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Cyclical Physiology of Elite Female Athletes: Longitudinal Quantification of Wellness Parameters Considering Menstrual, Weekly, and Seasonal Variations

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Abstract: The purpose of the study is to identify variations in wellness parameters among elite female athletes, considering simultaneously the influence of natural menstrual cycle (MC) or hormonal contraception (HC) phases and weekly and seasonal variations. A total of 54 elite female athletes were followed up with through a 6-month daily monitoring of their reported fitness, sleep quality, mood, and menstrual symptoms. Estimated cycle phases, days of the week, and seasons were all integrated into a single model to study cyclicities concomitantly. A total of 263 cycles were analyzed, totaling 7370 pieces of daily self-reported data. We observed more frequent symptoms during the menstruation and the pause phase. Reported fitness was greater in the mid-cycle and mood was lower at the end of the cycle for the MC group. Wellness parameters were rather stable for HC users. For both groups, symptoms were more frequent in summer. Reported fitness levels were lower on Monday, while mood scores were highest on Saturday and Sunday. In summer and autumn, fitness, sleep quality, and mood were greater. A cyclical wellness rhythm was identified in the menstrual cycle and persists even when considering weekdays and seasons cyclicities. This comprehensive approach helps to identify physiological influence on human behaviors, considering the specificities of women.

Keywords: cycles; female athletes; monitoring; performance; wellness

Academic Editors: Marios Hadjicharalambous and Nikolaos Zaras

Received: 6 December 2024
Revised: 20 January 2025
Accepted: 23 January 2025
Published: 28 January 2025

Citation: Badier, N.; Dupuit, M.; Dormion, G.; Chassard, T.; Barlier, K.; Lafitte, A.; Delrieu, L.; Toussaint, J.-F.; Antero, J. Cyclical Physiology of Elite Female Athletes: Longitudinal Quantification of Wellness Parameters Considering Menstrual, Weekly, and Seasonal Variations. *Appl. Sci.* **2025**, *15*, 1357. https://doi.org/10.3390/app15031357

1. Introduction

Menstruating women who have natural menstrual cycles (MC) or those who use intermittent hormonal contraception (HC) experience variations in female sex steroid hormones, notably estradiol and progesterone [1], guided by the gonadotropic axis or induced by the concentration levels of their contraceptive method. These hormonal fluctuations may influence women's wellness on multiple levels, affecting parameters such as sleep quality [2], mood [3], or fitness [4,5], and may be accompanied by symptoms [6]. Additionally, hormones may impact fatigue, cardiovascular, muscular, and metabolic functions, as well as mood and sleep disturbances, which can modulate both training adaptations and athletic performance [7–9]. A study involving 3.3 million women across 109 countries showed that the MC has the greatest impact on most of the 15 measured dimensions of mood, behavior, and vital signs across daily, weekly, seasonal, and menstrual fluctuations [3].

The study of wellness indicators in elite athletes has notable gaps. No study has investigated a potential cyclic pattern in female athletes' wellness as it is associated with either the MC or HC in light of concomitant cyclicities that have previously shown interactions with human behavior and wellness, such as weekly or seasonal cycles. The monitoring of elite athletes' wellness is commonly used in sport settings to evaluate athletes' readiness, reduce injury risks, and individualize training plans [10–12]. Hence, a better understanding of the potential physiological or structural cyclicities of elite athletes' wellness is needed to better manage and anticipate athletes' responses. Elite athletes' lifestyles are sport-oriented, focused on performance; all surroundings are organized to favor optimal fitness on a weekly and seasonal basis. Consequently, the weekly or seasonal cyclicities may differently interfere with the athletes' wellness as compared with what has been reported in the general population [3]. Such impact may also "smooth" the MC potential effect. Thus, understanding the physiological cyclicities among athletes with natural MC or HC would increase knowledge of elite athletes' monitoring, which may also favor training individualization [5].

Therefore, we aimed to investigate a potential cyclical pattern in elite athletes' wellness (i.e., mood, fitness, sleep quality, and menstrual symptoms) considering concomitantly the influence of MC or HC, weekly, and seasonal variations.

2. Materials and Methods

2.1. Subsection

A prospective longitudinal follow-up based on daily questionnaires of an elite athletes' cohort was used.

2.2. Participants

We collected data from 85 French elite female athletes [13] naturally menstruating, group MC, or using monophasic pills with a 7-day break, group HC. Athletes were informed and volunteered to take part in this study for at least 6 months in a row. The study took place from 18 April 2020 and 25 August 2023.

2.3. Procedures and Monitored Parameters

Before the beginning of the follow up, a meeting was held with the athletes to present and explain the protocol in detail. All of them were asked to fill in a questionnaire every morning upon waking regardless of whether they were in active training periods, competition phases, or rest periods, for at least 6 months. A smartphone application, previously described [14], was used.

First, athletes with MC were asked to report the start and end dates of their periods, while athletes using HC indicated the break period in their pill intake. In addition, athletes completed a list of common menstrual symptoms [15] where they could select one or more symptoms they experienced each day. Then, a Likert rating scale ranging from 1 to 10 was used, where 1 means "very bad" and 10 means "excellent", to evaluate their wellness using three dimensions: fitness, sleep quality, and mood [14]. The fitness dimension focused on athletes' perceived physical readiness to train or compete. Sleep quality was assessed by asking participants to rate the quality of their sleep from the previous night. Mood was evaluated by asking them to rate their overall emotional state.

2.4. Cycle Phase Division

The athletes' cycle phases were based on menstrual information from the daily questionnaire. Six phases were estimated for athletes with natural MC [5]: menstruation, mid-follicular, late follicular, early luteal, mid-luteal, late luteal. As part of another study, 18 athletes with natural MC performed hormonal salivary sampling [16], which provided a basis for validating the phase identification methodology. The phases of these athletes' cycles were obtained from the hormonal variations in sample results. The ovulation day of the remaining athletes was predicted, based on a linear regression relying on data of more than 30 000 women with ovulation confirmed [17,18]:

$$Follicular\ cycle\ length\ (days) = -5.2835 + 0.7344 * Actual\ cycle\ length\ (days)$$

Athletes reported the beginning and the end of the menstruation phases directly in the daily questionnaire. The remaining days between the last day of menses and the estimated day of ovulation was divided into 2 sub-phases. The late-follicular phase included the estimated day of ovulation and the 3 days before [19]. The remaining days between menses and the late follicular phase were defined as the mid-follicular phase. Similarly, the post-ovulatory part was divided into 3 phases. Five to nine days after the estimated ovulation were defined as the mid-luteal phase [17,19]. The days before this phase was the early luteal phase and the days after, up to the next cycle, was the late luteal phase.

For HC users, the schedule was divided into four phases, using a 28-day pill pack cycle, which includes 7 days off and 3 weeks, with each 7 days of taking the pill.

2.5. Data Analyses

Empty cycles, where all data were missing, were excluded from further analysis. Irregular cycles, defined when their duration was shorter than 21 days or longer than 35 days [20], anovulatory cycles (among those measured), and atypical HC use, defined when the duration was not equal to the 28 days of a pill pack, were removed. Only athletes with at least two uninterrupted full cycles with complete wellness data were retained.

Athletes and their sport were described using number and frequency. Wellness variables were described using mean and standard deviation (SD). Student's t-test was performed to check differences between each wellness parameter of athletes with MC and athletes using HC.

Each wellness variable, that is sleep quality, fitness, mood, and number of menstrual symptoms, were transformed from an ordinal scale into continuous data to perform a linear regression. To look at intra-individual variation, each athlete's averages for each well-being indicator were subtracted. Thus, each athlete had a zero mean for each indicator [3]. Then, the assumptions of homogeneity of variances and data normality, linearity, and independence were verified.

Let Y be the wellness variable:

$$Y = \alpha + \sum_{i=1}^{3} \kappa_{s[i]} X^{s[i]} + \sum_{j=1}^{6} \eta_{t[j]} X^{t[j]} + \sum_{k=1}^{5} \gamma_{p[k]} X^{p[k]} + \varepsilon$$

α was the intercept that serves as the baseline reference point;
$\kappa_{s[i]}$ was the regression coefficient of the season i;
$X^{s[i]}$ was the indicator of the season i;
$\eta_{t[j]}$ was the regression coefficient of the weekday j;
$X^{t[j]}$ was the indicator of the weekday j;
$\gamma_{p[k]}$ was the regression coefficient of the cycle phases k;
$X^{p[k]}$ was the indicator of the cycle phase k;
ε represents the residuals.

Menstrual cyclicity was analyzed separately for athletes with a natural MC and for athletes using HC. The menstruation phase for MC-athletes and the pill break phase for

HC-athletes were used as references. Cycle phases, days of the week, and seasons were all integrated into a single model to study the menstrual cyclicity considering the weekly cyclicity and the seasonal cyclicity concomitantly. Weekly and seasonal cyclicities were analyzed for MC- and HC-athletes together. Then, cycle phases were not included in this second model. Monday and spring were arbitrarily set as the references for the weekly and seasonal analyses.

Each coefficient represents the average difference in wellness between the coefficient category and the reference category. The threshold of significance was defined as $\alpha = 0.05$. R software was used for all analyses (Version 4.3.3, R Foundation for Statistical Computing, Vienna, Austria).

3. Results

3.1. Participants

After processing data, 31 athletes were excluded as explained in Figure 1. A total of 54 athletes practicing 7 different sports were retained: athletics, rowing, cycling, soccer, gymnastics, swimming, and skiing. Among them, 40 athletes were in the MC group and 14 athletes in the HC group. Fourteen athletes with natural MC (35.0%) took a total of 132 hormone samples, representing 35 cycles (17.4%). This dataset encompasses a total of 263 full cycles, on average 4.9 ± 1.9 cycles per athlete, during the follow-up period, totaling 7370 pieces of daily self-reported data and a daily response rate of 81.6%.

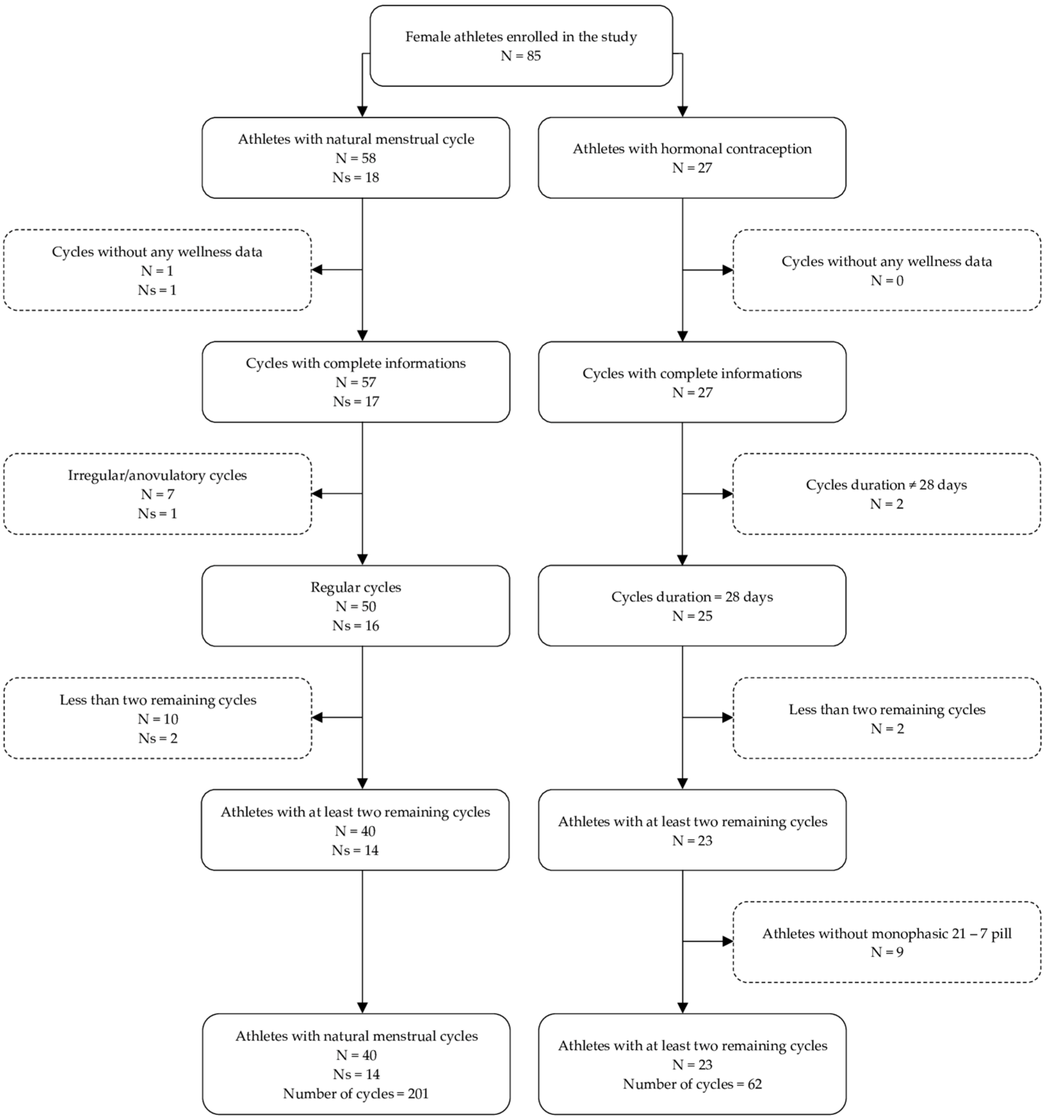

Figure 1. Flowchart of subjects' inclusion, data processing and description of the remaining data. N is for the total number of athletes; Ns is for the number of athletes who performed hormonal sampling.

3.2. Wellness Variables

For all athletes, on a 1 to 10 scale, average sleep quality score was 6.8 ± 1.9, average fitness score was 6.0 ± 1.9, average mood score was 6.7 ± 1.8, and average daily number of symptoms was 0.5 ± 1.1.

Sleep quality and symptoms number were significantly higher in the MC group ($p < 0.001$) in comparison to the HC group (Table 1).

Table 1. Description of wellness variables across the groups.

	Overall	Natural Menstrual Cycle	Hormonal Contraception	*p*-Value
	N = 7370	N = 5634	N = 1736	
Sleep Quality	6.8 ± 1.9	6.8 ± 1.9	6.6 ± 1.7	<0.001
Fitness	6.0 ± 1.9	6.1 ± 2.0	6.0 ± 1.8	0.5
Mood	6.7 ± 1.8	6.8 ± 1.9	6.7 ± 1.7	0.2
Number of Symptoms	0.5 ± 1.1	1.6 ± 1.2	0.4 ± 0.6	<0.001

Wellness variables are described using means and ± standard deviation; N corresponds to the number of data analyzed.

3.3. Cyclicities

Considering the effects of the MC's, of the week's, and of the season's cyclicities on wellness parameters, we observed a greater reported fitness score in the mid-follicular ($p = 0.007$) and late follicular phases ($p = 0.014$) among athletes with natural and regular MC. We observed no significant difference between the pill's weeks for athletes using HC. Reported fitness level was higher on Tuesday ($p = 0.010$), Wednesday ($p = 0.025$), Saturday ($p = 0.007$), and Sunday ($p < 0.001$) compared to Monday for all athletes, within the same season. Reported fitness scores are greater in summer ($p = 0.005$) and autumn ($p = 0.003$), when compared to spring, and adjusted by the weekday (Figure 2A).

We did not observe any significant difference in the reported sleep quality across the MC or HC group, nor among the week days.

A greater sleep quality was reported in summer and autumn ($p \leq 0.001$) when compared to spring and adjusted to the weekday (Figure 2B).

The reported mood was found to be higher in all MC phases except the late luteal phase (mid-follicular: $p = 0.002$, late follicular: $p = 0.005$, early luteal: $p = 0.022$, mid-luteal: $p = 0.026$) when compared to the menstrual phase and adjusted by the weekday and season. Mood is greater on Saturday ($p = 0.013$) and Sunday ($p < 0.001$) compared to Monday within the same season. It is also higher in summer and autumn ($p < 0.001$) compared to spring on the same weekday for all athletes.

No significant difference in the reported mood appeared between weekdays in athletes using HC (Figure 2C).

The number of symptoms was lower in all MC phases ($p < 0.001$) compared to the menstrual phase regardless of the weekday and season for athletes with natural MC. It is lower in all cycle weeks ($p \leq 0.001$) compared to the pill's break week, adjusted to the weekday and season in the HC group. There was no significant difference between days of the week for all athletes. There were more symptoms in summer and fewer symptoms in autumn and winter ($p < 0.001$) compared to spring on the same weekday for all athletes (Figure 2D).

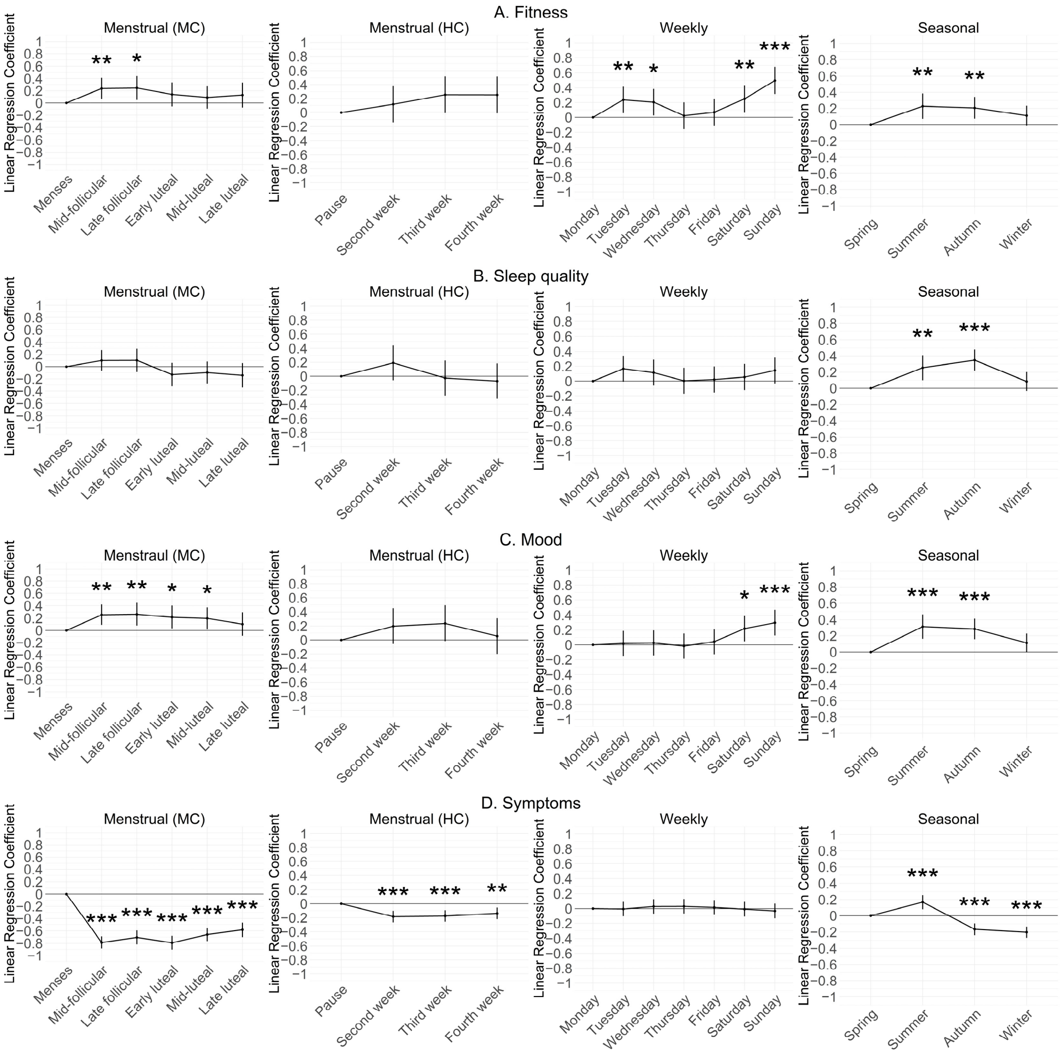

Figure 2. Menstrual, weekly, and seasonal variations for each fitness (**A**), sleep quality (**B**), mood (**C**) score, and number of symptoms (**D**) for all athletes. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

4. Discussion

This study represents the first attempt to concurrently evaluate the cyclicity of physiological influences, such as those defined by the MC or seasonal variations, alongside non-physiological influences or oral contraceptive pills and weekdays, in commonly monitored parameters of elite athletes' wellness.

4.1. Main Findings

Menstrual, weekly, and seasonal cycles exhibit similar patterns in elite athletes and the general population [3]. However, some distinctions between athletes with MC and those using HC were noted, and additional parameters were considered beyond mood [3].

The MC follows an infradian rhythm, with positive feelings peaking just after the menstruation phase (MC) or following the pill break (HC) and diminishing towards the end of the cycle. These findings align with results observed in the general population [3]. Some studies highlight the impact of hormonal fluctuations, particularly the rise in estrogen during the follicular phase, as a contributing factor to improved mood and overall wellness [21]. Elevated estrogen levels are associated with increased serotonin availability, a neurotransmitter linked to positive mood regulation [22]. Consequently, athletes with natural MC often experience heighten energy levels, motivation, and improved cognitive function during the early phases of their MC [23,24]. Conversely, the decline in estrogen and the simultaneous drop in progesterone levels at the end of the cycle can contribute to lower mood scores and a decrease in overall wellness [22,25]. This aligns with the observed negative mood symptoms during the end of the MC in this study or with what is commonly observed in the general population [3]. Such cycle variations have been shown in studies involving rowers [5], rugby players [23], and soccer players [24].

For athletes using HC, the pattern slightly differs, possibly due to diminished hormonal fluctuations caused by the downregulation of the gonadotropic axis. Positive feelings are often reported following the break of the hormonal pills, mimicking the rise in estrogen seen in the MC. However, during the pill's inactive phase, when exogeneous hormonal levels decline, athletes may experience a dip in mood and energy levels, similar to the hormonal fluctuations in the late stages of the MC. It also explains the prevalence of symptoms observed during the menstruation phase and the pill break [15,26], similarly observed in the general population [27]. The magnitude of hormonal variation with HC use is lower compared to a natural cycle, leading to reduced hormonal fluctuations, which may contribute to more stable levels of mood, motivation, and energy. This stability can be perceived as beneficial for athletes who need to maintain consistent levels of performance. Current evidence is insufficient to determine whether HC use has a positive, neutral, or negative impact on performance over the long term. Additionally, this stability may present disadvantages, such as limiting potential positive physiological effects associated with the estrogen rise, like enhanced physical capacity to endure intense training [16,28]. No differences related to menstrual symptoms were observed over the week, showing that athletes were able to distinguish symptoms related to their menstrual cycles from any sports-related pain. The potential influence of seasons, with symptom frequencies higher in summer and lower in autumn and winter, needs to be interpreted with caution due to the off-season. A majority of the athletes were not monitored during summer because they interrupted their training. It is therefore possible that only those with the most painful symptoms reported them.

While the general population shows better wellness indicators on Saturdays followed by a decline on Sundays [3], athletes in our study exhibit consistent mood levels across weekend days and a re-increase in fitness levels on Tuesday and Wednesday. These variations can be attributed to the specificities of our athlete's schedule where Sunday is the usual competition day, boosting greater motivation and improved mood, whereas Monday is a rest day following the competitive weekend. Regular physical activity has been linked to the release of various hormones and neurotransmitters that act as natural mood lifters, reducing stress and improving overall wellness, sleep quality, and cognitive function [29–31]. Thus, returning to training on Tuesday could influence an athlete's motivation and positivity.

Findings about seasonal variations aligned from those typically observed in the general population in the summer with heightened wellness indicators. The summer season, with its longer days and increased exposure to natural light, has a positive effect on physical and mental health. Exposure to sunlight stimulates the production of vitamin D, which can improve mood and reduce symptoms of depression [32]. The positive impact of warmer seasons on well-being indicators could also be explained by changes in social behavior. The summer months, with their more pleasant climate, encourage social interaction, a factor recognized for its beneficial effects on mental and emotional well-being [33]. A notable distinction is identified in autumn. If the general population often experiences a decrease in mood [3], our athletes' cohort exhibits improved feelings. Again, this disparity could be explained by the athletes' lifestyle specificities. As autumn marks the return to regular training routines after potential off-season breaks, the resumption of athletic activity could significantly contribute to the observed positive shift in mood. The reintegration into structured training schedules, accompanied by the mental and physical benefits of exercise, contrasts with the general population's response to diminishing daylight and the onset of colder weather during autumn [34,35]. It is important to note that seasonal variations are also influenced by individual factors, such as lifestyle, eating habits, and access to resources like outdoor spaces.

The similarities between our findings regarding the MC and previous findings in the general population reinforce findings of a physiological impact on wellness parameters of the MC [3]. This impact persists even with a high level of physical activity practice, which is known for its beneficial impact on wellness parameters of its practitioners. However, our findings suggest a more limited effect of seasons or weekdays, which is likely related to the impact of physical activity.

4.2. Limits and Strengths

The exclusion of athletes with irregular menstrual cycles or incomplete data may have limited the generalizability of our results to a wider population of female athletes. However, exclusions are evenly distributed. The requirement to follow at least two uninterrupted cycles ensures that athletes can continue to be monitored on a daily basis in real-life conditions. While our study benefits from a large and diverse cohort of elite athletes representing various sports, it is important to note that providing the exact timing of follow-up for each participant is not feasible. This is because training schedules, competition periods, and rest phases vary significantly, not only between sports but also among individual athletes, even within the same team. However, this diversity represents a strength of our methodology, as it ensures that the data captured reflects the athletes' real-life schedules. By incorporating participants from a wide range of sports, our findings are more broadly applicable to elite athletes in diverse contexts. Interaction tests between menstrual, weekly, and seasonal cycles were not statistically significant, but several factors may explain this result. Firstly, the variability of individual responses to these cycles could introduce heterogeneity, potentially masking significant interactions. Then, external factors such as variations in training programs, environmental influences, or unmeasured confounders may have diluted potential interaction effects. We recognize that the results may not be fully generalizable to amateur athletes or women of different age groups, as their experiences may vary due to factors such as training intensity, hormonal fluctuations, or other lifestyle factors. However, many of the patterns observed in our study, such as the impact of menstrual and seasonal cycles on mood and physical readiness, align with findings in the general population [3]. For instance, individuals in non-athletic contexts might also experience lower energy levels and mood disturbances during the premenstrual phase or improved overall wellness during summer months, which could influence daily life, such as workplace productivity or social engagement. At the same time, elite athletes differ from non-athletes in several respects. Their higher levels of physical activity and structured lifestyles—characterized by intense training schedules, precise recovery strategies, and careful monitoring of physiological metrics—may amplify or stabilize certain cyclical patterns. For example, regular physical activity is known to mitigate mood swings and improve sleep quality, which could buffer some of the fluctuations typically seen in non-athletic populations. The wellness data collected in this study relied on self-reported measures, which were inherently subjective. However, this subjectivity aligned with the aim of capturing the athletes' personal perceptions [36,37] of their mood, sleep quality, and fitness levels. These variables were best assessed through self-report, as they reflected the athletes' lived experiences [38]. Daily reporting through a familiar application further ensured the reliability and consistency of the data. Fewer data points were collected during the summer due to the off-season for many athletes resulting in an uneven distribution of data across seasons. However, while some athletes had reduced training periods, many maintained a consistent training load. Conducting comprehensive daily monitoring for high-level athletes is challenging due to competitions and international travel. For the same reasons, only 35.0% of the included athletes performed accurate hormonal measurements, which may raise questions about the accuracy of our phase division. We acknowledge that a phase estimation may include anovulatory cycles and potential luteal phase deficiencies, comprising heterogenous hormonal profiles. Hence, the results cannot be attributed to hormonal fluctuations but rather to the moment in the cycle the athletes are in. We repeated the analyses on the sample of athletes who performed the saliva sampling, allowing a better phase determination, and the findings were similar. The levels of significance varied, certainly due to the samples' size, but the general trend is the same (Supplementary Figure S1). This study adopted a model previously validated in the general population [3] to explore common cyclical influences on well-being variables in elite athletes. Similarly, we sought to identify common cyclicity among elite athletes. Confounding variables specific to our study population, such as type of sport, level of training, or age, may impact our results. We did not consider them in order to conform to the model developed in the general population, but we recognize that this is a limitation of our study and that it would be relevant to explore these variables in greater detail. However, the homogeneity of our cohort—composed exclusively of elite athletes with comparable training intensities and competition schedules—mitigates some of these potential confounding effects. However, it is crucial to acknowledge that the menstrual cycle is only one of many factors that may influence sports performance and wellness. Other factors, such as stress, dietary habits, personal life challenges, and environment, likely play a significant role. Despite these challenges, our study gains strength from successful data collection from a large number of athletes across several months, with over 80% of daily responses. This extended duration allows for a more comprehensive understanding of the cyclic patterns. This type of monitoring is very common in top-level sports [38], and this study demonstrates the importance of taking into account the menstrual cycle, particularly the presence of symptoms, to identify athletes' readiness and interpret monitoring results in view of physiological cyclicities.

A unique aspect is the decision to analyze menstrual, weekly, and seasonal cyclicities in a unified model. While this approach might potentially decrease the significance compared to three separate models focusing on each cyclicity individually, we believe it enhances the robustness of the analysis. By considering the interplay and impact of each cycle on the others, we aim to provide a more comprehensive perspective in the study of physiological rhythms. Our study stands as the first one to explore the cyclic patterns of both athletes with natural MC and those using HC. We demonstrate here that the essential cyclic patterns in female high-level athletes align with those observed in the general population, even when considering their unique sport challenges.

5. Conclusions

The patterns of menstrual, weekly, and seasonal cycles are similar in both elite athletes and the general population. An infradian rhythm was identified among female elite athletes, with better reported wellness in the mid-cycle and lower evaluation during premenstrual and menses phases, with a similar trend observed in the HC group. These results demonstrate that this rhythm persists even when considering other cyclicities such as days of the week or seasons. Symptoms were more frequent during the menstruation phase compared to other cycle phases, as well as during the pill-pause period, where pill users experience more symptoms. Reported fitness peaked just after menses diminishing towards the end of the cycle, while in the HC group this parameter improved during the active pill phase. We noted an improvement in mood during weekends, in summer and autumn. Our findings highlight the importance of studying cycling patterns in female athletes, as each specific pattern contains valuable information that can be used to improve individualized training and optimize athletic performances. While we identified common patterns, it is crucial to recognize the individual nature of these parameters, particularly the inclusion of MC and HC, in athlete monitoring. Such a comprehensive approach may help to identify physiological influences on human behaviors, considering the specificities of female elite athletes.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app15031357/s1, Figure S1: Menstrual, weekly and seasonal variations for each fitness (A), sleep quality (B) and mood (C) score and number of symptoms (D) for athletes who performed salivary sampling. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Author Contributions: Conceptualization, J.A.; methodology, N.B. and G.D.; formal analysis, N.B. and G.D.; investigation, N.B.; data curation, T.C., K.B. and A.L.; writing—original draft preparation, N.B.; writing—review and editing, M.D., J.A. and L.D.; supervision, J.-F.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Ethics Committee (IRB00012476-2022-03-11-206).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Acknowledgments: We would like to thank both INSEP and ANS institutions for their support, notably the technical support for data collection and security. We also would like to thank all the athletes that participated in this study, as well as all the staff from the seven French federations.

Conflicts of Interest: The authors declare no conflicts of interest.

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