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How Do Fluctuations in Endogenous Sex Hormones Affect Breast Pain in Female Athletes?

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ABSTRACT

Cyclic breast pain (mastalgia) is speculatively associated with hormonal fluctuations during the menstrual cycle. No research to date has quantified this effect through circulating concentrations of estradiol and progesterone in a sample of female athletes. Such data are essential for understanding how hormonal changes contribute to the incidence and severity of cyclic breast pain, with implications for enhancing breast pain management and athletic performance in women's sport. Twenty-four female Australian First Nation athletes from the National Rugby League Indigenous Women's Academy pathways program participated in a Female Athlete Research Camp. Over 5 weeks, participants completed a daily survey about their experience of breast pain and, at three approximate phases of the menstrual cycle (Phases 1, 2, and 4), presented to the laboratory for venous blood samples to track circulating estradiol and progesterone concentrations. Average mastalgia ratings spiked during the commencement of the menstrual period and 14–26 h prior to ovulation. Higher levels of estradiol and progesterone were associated with a decreased likelihood of experiencing mastalgia; elevated progesterone levels were also linked to a reduction in mastalgia severity. These effects were highly interdependent, such that the effect that progesterone had on mastalgia was dependent on the value of estradiol, and vice versa. This study provides the first quantitative evidence that circulating estradiol and progesterone levels influence the occurrence and severity of cyclic breast pain in female athletes. These findings support the development of targeted strategies for managing mastalgia, ultimately promoting well-being and enhancing performance for women in sport.

1 | Introduction

Cyclic mastalgia, or breast pain related to the menstrual cycle, affects up to 70% of women [1–3] and represents the most frequent breast-related symptom for which women seek medical advice [4]. This pain is typically characterized as diffuse heaviness or soreness that radiates from the upper-outer quadrant of the breast towards the axillae [2]. In some instances, cyclic mastalgia can be debilitating, limiting participation in physical activities and negatively impacting daily quality of life [1, 5]. This is particularly relevant for female athletes, as 32%–60% report experiencing cyclic mastalgia that can negatively impact sports performance [6–10]. Research has consistently documented cyclic mastalgia across various levels of competition and sports, presumptively linking its presence and intensity to hormonal fluctuations during the menstrual cycle. However, the precise etiology of cyclic mastalgia remains poorly understood and research in this space is further complicated by the potential for exercise-induced breast pain and breast injuries to confound participant reports of mastalgia [6, 11, 12].

Some credible theories suggest that cyclic mastalgia may be the result of abnormally elevated estradiol and/or depressed progesterone levels [4, 5, 13–15]. Throughout the cycle, rising estradiol promotes breast tissue growth and fluid retention; these effects are typically modulated by progesterone, whereby progesterone levels that are abnormally low (or insufficiently high to counter-balance elevated estradiol) may contribute to increased tissue sensitivity, tenderness, and inflammation [1]. While this hypothesis is favored by many experts, findings are inconsistent, as randomized controlled trials have reported normal serum progesterone levels in patients with untreated mastalgia [16]. This inconsistency highlights the complex nature of cyclic mastalgia, suggesting that additional, non-hormonal factors may also contribute to its incidence and severity.

Indeed, other factors, such as age and breast size, have been associated with increased severity of cyclic mastalgia [7, 8, 17]. As women age, more pronounced fluctuations in estrogen and progesterone may heighten breast pain by increasing tissue sensitivity and amplifying hormonal imbalances, with the highest incidence of cyclic mastalgia reported in women 30–50 years of age [2, 4, 5, 18]. Larger breast size, coupled with increased breast weight and movement, may further intensify mastalgia by imposing mechanical strain on suspensory ligaments, especially in physically active women [14]. Limited research on female athletes supports this association, noting that mastalgia is more prevalent in those with larger breasts [6, 7]. Research has also shown that mastalgia is more common in women who are wearing an incorrectly fitting bra [18], an issue disproportionately affecting women with large breasts [19]. Therefore, it is essential to consider individual characteristics like age and breast size as they relate to mastalgia for developing effective, targeted management strategies that could reduce breast pain and improve comfort and performance in female athletes.

Previous research on cyclic mastalgia in female athletes has largely relied on retroactive self-reports of mastalgia intensity and, when included, rough estimates of menstrual cycle phase, leaving the quantitative relationship between fluctuating hormone levels and mastalgia largely unexplored in this population. Such data are vital in understanding how fluctuating levels of hormones contribute to the incidence and severity of cyclic breast pain throughout the menstrual cycle, providing insights that may enhance breast pain management and overall well-being, as well as remove barriers to optimal performance in women's sport. Therefore, this exploratory study aims to integrate measurements of estradiol and progesterone collected at quantitatively verified phases of the menstrual cycle with day-of participant reports of mastalgia, with consideration for age and an objective assessment of breast size.

2 | Materials and Methods

2.1 | Study Design

This study formed part of the Female Athlete Research Camp (FARC 1.0) originally described in McKay et al., 2024 [20]. Participants completed 5 weeks of menstrual cycle tracking (a daily survey about their experience of mastalgia and menstrual cycle; see Section 2.4), as well as a residential training camp comprised of resistance-exercise and skills-based training at the Australian Institute of Sport (AIS) in Canberra, Australia. During the training camp, participants reported to the laboratory on three occasions (approximately aligned with Phases 1, 2, and 4 of each participant's menstrual cycle for naturally menstruating athletes and at corresponding timepoints for hormonal contraceptive users) to provide a blood sample, which was used to determine estradiol and progesterone concentrations (see Section 2.5). Written informed consent was obtained prior to participation. Ethics approval to conduct this study was obtained from the Australian Catholic University Human Research Ethics Committee (2021-285HI) and cross-institutional approval was also obtained from the University of Canberra Human Research Ethics Committee (ID: 11851).

2.2 | Participants

Forty-three female Rugby League players (18–29 years of age) from the National Rugby League Indigenous Women's Academy pathways program were nominated for participation by the National Sporting Organisation in Australia. Inclusion criteria were "highly trained" athletes [21] who were willing and able to complete the study requirements; there were no exclusion criteria based on menstrual status. Ultimately, 24 athletes (mean age: 21.6 ± 3.4 years; height: 164.9 ± 4.6 cm; body mass: 76.3 ± 12.1 kg) completed the 16 weeks of FARC 1.0 and are included in the present study. A similar number of participants were experiencing a natural cycle ($n = 11$) as those using hormonal contraception ($n = 13$); of those using hormonal contraception, eight participants were using a hormonal implant (Implanon), four were using oral contraception, and one was using a hormonal injection.

2.3 | Breast Size

In a single session, the breast volume of each participant was quantified using three-dimensional scanning in accordance with a standardized protocol [22–24]. Prior to scanning, participants were fitted into a standardized style of encapsulation bra (New Legend, Berlei, NSW, Australia) using professional bra fit criteria [19] and 5 mm adhesive dots were placed on each participant's sternal notch and around the outer boundary of her breast tissue and bra, as identified by gently palpating the perimeters of her right and left breast. The participant's breasts were then scanned using a hand-held scanner (ArtecTM Leo 3D Scanner, Artec Group) while she assumed an upright posture for approximately 10 s, as per previous research [24]. The three-dimensional torso scans were then imported into Geomagic Studio (Version 12; 3DSystems, South Carolina, USA) and a three-dimensional model of each breast was created based on a previously validated methodology [22, 23].

2.4 | Mastalgia

During the 5-week training camp, participants recorded their experience of mastalgia via a daily online survey: *"Mastalgia" is hormonal breast pain not directly caused by activity* (i.e., *tender or painful breasts related to your menstrual cycle*). *Please rate the severity of mastalgia that you experienced today.* Participants then used a digital slider to indicate their level of mastalgia on a simplified scale where the far left of the scale (lowest possible value) was associated with "no pain," the middle of the scale was associated with "moderate pain," and the far right of the scale (highest possible value) was associated with "worst pain." Responses were coded from 0 to 100 based on their relative position on the scale.

Approximately 5 weeks of daily mastalgia ratings resulted in an average of 35 total mastalgia ratings per participant. To associate these ratings with hormonal data collected at three specific timepoints (Phases 1, 2, and 4), mastalgia ratings recorded on the start date of each phase (day t) ± 2 days on either side of this date were averaged using weights 0.4 for day t, 0.2 for day $t \pm 1$, and 0.1 for day $t \pm 2$ to create a weighted moving average mastalgia score (mastalgia$_{\text{WMA}}$) for the start of each phase. In studies of menstrual phases, slight day-to-day shifts in hormonal levels and individual variations in cycle timing can make it difficult to accurately assign a single, precise date to each phase's start, even with the support of quantitative data [25, 26]. This variability can introduce measurement error for symptoms like cyclic mastalgia, which may peak just before or after an assigned date. By allowing for a range around phase starts, this approach aimed to account for natural variability in cycle timing and align mastalgia symptoms more accurately with underlying hormonal changes.

2.5 | Estradiol and Progesterone Concentrations (Phases 1, 2, and 4)

The methodology used to determine circulating hormone concentrations is published in greater detail in McKay et al., 2022 [21]. In brief, participants presented to the laboratory for venous blood samples at three timepoints during their five-week residence at FARC 1.0. Naturally cycling participants were tested in:

- Phase 1: approximately 2 days after first report of menstruation (characterized by low estradiol and low progesterone);
- Phase 2: elevated estrogen metabolite concentrations detected by the home urinary ovulation kits (characterized by elevated estradiol and low progesterone); and
- Phase 4: approximately 7 days after ovulation, or in cases where ovulation was not determined ($n = 1$), 21 days after first report of menstruation (characterized by elevated estradiol and elevated progesterone), as described by Elliott-Sale et al. (2021) [27].

For athletes using hormonal contraception, arbitrary testing dates separated by 7–10 days were chosen to replicate the approximate pattern of blood collection from the naturally cycling athletes. Due to study limitations around resources and athlete availability, no testing was conducted in Phase 3 for naturally cycling participants nor those using hormonal contraception. The concentration of circulating estradiol and progesterone was determined according to methods described by McKay et al. (2024) [20].

Upon reviewing the menstrual phases using blood samples collected during the study, it was discovered that Phase 2 had been misclassified in five of the 24 athletes in the study whose hormone levels did not align with established criteria (i.e., higher estradiol in Phase 4 than Phase 2) [27]. It is likely that peak estrogen levels were not consistently captured, and consequently, the data should be considered approximations of the corresponding phases, rather than strictly following definitions from Elliott-Sale et al. (2021) [27].

2.6 | Statistical Analysis

All statistical analyses were conducted using RStudio (version 2024.04.0+735, R Foundation for Statistical Computing, Vienna, Austria). A multilevel hurdle lognormal model with a random intercept for each participant was created to model the effect of estradiol and progesterone (and the interaction of these) on mastalgia scores, while controlling for age and average breast volume. The hurdle model was chosen due to the large proportion of zero values (52 out of 72) in the mastalgia$_{\text{WMA}}$ variable and allowed for two processes to be modeled simultaneously: (1) a logistic regression model to determine if the expected mastalgia$_{\text{WMA}}$ is 0 or not (based on the predictors), and (2) a lognormal model to determine the expected mastalgia$_{\text{WMA}}$ for non-zero scores (based on the predictors). A lognormal link function was chosen to transform the non-normally distributed non-zero mastalgia$_{\text{WMA}}$ scores into normally distributed log-transformed mastalgia$_{\text{WMA}}$ scores. In addition, both main predictors (estradiol and progesterone) and the covariates (age and breast volume) were non-normally distributed and were all log-transformed using a natural logarithm for the modeling process. The hurdle lognormal model was specified via a Bayesian framework using the *brms* R package [28]. The posterior distributions of the model coefficients are presented as the highest *Maximum* A Posteriori probability estimate (MAP), 95% highest density credible intervals (HDIs), and the probability of direction (P; i.e., the probability of a positive or negative effect). The model coefficients for the logistic hurdle process are reported as the change in log odds of reporting a zero mastalgia compared to a non-zero mastalgia for every one unit change in the log of a given predictor. The model coefficients for the lognormal process are reported as the percent change in mastalgia for a 1% change in a given predictor. However, to enhance interpretation, we also provide a description of the percent change in odds of reporting a zero mastalgia and the percent change in mastalgia for a 10% change in a given predictor, calculated as $(1.10^{\beta} - 1) \times 100$. Descriptive statistics are reported as median and interquartile range (IQR) unless otherwise specified.

3 | Results

3.1 | Breast Volume

Participants had an average breast volume of 361.5 ± 158.6 mL and a median breast volume of 357.2 mL. According to the breast volume classification structure [29], 42% of participants (n = 10) had small breasts (< 350 mL) and 58% (n = 14) had medium breasts (350–700 mL). The smallest recorded breast volume was 139.9 mL and the largest was 600.8 mL.

3.2 | Mastalgia

Median (± IQR) daily mastalgia recorded on a scale from 0 to 100 across the menstrual cycle was 5 ± 5 for non-zero values (Figure 1A). Median (± IQR) $\text{mastalgia}_{\text{WMA}}$ was 5.4 ± 4.2 at Phase 1; 3.4 ± 2.4 at Phase 2; and 4.3 ± 5.4 at Phase 4 (Figure 1B).

3.3 | Estradiol and Progesterone Concentrations (Phases 1, 2, and 4)

Median (± IQR) estradiol was 30.9 ± 23.2 pg/mL at Phase 1; 54.0 ± 63.8 pg/mL at Phase 2; and 83.7 ± 124.1 pg/mL at Phase 4 (Figure 2A). Median (± IQR) progesterone was 1.2 ± 1.3 nmol/L at Phase 1; 1.3 ± 1.6 nmol/L at Phase 2; and 2.2 ± 22.7 nmol/L at Phase 4 (Figure 2B).

3.4 | Effect of Estradiol and Progesterone on Mastalgia

The WMA for daily mastalgia and the estradiol and progesterone concentrations at Phases 1, 2, and 4 are shown in Figure 3A (for naturally cycling participants not using contraception) and Figure 3B (for participants who were using hormonal contraception).

On average, a 10% increase in estradiol was associated with an 11.8% increase in the odds of reporting a mastalgia of 0 (compared to a non-zero value) (log odds = 1.17, 95% HDI = −0.16 to 3.94, PD = 0.97). In addition, on average, a 10% increase in progesterone was associated with a 73.9% increase in the odds (log odds = 5.81, 95% HDI = −1.19 to 13.31, PD = 0.96) of reporting a mastalgia of 0 (compared to a non-zero value). A 10% increase in progesterone was associated with a 26.5% decrease in mastalgia for non-zero values (95% HDI = −45.8 to 5.2, PD = 0.96).

However, an interaction was revealed between estradiol and progesterone, indicating that the effect that progesterone had on mastalgia was dependent on the value of estradiol, and vice versa (Table 1, Figures 4 and 5). Specifically, the effect of progesterone became "more positive" as the values of estradiol increased. For example, a 10% increase in progesterone was associated with a 5.9% decrease (95% HDI = −14.9 to 2.7, PD = 0.92) in mastalgia when estradiol was at the quartile one (Q1) value (27.71); a 1.6% decrease (95% HDI = −8.1 to 3.8, PD = 0.76) in mastalgia when estradiol was at the median value (51.07); and a 3.2% increase (95% HDI = −2.6 to 8.9, PD = 0.88) in mastalgia when estradiol was at the quartile three (Q3) value (111.03) (Figure 5A). Similarly, the effect of estradiol became "more positive" as the values of progesterone increased. For example, a 1% increase in estradiol was associated with a 0.9% decrease (95% HDI = −7.5 to 8.3, PD = 0.46) in mastalgia when progesterone was at the Q1 value (0.88); a 3.9% increase (95% HDI = −3.6 to 13.2, PD = 0.84) in mastalgia when progesterone was at the median value (1.62); and a 7.0% increase (95% HDI = −3.3 to 17.8, PD = 0.92) in mastalgia when progesterone was at the Q3 value (2.43) (Figure 5B).

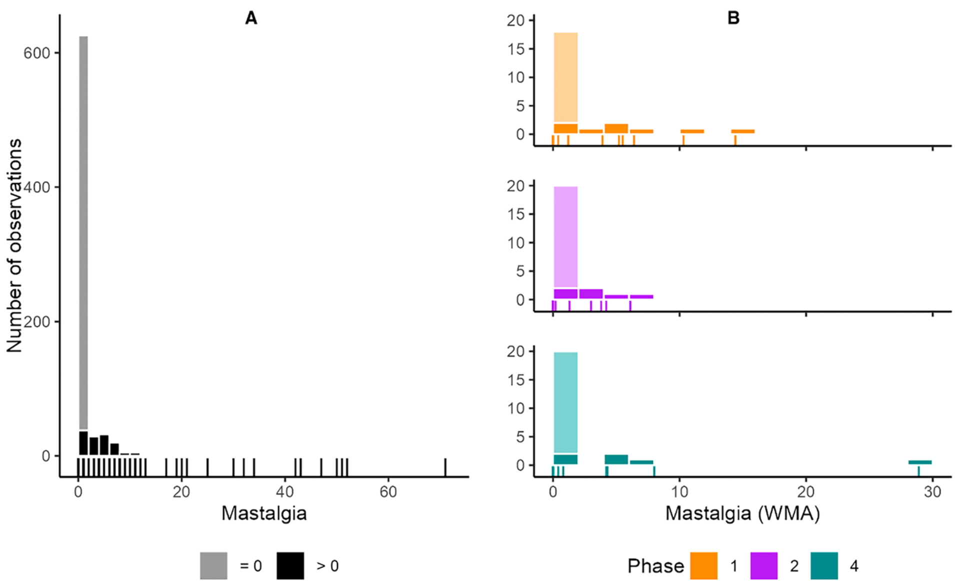

FIGURE 1 | The distribution of (A) daily mastalgia values across the menstrual cycle and (B) the 5-day weighted moving average (WMA) for mastalgia at Phases 1, 2, and 4. The bars show the number of observations between a given range of values. The dashes below the bars show the individual data points. The lighter colored bars for both (A) and (B) show the number of observations that were 0, and the darker colored bars show the number of observations that were > 0.

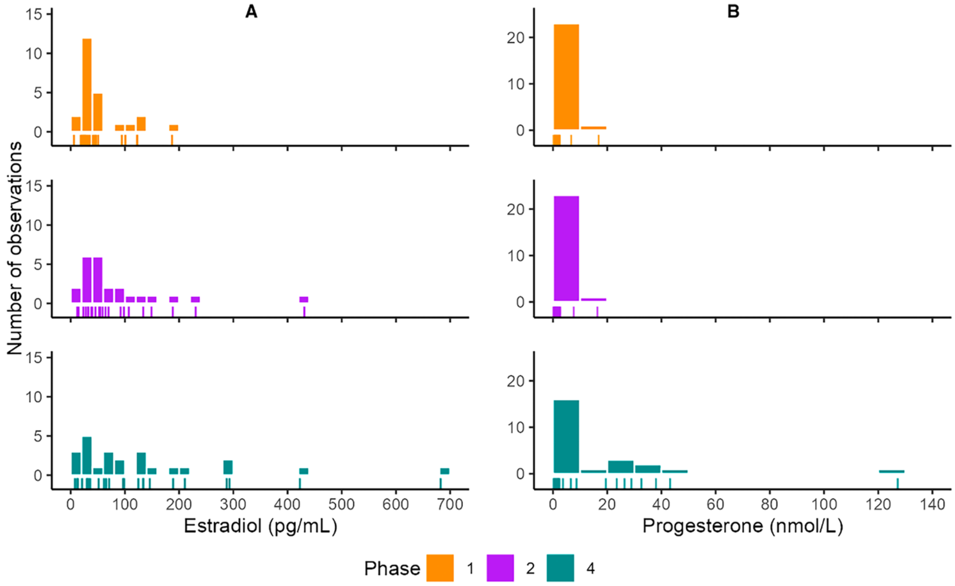

FIGURE 2 | Estradiol (A) and progesterone (B) at Phases 1, 2, and 4. The bars show the number of observations between a given range of values. The dashes below the bars show the individual data points.

4 | Discussion

This is the first study to quantitatively examine the effect of estradiol and progesterone on the occurrence and severity of mastalgia throughout the menstrual cycle in a cohort of highly trained female rugby league players. Higher levels of estradiol and progesterone were associated with a decrease in the occurrence of mastalgia; higher levels of progesterone were also associated with a reduction in the severity of mastalgia. These effects were highly interdependent, such that the effect progesterone had on mastalgia was elevated based on higher values of estradiol and vice versa. The implications of these findings for managing cyclic mastalgia in female athletes are discussed below.

Interestingly, 72% of mastalgia ratings recorded in this study (52 out of 72) were zero, and the median severity of daily mastalgia was five out of 100 (or approximately 0.5 out of 10 on a 10-point scale), indicating a low incidence and severity of mastalgia (most experts agree that pain rating ≥ 3 on a 10-point scale is clinically significant) [30]. These findings are somewhat at odds with previous research, which has suggested that 32%–60% of female athletes experience cyclic mastalgia [6–8] and the severity among athletic populations is an average of three out of 10 [9, 10]. One possible explanation for this discrepancy is the physicality of rugby league; athletes may perceive breast pain as minor relative to other injuries and impacts regularly experienced, leading them to report low levels of breast pain when compared to other athlete populations across non-contact and pseudo-contact sports such as soccer, hockey, shot-put, and rowing [9, 10]. Another possibility is a general lack of education about what constitutes mastalgia; many women have been socialized to believe that breast pain is "normal" and "unavoidable," which may result in a bias towards ignoring and downplaying this pain when reporting [31]. Thirdly, a majority of previous studies have relied on retrospective reporting [6–10], while the present study collected daily data from athletes on their experience of mastalgia; this study methodology was chosen to reduce recall bias and may have accounted for differences in the prevalence of mastalgia reported here. Finally, cultural factors may also have contributed to under-reporting of breast pain in the present study. Previous research on women's sexual and reproductive health within Aboriginal and Torres Strait Islander communities has documented that topics deemed "women's business" are less likely to be presented to healthcare professionals and health researchers, as these matters are considered private and sacred [32].

Furthermore, it is important to consider the homogeneity of the present sample, as the age range of participants was 18–29 years (median: 21 years). Similarly, although the median breast size observed in this study (362 mL) was in line with previous research of Australian female rugby players (median: 342 mL) [23] and the general Australian population (median: 363 mL) [29], there was a complete lack of representation for women with large (700–1500 mL) and hypertrophic breasts (> 1500 mL). Considering the positive association between mastalgia and both higher age [2, 4, 5, 18] and larger breast size [6, 7, 14], this homogeneity is likely to have affected the occurrence and severity of mastalgia reported in the current study. Further research in more diverse cohorts of women in terms of age and breast size across a range of sports is necessary to improve the sensitivity of the model [6].

When examining the pain reported in this study relative to the menstrual cycle, mastalgia was found to be most severe at approximate Phase 1 (commencement of the period), during which time median estradiol and progesterone were the lowest (30.9 pg/mL and 1.2 nmol/L, respectively). Conversely, mastalgia was the least severe during approximate Phase 2 (after commencement of the menstrual period, in the 14–26 h prior to ovulation), during which time median estradiol and progesterone were the highest (83.7 pg/mL and 2.2 nmol/L, respectively). These findings are somewhat consistent with previous literature, which has suggested that depressed levels of progesterone, typically responsible for combatting the water retention and tissue stimulation associated with estradiol,

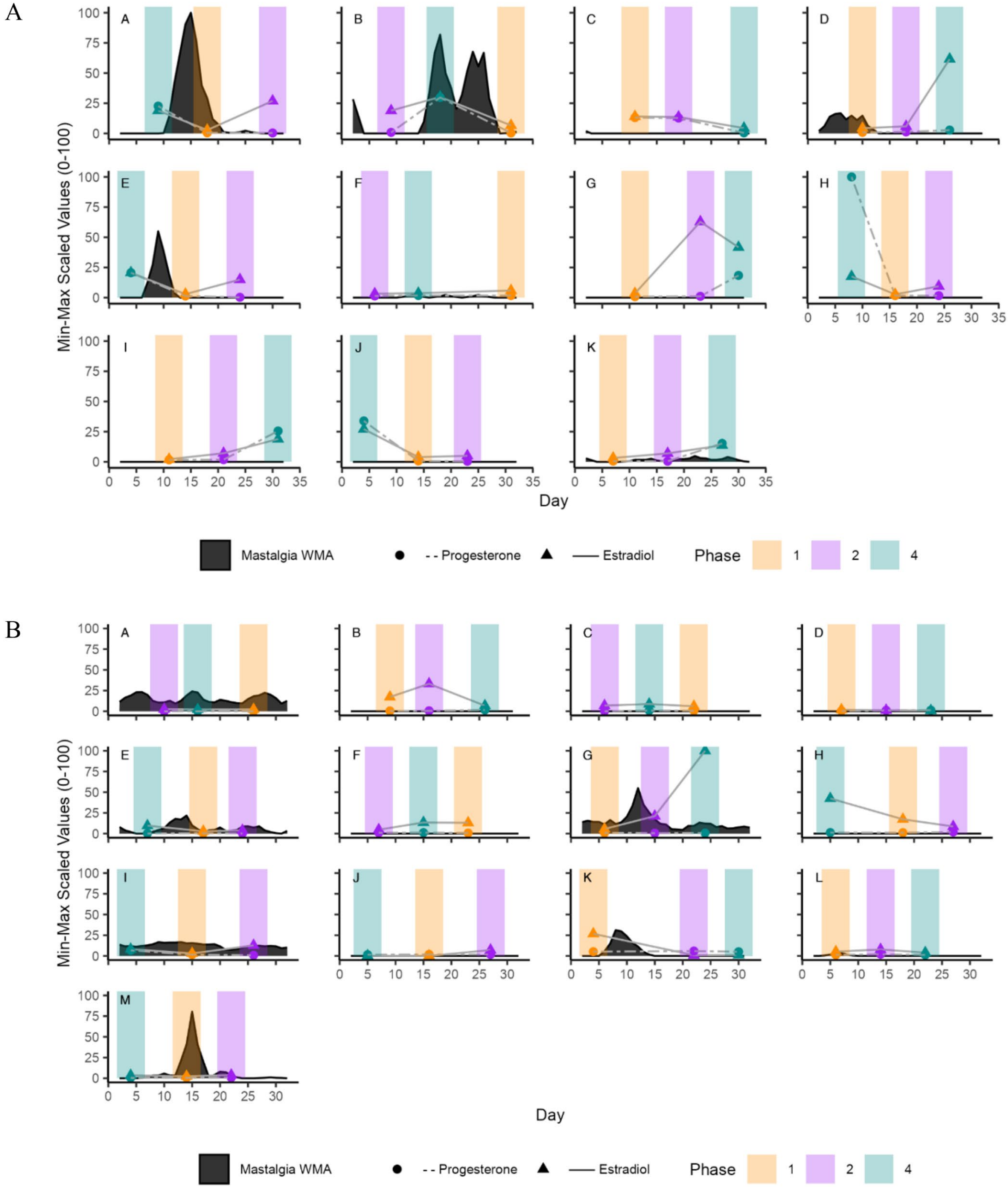

FIGURE 3 | Daily mastalgia (WMA) across the menstrual cycle, and estradiol and progesterone at the three data capture points (Phases 1, 2, and 4) for participants who were (A) naturally cycling and not using hormonal contraception and (B) who were using hormonal contraception. Each Figure (A–M) shows the data for an individual participant. Mastalgia (WMA), estradiol and progesterone have been scaled using a min–max transformation to represent each of these variables on a scale of 0–100 for the purpose of visualization.

contribute to cyclic mastalgia [4, 5, 13–15]. However, opposing findings have also been demonstrated [16]. It is therefore important to emphasize that the exact etiology of mastalgia remains speculative and the impact of hormone fluctuations on breast pain is still somewhat unknown [4, 5, 14]. General consensus among experts suggests a complex interplay of

TABLE 1 | The posterior distribution of the hurdle lognormal model coefficients.

Parameter	MAP	95% HDI lower	95% HDI upper	PD
Hurdle process				
Intercept	10.37	−42.70	74.42	0.71
Estradiol (log)	1.17	−0.16	3.94	0.97
Progesterone (log)	5.81	−1.19	13.31	0.96
Estradiol (log) * Progesterone (log)	−1.30	−2.89	0.25	0.96
Average breast volume (log)	−0.74	−6.54	3.88	0.65
Age (log)	−3.89	−20.87	12.92	0.73
Lognormal process				
Intercept	−1.35	−28.15	23.96	0.52
Estradiol (log)	−0.04	−0.71	0.91	0.55
Progesterone (log)	−3.23	−6.43	0.53	0.96
Estradiol (log) * Progesterone (log)	0.68	−0.03	1.53	0.97
Average breast volume (log)	−0.81	−3.13	1.16	0.80
Age (log)	2.11	−4.75	8.94	0.73

Note: The slope coefficients for the hurdle process are presented as the predicted change in log odds of reporting a zero compared to a non-zero value for mastalgia (for a 1-unit increase in the log of each predictor). The slope coefficients for the lognormal model are presented as the predicted percent change in mastalgia for a 1% change in the given predictor.
Abbreviations: HDI, highest density credible intervals; MAP, maximum a posteriori probability estimate; PD, probability of direction.

endogenous hormones, and among athletes using hormonal contraception, possibly an influence of exogenous hormones that have not been quantified in this study.

The present study suggests that both estradiol and progesterone are associated with variations in the occurrence and severity of mastalgia. Specifically, an increase in either estradiol or progesterone concentrations was linked with higher odds of reporting no mastalgia (a score of zero). Moreover, among those participants who reported experiencing some mastalgia, progesterone was associated with a decrease in severity, suggesting a potential ameliorating effect of progesterone on pain levels. A similar effect of estradiol was not observed, possibly because of the moderating effect of progesterone on estradiol (suggesting an indirect influence of estradiol). These findings suggest that both estradiol and progesterone play a role in moderating the occurrence of mastalgia throughout the menstrual cycle, though the exact nature of this relationship requires further investigation.

Study limitations notwithstanding, the interdependent effects of estradiol and progesterone on mastalgia could have significant implications for managing breast pain in female athletes. Educating female athletes about this dynamic could empower them to track and understand their own hormonal patterns, potentially leading to more effective self-management of symptoms. At present, the most effective strategy for managing mastalgia is still the use of a correctly fitting sports bra to provide breast support during activity. This has been shown to alleviate symptoms for as many as 85% of women, even compared to pharmacological interventions (58%) [33]. Bra fitting and education have had a similarly profound effect on reducing breast pain [19]. Education about mastalgia, bra-fitting services, and access to high-support sports bras are therefore the most critical interventions for sporting organizations to implement in pursuit of reducing mastalgia for players.

As with all research, the study findings must be interpreted in light of their limitations. Firstly, the high proportion of zero values recorded for mastalgia (i.e., limited inter-participant and intra-participant variability in mastalgia ratings across the cycle) was a substantial constraint on the overall sensitivity of the analysis, making it difficult to observe subtle effects of estradiol and progesterone on breast pain. This limitation likely contributed to the small magnitude of association and broad HDI range documented in the present model, thus underscoring a need for future studies to explore the relationship between endogenous hormones and mastalgia in a purposive sample of women who experience more severe breast pain to better assess nuanced hormonal effects. Secondly, the participant sample was relatively homogenous in terms of age and breast size. We recommend future research recruit a more diverse sample of athletes in terms of age, breast size, and sport to confirm study findings. Thirdly, this study only considered the effect of two endogenous hormones (estradiol and progesterone) on the experience of mastalgia but did not quantify exogenous hormones that may also play a role in breast pain among athletes. Analysis was combined for athletes who were naturally menstruating and those using hormonal contraception. This was appropriate as we considered the absolute value of estradiol and progesterone; however, it is possible that the effects of hormonal contraception on these exogenous hormones may be implicated in the mastalgia responses reported by these participants, confounding our analysis. Finally, we were not able to examine the effect of the Phases of the MC on mastalgia, as recommended in previous research [27]. Given that these Phases were estimated from tracking data, potential constraints imposed by self-reported menstrual tracking and retrospective hormone confirmation may have led to imprecise timing of estrogen peaks in some participants. Future research may benefit from daily hormone monitoring to mitigate this study limitation.

5 | Perspective

These findings contribute to the understanding of hormonal influences on mastalgia, highlighting the nuanced and potentially complex roles that estradiol and progesterone play in positively modulating breast pain in female athletes. The tendency of these hormones to reduce the occurrence and/or severity of mastalgia in female athletes aligns with some previous research [4, 5, 13–15], but limitations in the present study underscore the need for further research to clarify these

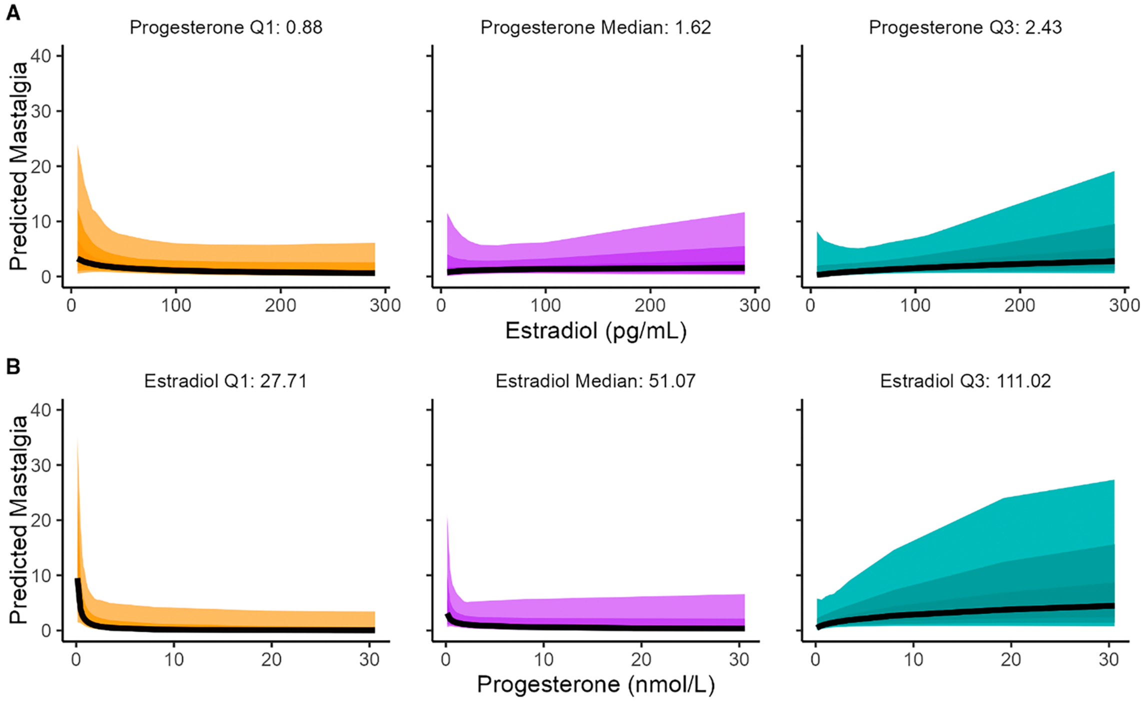

FIGURE 4 | (A) Predicted mastalgia for continuous values of estradiol and Q1, median and Q3 values for progesterone, and (B) predicted mastalgia for continuous values of progesterone and Q1, median and Q3 values for estradiol. For both A and B, mastalgia has been predicted for the mean values of breast volume (361.5) and age (21.6) The black lines represent the median expectation of the posterior predictive distribution, and the varying shaded ribbons represent the 50%, 80% and 95% quantile intervals.

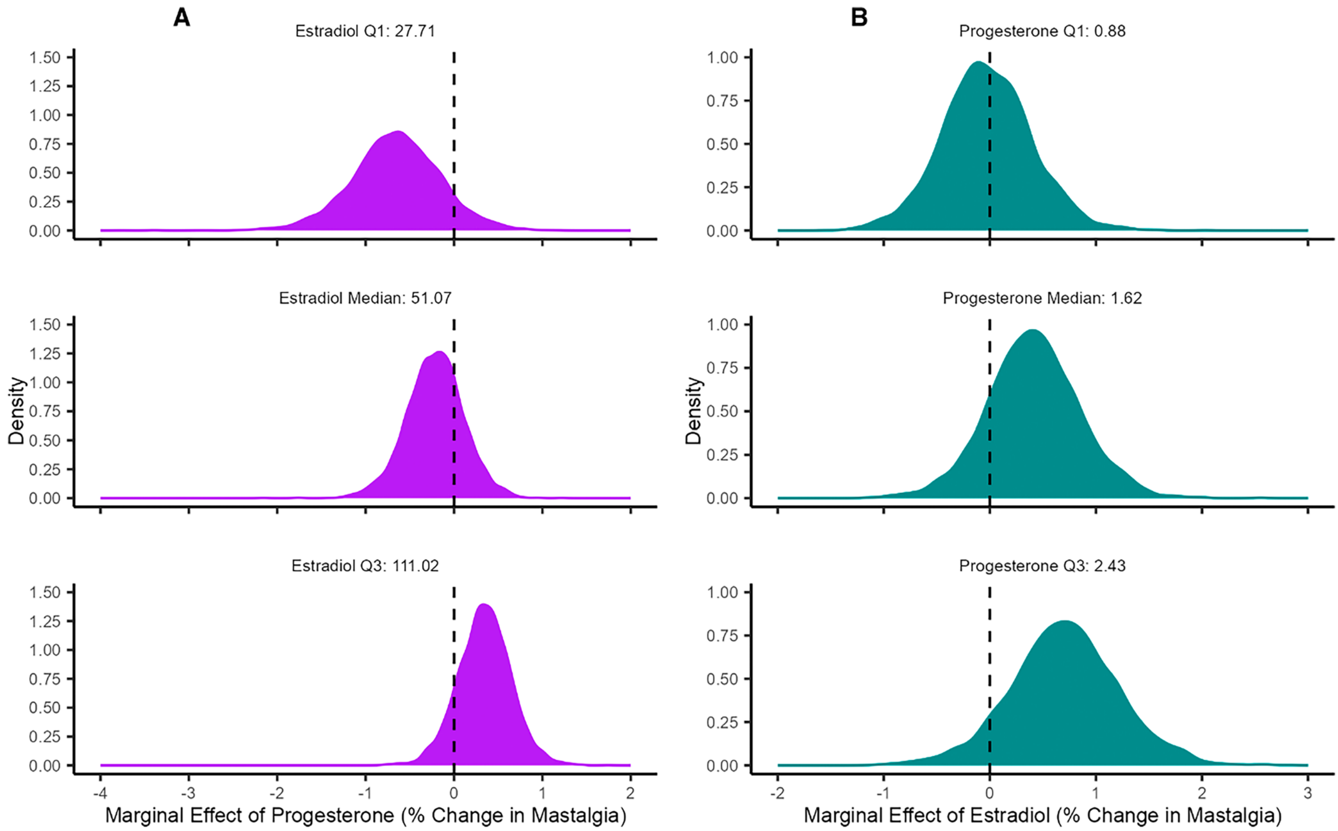

FIGURE 5 | (A) The marginal effect of progesterone at the Q1, median, and Q3 values of estradiol, and (B) the marginal effect of estradiol at the Q1, median, and Q3 values of progesterone. Marginal effects are presented as the percent change in predicted mastalgia for a 1% increase in progesterone (A) or estradiol (B). Density is calculated using a kernel density estimator.

relationships, with specific regard for a larger, more diverse sample (in terms of age and breast size) of female athletes with more severe mastalgia. Such data are vital to the understanding and management of breast pain, which, despite a high clinical incidence and known impact on quality of life, remains poorly understood from an etiological standpoint. Education, bra-fitting services, and access to high-support sports bras should be a priority for sporting organizations, as these have been shown to effectively reduce the severity of mastalgia symptoms more than any other intervention.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Research data are not shared.

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