •	18.8 ± 5.3 #	17.4 ± 4.9 • #
Time in REM sleep (%)	26.4 ± 4.1 *φ*	26.4 ± 5.0 •	25.7 ± 5.4	25.2 ± 4.6 • *φ*
Sleep efficiency (%), mean	82.5 ± 8.0 *o*	79.7 ± 10.1*o*	80.2 ± 10.6	81.4 ± 8.7
Sleep need, mean (0-100)	51.3 ± 19.0 *φ*	51.2 ± 17.9 •	48.0 ± 17.6	46.0 ± 17.7 • *φ*
Energy level (0-100), mean	58.5 ± 21.5	61.3 ± 19.8 •	60.3 ± 19.0 #	55.8 ± 20.0 • #
Muscular feeling (0-100), mean	63.4 ± 19.8 *λ*	59.3 ± 22.0	55.8 ± 21.6 *λ*	59.3 ± 19.8

Notes. P-values <.05 with values from .000 - .044 are marked with symbols: • = menstrual*luteal, # = follicular*luteal, ∇ = follicular*menstrual, λ= follicular*pre-menstrual, φ =luteal*pre-menstrual, o = menstrual*pre-menstrual. For all significant findings the effect size was found to be small with partial eta squared (η_p^2) in the interval .013 - .042.

A difference in energy level with participants having less energy in the follicular phase compared to the luteal phase (see Table 1) was found. This might coincide with our hypothesis, which suggested that more light sleep will have a negative effect on energy level. Higher muscular tenderness was found in the follicular phase compared to the pre-menstrual phase, which also might coincide with our hypothesis.

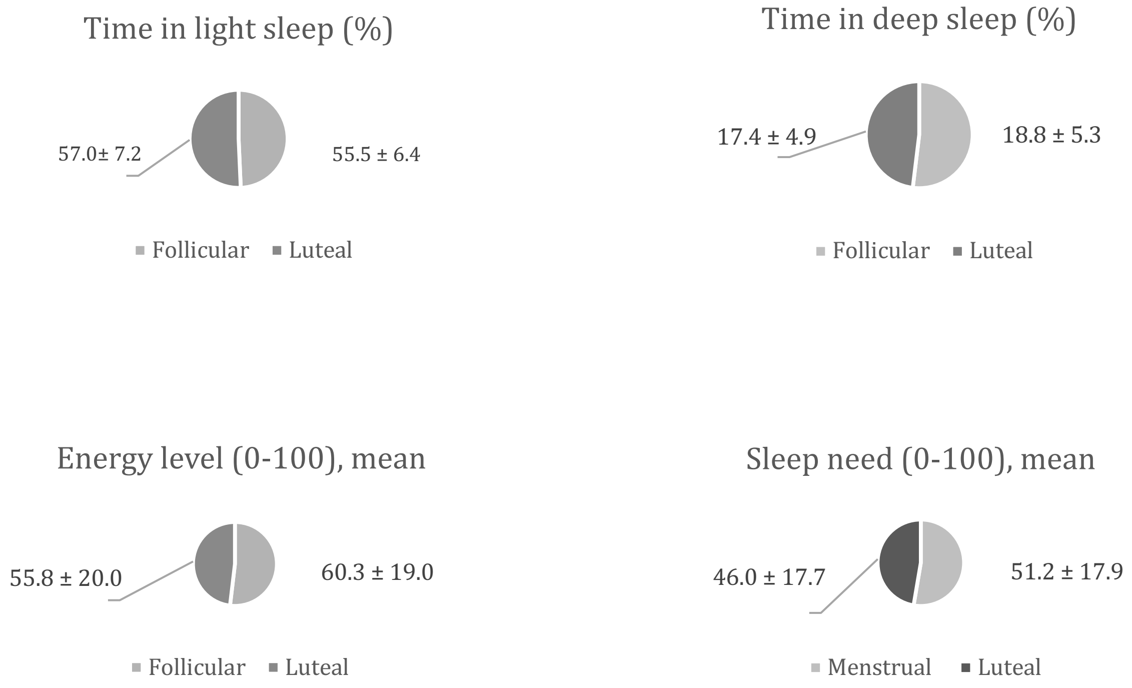

Figure 3: Illustration of main findings including; objective time in light sleep and deep sleep, and subjective sleep need and energy level in different menstrual cycle phases among young female endurance athletes.

4 DISCUSSION

In this study, our primary objective was to investigate whether sleep differs between the different phases of the normal menstrual cycle among female junior endurance athletes. The secondary objective was to investigate the coinciding effects on the subjective muscular feeling and energy level during the menstrual cycle. The main findings were as following**;** 1) less deep sleep and more light sleep in the luteal phase compared to the follicular phase, 2) more energy in the luteal phase compared to the follicular phase, 3) higher sleep need in the luteal phase compared to the menstrual, and higher sleep need in the other luteal days compared to the pre-menstrual days, 4) most significant differences among sleep variables in the menstrual cycle was found in the luteal and menstrual phase, and 5) only small effect sizes were found among the significant findings.

As expected from our hypothesis, we found reduced objective sleep quality in the luteal phase compared to the follicular phase, which correspond with other studies (14, 17, 31). Changes in EEG during the menstrual cycle have prior been associated with, and explained by the hormone progesterone (14, 17). However, we did not directly measure the levels of progesterone and melatonin in the current study and can therefore not conclude whether these are the main hormones contributing to this result. These findings could be a result of the hormones themselves or symptoms during the menstrual cycle. For finding the main hormones and symptoms possibly contributing to our result, further studies should be done including e.g. extensive analyzes regarding specific symptoms and hormone concentration. Our hypothesis also suggested a longer sleeping time in the luteal phase to compensate for lower sleep quality, but this was not the case in our study, which coincides with other studies (24, 27). Our results indicate that the sleeping time is the same, and the high amounts of light sleep is “taken” from deep sleep in the luteal phase. There could be different reasons for this result; e.g. the time schedule does not make increased sleeping time possible, or there is no effect on sleeping time during the menstrual cycle.

Higher subjective sleep need was detected in the luteal phase compared to the menstrual phase, which coincide with the poorer sleep quality in the luteal phase. Other studies have showed lower reported subjective sleep quality during the pre-menstrual days (27, 32), and the first days of menstruation compared to the midcycle (27). However, there are different conclusions on the significance of these findings. One found a small change and concluded that the menstrual cycle is of minimal clinical significance in determining subjective self-reported sleep quality (32), the other did not. This indicates that there might be a change in subjective sleep need during the menstrual cycle, but more studies need to be done to make an overall conclusion.

Between the luteal and menstrual phase, the highest number of significant differences were registered, including *time in light sleep, time in deep sleep, time in REM sleep, sleep need* and *energy level*, with p-values ranging from .00 - .03. This result is novel and of high interest, because these phases are the two with biggest variation in hormonal concentration during the menstrual cycle. This indicates an effect of the female hormones that affects different mechanisms and processes in the female body, which grasps outside the reproductive functions. This might affect variables considering both their recovery and performance. Even though differences among variables were detected, the effect size on all findings is small, which means that our detected differences exist, but they are of small effect.

Lower energy was reported in the follicular phase compared to the luteal, and higher muscular tenderness was found in the follicular phase compared to the pre-menstrual phase. This could be explained by lack of high-quality sleep in the prior days to follicular phase. In other words; the effect of reduced sleep quality on energy level and muscular tenderness might be delayed and might be a result of poor sleep quality and consequently poorer recovery in the luteal and pre-menstrual phase, which comes to expression in the follicular phase. These data are novel as subjective energy level, muscular feeling and objective sleep quality during the menstrual cycle among endurance athletes and have not been analyzed in other studies. Still, our results indicate that energy level and muscular feeling is associated with the menstrual cycle and sleep phases. This should therefore be investigated altogether in a bigger context to exclude possible bias like accrual training, and whether the menstrual hormones, symptoms, sleep change and other factors possibly contributing to the results.

The study has both strengths and limitations. The well-defined group of participants with females ranging from 17 to 19 years and who are having the same type of exercises and training load, is a strength in this study. We also managed to exclude the ones using hormonal contraceptives, which are important in terms of minimizing hormonal bias. We have a high percent of sleep data, and subjective data registered during the menstrual cycle phases in the study, respectively 89.3% and 86.0%, which are high numbers. However, there are also some limitations. The study is based on 16 subjects and 8 weeks of data, which involves maximum 8-9 phases per person. For calculating the phases of the menstrual cycle, the menstrual bleeding was used, which means we do not have a detection of the ovulation based on other measures, e.g. body temperature, which could contribute to some inaccuracy. The menstrual cycle can be divided into different defined phases, but there is no common answer on how to do this, which could be a negative factor. We chose to divide into 4 phases based on the menstrual bleeding, because our biggest interest was to compare the luteal and follicular phase, and also compare the pre-menstrual and menstrual phase. Menstrual irregularities or disorders that possibly could have an impact on the sleep variables, energy level and muscular feeling was not detected before the study. The sleep monitor has in prior studies been compared to polysomnographic measures with good result (28, 33, 34) but has some limitations e.g. if more than one person sleep in one bed (33).

4.1 Conclusion

The current study did not find any menstrual cycle effect on total sleeping time but indicate an effect on sleep quality. This includes both more light sleep and less deep sleep, contributing to lower sleep quality in the luteal phase. The changes of sleep quality during the menstrual cycle seem to affect the athlete's subjective energy level and muscular feeling in a negative way, as hypothesized. There might be a delayed negative effect of reduced sleep quality, and consequently poorer recovery in the luteal phase coming to expression as higher muscular tenderness and lower energy in the follicular phase. Sleep quality, energy level and muscular tenderness are factors that together might have extensive impact on the athlete's ability to recover and perform at a high level. Consequently, this might indicate that there is a difference of quality in recovery during the menstrual cycle, which should be taken into account among female athletes. However, these findings are of small effect size, and the study should be considered as a pilot for further studies on these subjects.

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