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Effects of menstrual cycle phases on approach-avoidance behaviors in women: a behavioral and event-related potentials study

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Abstract
Menstrual cycle influences approach-avoidance behavior in females as a result of fluctuations in sex hormone levels, but the underlying neuropsychological processes are unknown. Therefore, we collected the approach-avoidance behavior and electroencephalogram (EEG) data of 27 naturally cycling women during early follicular, late follicular, and mid-luteal phases, focusing on the effects of estradiol and progesterone levels on women's approach-avoidance behavior. Results found that women in the late follicular phase approached positive stimuli more quickly, and N2 amplitudes were the smallest for impulsive benefit-approach reaction. Women in the mid-luteal phase avoided negative stimuli more quickly, and P1/N2 amplitudes were the smallest for impulsive harm-avoidance reaction. Correlation results showed that estradiol levels positively predicted benefit-approach behavior, and progesterone levels positively predicted harm-avoidance behavior. Behavioral and event-related potential (ERP) results suggest that women in different menstrual cycles have different sensitivities to approach-avoidance behaviors of different emotional stimuli, characterized by less consumption of cognitive resources in the early stages of emotional motivation processing, which is in part mediated by estradiol and progesterone. These findings provide a deeper understanding of the relationship between ovarian hormones and approach-avoidance behavior in women.

Keywords Menstrual cycle, Approach-avoidance behavior, ERP, Estradiol, Progesterone

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Introduction

Approach and avoidance responses are fundamental behavioral principles that regulate organism needs [1]. Seeking advantage and avoiding harm is the instinct of organisms. Profit seeking enables organisms to acquire stronger survival abilities, while avoidance of harm enables individuals to continue their lives. Approach-avoidance behaviors also occurs in many social contexts. For example, how can athletes be more motivated to win, and how can they better avoid injuries. Therefore, appropriate approach-avoidance behaviors based on goals and changing circumstances are critical to female growth and development.

Researchers have found that people approach positive stimuli and avoid negative stimuli more quickly than approach negative stimuli and avoid positive stimuli, a phenomenon called as the stimulus-response compatibility (SRC) effects [2]. Automatic behavioral control is essential for social interactions, and flexible behavior requires the management of situational emotional responses. Cognitive control is key to resolving conflict in SRC tasks [3].

The menstrual cycle is a sign of female physiological maturity, not only that, it also affects the psychological behavior of women [4]. The menstrual cycle is accompanied by fluctuations in sex hormone levels. For female approach-avoidance behavior, research published by our laboratory in 2022 have shown a strong correlation with the level of female sex hormones (estrogen and progesterone) [5]. Estradiol levels are positively correlated with positive stimulus approach behavior and negatively correlated with positive stimulus avoidance behavior, while progesterone levels are positively correlated with negative stimulus avoidance behavior and negatively correlated with proximity to negative stimuli [5]. This suggests that estradiol motivates the approach of positive stimuli, while progesterone motivates threat stimulus avoidance. However, behavioral results alone cannot explain underlying mechanisms and the electrophysiological changes, and this result needs to be further expanded and confirmed in neurological and physiological aspects.

It is worth introducing that estradiol and progesterone are the most important sex hormones, and their levels fluctuate during the 28–35 days of the human menstrual cycle, changing during the menstrual, follicular, and luteal phases. Estradiol and progesterone levels are low during menstruation and the early follicular phase, after which estradiol increases slowly in the late follicular phase and declines after reaching a peak on ovulation day; progesterone levels remain low. After entering the luteal phase, progesterone levels increase slowly and peak in the middle luteal phase when estradiol peaks a second time [6]. Therefore, in order to study the specific effects of estradiol on women's behavior, researchers can compare the performance of women in the late follicular phase and the early follicular phase. Similarly, the effect of progesterone on women's behavior can be compared to the differences during the late follicular phase and the middle luteal phase. With this approach, we can more accurately understand the independent effects of estradiol and progesterone on female behavior [7].

A common feeling among women is that their emotions and behaviors vary greatly during different menstrual phases. For example, premenstrual syndrome manifests as physical discomfort and negative emotional symptoms in women during the luteal phase [8], and decreased estradiol levels and increased progesterone levels during the luteal phase before the start of menstruation may also trigger premenstrual anxiety [9]. Dreher (2007) et al. found that both expected and actual monetary rewards caused higher activation of the reward system in mid-follicular, and this response was related to estradiol levels [10]. In contrast, women in the luteal phase are more sensitive to infectious and threatening faces that contain negative information [11]. Response speeds to non-social threat stimuli (such as snakes and tigers) are faster, but response times to neutral stimuli (such as plants) are not different [12]. These findings provide important clues for researchers to better understand the relationship between female approach-avoidance behavior and sex hormone levels.

Though the internal neural mechanisms that connect the menstrual cycle with approach-avoidance behavior have not been explored, previous studies on the relationship between menstrual cycle and emotional processing and cognitive control using event-related potentials can be used for reference. First, frontal-central N2 ERP was used as an indicator of early response inhibition [13, 14]. The larger amplitude of P1 ERP can reflect the automatic attention of emotion-related situation capture [15, 16]. LPP components reflect deep processing and classification of stimuli [17], also reflects how much psychological resources people invest [18]. Secondly, Wu et al. (2014) used the oddball paradigm to investigate the time course of negative emotional stimulus processing in different menstrual cycle phases. ERP revealed that the N2 amplitude of moderately negative (MN) was greater than neutral in the late luteal phase, but no such difference was found in the follicular phase. In addition, N2 stimulated by highly negative (HN) was greater in the late luteal phase than in the follicular phase, suggesting that women are more sensitive to negative emotions in the luteal phase than in the follicular phase [19]. Inadequate emotional regulation can lead to anxiety and depression disorders, which are more common in women than men. During the inhibition process of emotional regulation tasks, the N2 amplitude is higher in women during the mid-luteal phase compared to men [20], suggesting that mid-luteal women may be significantly weaker than men in inhibiting cortical processing of negative stimuli, but this is only speculative. While mid-luteal women report greater emotional distress than men, mid-luteal women also work harder than men to suppress their emotional responses. Both P1 and N1 were higher in mid-luteal women than in men, indicating earlier attention processing. P3 and LPP did not differ significantly by gender or menstrual phase [20]. One study also found that a significantly larger P3 amplitude was evoked by probes following the presentation of disgusting food cues in the mid-luteal phase than the late follicular phase, which may indicate that the mid-luteal phase is a relatively sensitive stage in the menstrual cycle for women to regulate their appetite and eating behavior [21]. Studies focusing on responses to positive emotional cues associated with sex hormones have found that higher estradiol-concentrations were associated with more positive LPP-amplitudes towards erotic- than to neutral words during the follicular phase and ovulation [22].

Approach-avoidance behavior is critical to women's growth and safety in life and sometimes requires the control of adaptive responses and the suppression of self-desires in social interactions and external environments. Here, we want to explore whether this automatic and controlled approach-avoidance behavior is modulated by the menstrual cycle and its electrophysiological characteristics. We compared the approach-avoidance behavior and ERP characteristics of women in early follicular (low estradiol level) and late follicular (high estradiol level) phases to explore the profound effect of estradiol level on approach-avoidance behavior, and compared the approach-avoidance behavior and ERP characteristics of women in the late follicular phase (low progesterone level) and the middle luteal phase (high progesterone level) to explore the profound influence of progesterone level on approach-avoidance behavior. Similar to the study of Li (2022) [5], this study investigated the behavioral characteristics of approach-avoidance responses at different menstrual phases. Different from Li (2022) [5], this study innovatively included ERP technology and observed changes in brain potentials. Based on previous studies [5, 12, 19, 20], our primary hypotheses were that women in the late follicular phase approached positive stimulation more quickly than women in other phases, and women in the middle luteal phase avoided negative stimuli more quickly than women in other phases. Estradiol and progesterone levels significantly correlated with the speed of the approach–avoidance responses observed for the women. And the electrophysiological processing characteristics of female approach-avoidance behavior may be different in different menstrual cycle phases.

Methods

Participant

G* Power 3.1.9.4 was used for a priori computation of the sample size. We set a medium effect size F (the value is 0.25), given the α value (0.05), power value (0.80), and a sample size of 24 people was suggested. In addition, we refer to previous ERP studies [19, 23] on menstrual cycles and emotional processing, with sample sizes ranging from 16 to 29. So in this study, we recruited 30 female college students from a University in Shanghai, China, through advertising. They reported their emotions (e.g., depression), behaviors (e.g., insomnia), and daily physical symptoms (e.g., breast tenderness) graded by severity (asymptomatic, mild, moderate, and severe) using a prospective record of the impact and severity of menstrual symptoms (PRISM) [24] every day for three consecutive menstrual cycles. Participants completed a menstrual cycle questionnaire, and participants included in the study had stable menstrual cycles of 26–35 days in the last 3 months, had taken no hormone contraceptives (oral, IUD, implants, etc.), and had not been pregnant in the past 6 months. A total of 27 female right-handed college students of ages 19–28 years (mean 20.70 ± 1.35 years), were invited to participate in the study. Participants were followed for an additional month following test completion to ensure cycle stability.

The reverse calculation method [25, 26, 27, 28] was used to estimate each phase of the participants' cycles. Participants completed the tests at the laboratory during the early follicular phase (2–5 d after menstruation onset), and late follicular phase (14–16 d prior to menstruation onset), and mid-luteal phase (6–8 d prior to menstruation onset) of their menstrual cycle. Ovulation tests (for luteinizing hormone) were performed every morning for 1 week before and after the late follicular phase to accurately determine the occurrence of ovulation. Saliva samples were also taken on the day of the experiment to confirm estradiol and progesterone levels. All participants had normal or corrected vision and no history of mental illness. This study was approved by the Ethics Committee of the local research institute and obtained the protocol number; prior to the experiment, participants were provided informed consent.

Subjective measures

Before the formal experiment, the Depression, Anxiety and Stress Scale (DASS) with high reliability and validity [29] was used to assess the emotional levels of depression ($\alpha = 0.95$), anxiety ($\alpha = 0.90$) and stress ($\alpha = 0.93$) on the day of their experiment. The State-trait Anxiety Inventory (STAI) [30] measured the levels of state anxiety and trait anxiety, aiming to excluded anxious trait participants. The Positive Affect and Negative Affect Scale

(PANAS) were applied to evaluate the current emotional state of the participants [31].

Materials

The affective picture material used in our study was selected from the International Affective Picture System (IAPS) [32]. Fifty positive (valence: $M = 7.27$; arousal: $M = 0.96$) and 50 negative (valence: $M = 2.73$; arousal: $M = 0.91$) images were presented as stimuli for the formal experiment. The affective picture materials were the same as those used in previous research [5]. The two picture sets had statistically significant differences in valence [t (114) = 26.16, $P < 0.001$] but not in arousal [t (114) = 0.17, $P = 0.26$]. In addition, six positive and six negative emotion pictures were selected for practice. In the experiment, pictures of participants' own faces appeared as the "manikin" in the "manikin task" to create an immersive experience. Photos were deleted after the experiment.

Study design

(1) Focus on the role of estradiol: the experimental design was a 2 × 2 × 2 within-subject design with menstrual cycle phase (early follicular phase or late follicular phase), emotion type (positive or negative), and motivation type (approach or avoidance) as the factors. (2) Focus on the role of progesterone: the experimental design was a 2 × 2 × 2 within-subject design with menstrual cycle (late follicular phase or mid-luteal phase), emotion type (positive or negative), and motivation type (approach or avoidance) as the factors.

Procedure

Participants were tested in a quiet, dimly lit, odorless lab. First, participants completed three scales (PANAS, DASS, and STAI), and their faces were photographed. Participants wore Electroencephalography (EEG) caps and sat comfortably in a chair with their eyes about 60 cm away from the screen. Participants were asked to minimize head movement, blinking, and mind-wandering during the manikin task. E-Prime 2.0 software was used to automatically record the accuracy and reaction times of participants. EEG and ECG data were collected using a 64-channel EEG amplifier (Brain Products, Gilching, Germany) with an electrode impedance < 5 kΩ. FCz was used as the reference electrode for online recording, and the bilateral mastoid was used as the reference for offline analysis. An electrode was placed 1 cm below the right eye to record vertical electromyography (VEOG), and an electrode was placed 1 cm outside the left eye to record horizontal electromyography (HEOG). The horizontal and vertical electromyography signals were extracted using independent component analysis (ICA). The instrument used in this study has been used in many studies [21, 33, 34], which supports its validity and reliability.

Manikin task: (1) A cross fixation point (600 ms) appears centered at the top or bottom half of the screen (randomized at 50% each). (2) A picture of the participant's own face appears at the same position as the fixation point (750 ms). (3) An emotional picture (2500 ms) appears in the center of the screen. After the picture appeared, participants had to judge the emotional type of the emotional picture according to different tasks of block1 and block2, and press keys with their right index finger as quickly and accurately as possible to make the face picture move up/down and complete the approaching or avoiding behavior. The participants reacted based on the position of their own face (up or down) and the valence of the emotional picture (positive or negative). Before each trial, the participants placed their right index finger on the "5" key of the keypad to ensure that they were starting from the same position when pressing the "8" or "2" keys to move their face picture. After pressing the key, the face image moves to the edge of the central emotional image or the edge of the screen to realistically mimic approach and avoidance. The face image and the central image then disappear. The screen turns blank for 3–4 s after the response and the next trial begins.

The formal experiment consisted of two blocks. Block 1 (compatible block) required participants to move their own picture closer to the positive emotion image and away from the negative emotion image. Block 2 (incompatible block) required participants to move their face picture closer to the negative emotion image and away from the positive emotion image; each block comprised 50 trials. Participants' face pictures were deleted after the study to preserve privacy. The experimental flow chart is shown in Fig. 1.

Prior to the formal experiment, 2-mL saliva samples were collected in 3-mL disposable freezer storage tubes [35] to prevent the stress caused by the task from affecting hormone levels, and stored at -20 °C prior to hormone level testing. To avoid saliva contamination, subjects were asked to refrain from eating for 2 h and not to drink coffee for 30 min before each the sessions.

Hormonal analyses of the saliva samples

Each participant provided three saliva samples to measure estradiol and progesterone levels during each menstrual cycle. The levels of estradiol (sensitivity 0.4 pg/mL) and progesterone (sensitivity 3.9 pg/mL) were analyzed by the Salivary Estradiol (SLV-4188) and Salivary Progesterone (SLV-2931) enzyme-linked immunosorbent assay (ELISA) kits (DRG, Marburg, Hessen, Germany) according to manufacturer instructions. For estradiol assays, the in-box and inter-box confidence levels were 2.1–3.8% and 2.6–6.9%, respectively; for progesterone assays, the

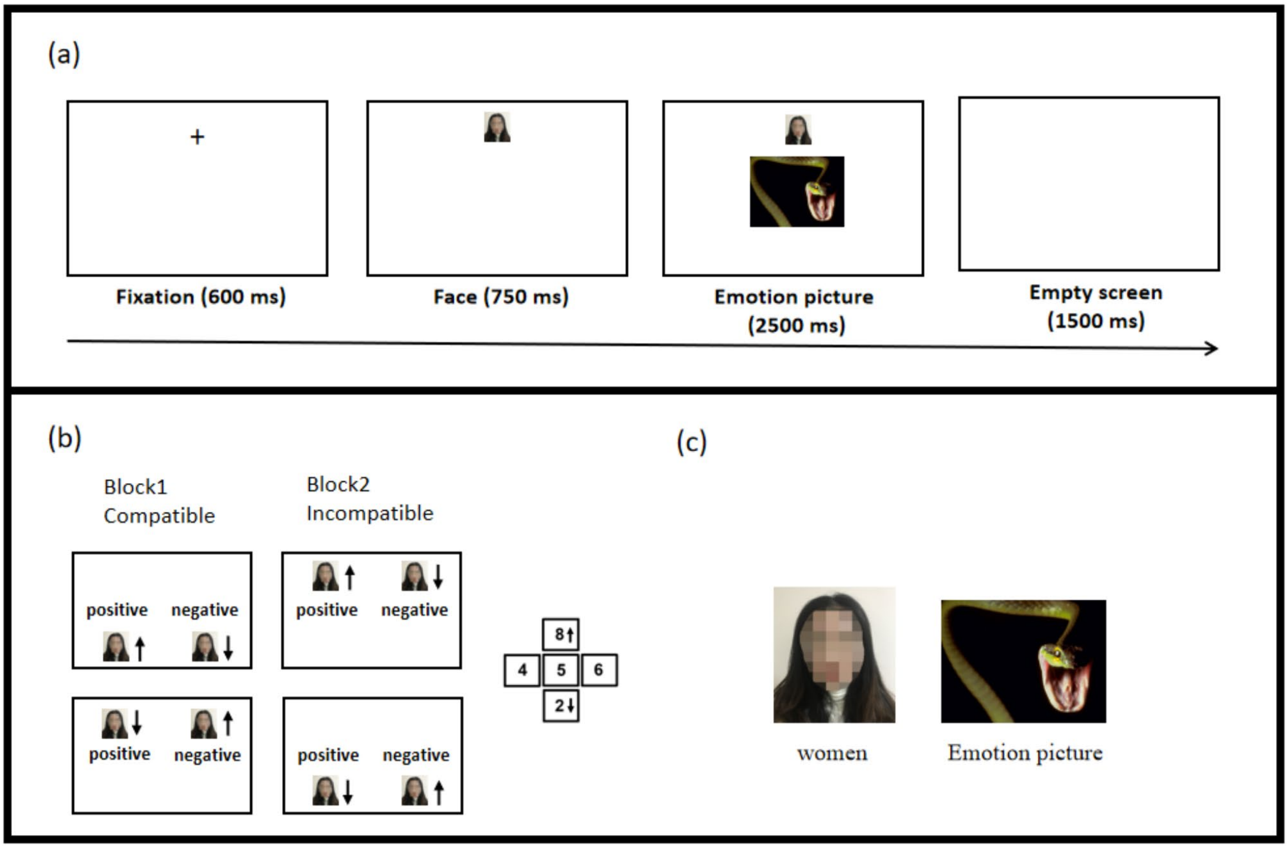

Fig. 1 Schematic illustration of the task. (**a**) Trial structure. In the manikin task, participants move the self-face which consisted of a schematic drawing of a women on the screen towards (approaching) or away from (avoiding) the affective stimulus. (**b**) Task requirements of two blocks. Compatible condition (Block1): approaching positive and avoiding negative stimulus. Incompatible condition (Block2): avoiding positive and approaching negative stimulus. (**c**) Stimulus details. We used the self-face of each participant as a unique self-referential stimulus and the emotional picture as the affective stimulus

in-box and inter-box confidence levels were 5.3–7.7% and 4.7–7.6%, respectively. Accuracy was within 15%. Hormone testing was completed by Beijing Protein Innovation Co., Ltd. (China), the domestic agent of DRG Company.

Data analysis

In this study, the independent effects of estradiol and progesterone on female avoidance behavior were analyzed separately. Analysis 1: For the role of estradiol, the difference of menstrual cycle phases between early follicular (low estradiol level) and late follicular (high estradiol level) phases were compared. Analysis 2: For the role of progesterone, the difference of menstrual cycle phases between late follicular (low progesterone level) and mid-luteal (high progesterone level) phases was compared. The indicators and methods of analysis are as follows.

Statistical analysis was performed using SPSS, version 20.0 (IBM SPSS, Inc., Chicago, IL, USA). Differences of Menstrual cycle phases in scale scores and salivary estradiol and progesterone levels were analyzed by paired samples t-test in SPSS (v.22.0, Chicago, IL, USA). Repeated-measures ANOVA was used to test for differences in reaction times for emotion type (positive or negative), motivation type (approach or avoidance), and menstrual cycle phase (early follicular phase or late follicular phase/late follicular phase or mid-luteal phase). Pearson correlation was used to test the relationship between estradiol/progesterone levels and the reaction times for approach-avoidance behaviors.

EEG data was analyzed by Brain Vision Analyzer 2.1 software (Brain Products GmbH, Gilching, Germany). EEG data were high-pass filtered with 0.1 Hz for event-related potential (ERP) analysis and low-pass filtered with 30 Hz (Butterworth filter, slope: 24 dB/oct). Amplitudes beyond ± 80 V were automatically rejected as artifacts. Independent component analysis was used to correct eye movements and blinks [36]. Segmentation was performed according to the study protocol. With the emotional picture stimulus as the zero point, the time range for analysis was set to range from − 200 ms to + 800 ms. Next, the data baseline was corrected to 200 ms before the presentation of the emotional picture stimulus. Finally, the correct trials of each condition were overlapped and averaged. The ERP components included the occipital region P1, P2, the prefrontal region N2, and the central-parietal region LPP. The ERP component peaks in the early and middle stages were sharp, so baseline peaks were used to measure P1, P2, and N2. The late LPP waveform was blunt, so the average amplitude was used to measure LPP. Generally, each ERP component is calculated from the average of the three or four electrode points with the highest amplitude to achieve a higher signal-to-noise ratio of the ERP result. The choice of time window for the analysis of electrode and ERP components was guided by existing literature [37, 38, 39, 40], EEG topographic maps, and ERP waveform maps. Specifically, for P1 component analysis electrodes Oz, PO7, and PO8, the peak detection window is 100–150 ms. The electrode points for P2 analysis were POz, PO3, PO4,Oz, O1, and O2, and the peak detection window was 180–300 ms. The electrode points for N2 analysis were Fz, FC3, FCz, FC4, and Cz, and the peak detection window was 200–300 ms. The electrode points for the analysis of LPP components were CPz, CP1, and CP2, and the average amplitude calculation window was 320–480 ms. We used the repeated-measures ANOVA to analyze the peak and average amplitude of the corresponding electrode points of these ERP components. The three factors analyzed were menstrual cycle phase (early follicular phase or late follicular phase/late follicular phase or mid-luteal phase), emotion type (positive or negative), and motivation type (approach or avoidance). The sphericity assumption was evaluated using Mauchly's test, and the Greenhouse–Geisser correction for the degrees of freedom was used in cases of non-sphericity. The Bonferroni correction was used to correct for multiple post hoc comparisons. The effect size for the statistically significant factors was estimated using partial eta squared (η_p^2). For pairwise comparisons, the effect size was determined by *Cohen's d* (small: >0.2, medium: >0.5, large: >0.8). 95% confidence interval (*95% CI*) of the effect size was reported. $P < 0.05$ was considered statistically significant. The datasets generated for this study are available on request to the corresponding author.

Results

Subjective measures

A paired sample T-test was used to compare the differences in women's scale scores in early and late follicular phases. The results of DASS scale showed stress [$t(52) = 1.78$, $P = 0.081$, $d = 0.48$, *95% CI*: -0.06, 1.02], anxiety [$t(52) = 0.94$, $P = 0.352$, $d = 0.26$, *95% CI*: -0.28, 0.79] and depression [$t(52) = 0.98$. $P = 0.330$, $d = 0.27$, *95% CI*: -0.27, 0.80] did not show the main effect of the menstrual cycle. The PANAS scale also showed no differences in the positive emotion [$t(52)$=-0.80, $P = 0.430$, d=-0.21, *95% CI*: 0, 0.73] and negative emotion [$t(52) = 1.12$, $P = 0.273$, $d = 0.30$, *95% CI*: -0.23, 0.84] among the two phase of menstrual cycle examined. STAI scores further showed no significant cycle effect [state anxiety ($t(52) = 0.12$, $P = 0.811$, $d = 0.03$, *95% CI*: -0.50, 0.57), trait anxiety ($t(52) = 1.47$, $P = 0.157$, $d = 0.40$, *95% CI*: -0.14, 0.94)].

A paired sample T-test was used to compare the differences in women's scale scores in early and late follicular phases. The results of DASS scale showed stress [$t(52)$=-0.76, $P = 0.450$, d=-0.21, *95% CI*: 0, 0.72], anxiety [$t(52)$=-0.48, $P = 0.633$, d=-0.13, *95% CI*: 0, 0.64] and depression [$t(52) = 0.07$. $P = 0.946$, $d = 0.02$, *95% CI*: -0.51, 0.55] did not show the main effect of the menstrual cycle. The PANAS scale also showed no differences in the positive emotion [$t(52) = 0.70$, $P = 0.492$, $d = 0.19$, *95% CI*: -0.35, 0.72] and negative emotion [$t(52)$=-0.85, $P = 0.407$, d=-0.23, *95% CI*: 0, 0.75] among the two phase of menstrual cycle examined. STAI scores further showed no significant cycle effect [state anxiety ($t(52)$=-0.51, $P = 0.617$, d=-0.14, *95% CI*: 0, 0.65), trait anxiety ($t(52)$=-0.73, $P = 0.470$, d=-0.20, *95% CI*: 0, 0.71)].

Hormone levels

A paired sample T-test was used to compare the differences in women's estradiol and progesterone levels in early and late follicular phases. The estradiol levels detected during early follicular and late follicular phases of the menstrual cycle showed significant differences [$t(52)$ = -4.39, $P < 0.001$, d=-1.19, *95% CI*: 0.62, 1.77], but no significant difference in progesterone levels [$t(52)$ = -0.32, $P = 0.754$, d=-0.09, *95% CI*: 0, 0.57]. Estradiol levels in the late follicular phase ($M = 7.39$) were higher than those of the early follicular phase ($M = 4.11$, $P = 0.005$), as shown in Fig. 2a.

A paired sample T-test was used to compare the differences in women's estradiol and progesterone levels in late follicular and mid-luteal phases. The levels of progesterone were significantly different between the late follicular phase and, and no significant difference in estradiol level [progesterone $t(52)$=-4.08, $P < 0.001$, d=-1.11, *95% CI*: 0.55, 1.68; estradiol $t(52) = 1.25$, $P = 0.216$, $d = 0.34$, *95% CI*: -0.20, 0.88]. Progesterone levels in the mid-luteal phase ($M = 167.23$) were significantly higher than those in the late follicular phase ($M = 85.49$, $p < 0.001$), as shown in Fig. 2b.

Reaction time

A 2 emotion type (positive or negative)×2 motivation type (approach or avoidance) ×2 menstrual cycle phase (early follicular phase or late follicular phase) repeated-measures ANOVA was performed to evaluate the reaction time. The main effect of the motivation type was significant [$F(1,26) = 14.02$, $P = 0.001$, $\eta_p^2 = 0.35$, *95% CI*: 0.08, 0.56] and the response time of approach motivation was significantly shorter than that of avoidance

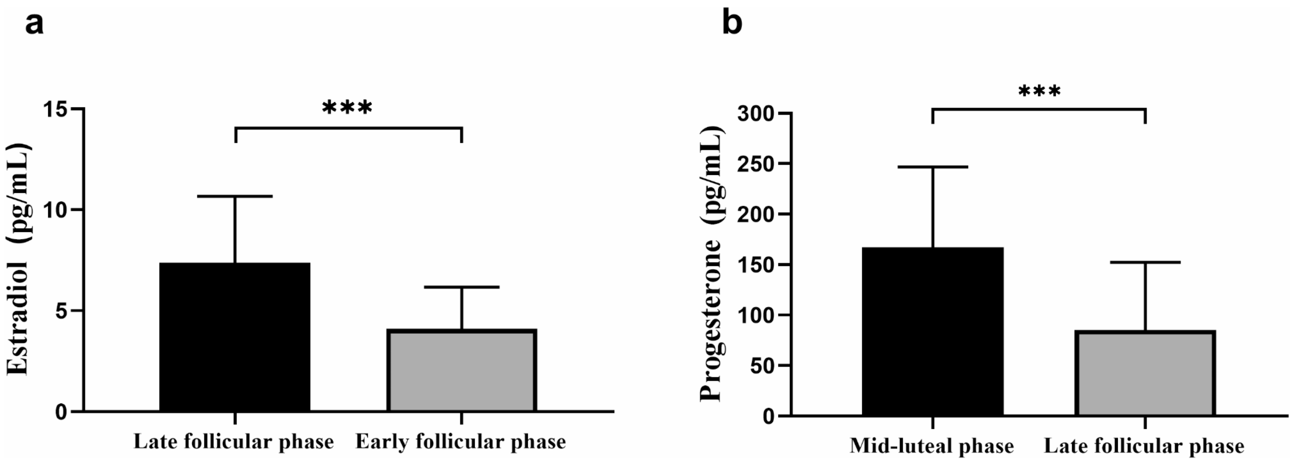

Fig. 2 Hormone levels. (**a**) Differences in the level of estradiol between the early follicular phase and late follicular phase. (**b**) Differences in the level of progesterone between the late follicular phase and mid-luteal phase. Error bars represent the standard error of the mean. *** $P < 0.001$

motivation (P=0.001). The interaction between emotion type and menstrual cycle was significant [F(1,26)=56.99, P<0.001, η_p^2 =0.69, *95% CI*: 0.44, 0.79], and the simple effect indicated that in the late follicular phase, the response to positive stimuli is faster than in the early follicular phase (938 ms vs. 1018 ms; P=0.002). And women in the late follicular phase, the response to negative stimuli is slower than in the early follicular phase (1017 ms vs. 969 ms; P=0.012). The interaction between emotion type and motivation type was significant [F(1,26)=13.17, P=0.001, η_p^2 =0.34, *95% CI*: 0.07, 0.55]. Simple effect analysis revealed that the approach response (925ms) was significantly faster than the avoidance response (1030ms) in the face of positive stimuli (P<0.001). The triple interaction of menstrual cycle, emotion type, and motivation type was significant [F(1,26)=6.87, P=0.010, η_p^2 =0.21, *95% CI*: 0.01, 0.44]. Simple effect analysis found that women in the late follicular phase (871 ms) had significantly shorter responses to approach positive stimuli than women in the early follicular phase (979 ms, P=0.002) (See Fig. 3a). No significant main effect of other factors, or interactions between factors, were observed (all Ps>0.05).

A 2 emotion type (positive or negative)×2 motivation type (approach or avoidance) ×2 menstrual cycle phase (late follicular phase or mid-luteal phase) repeated-measures ANOVA was performed to evaluate the reaction time. No significant main effect of factors were observed (all Ps > 0.05). The interaction between emotion type and menstrual cycle was significant [F(1,26) = 52.46, P < 0.001, η_p^2 =0.67, *95% CI*: 0.41, 0.78], and the simple effect indicated that in the mid-luteal phase, the response to negative stimuli is faster than in the late follicular phase (919 ms vs. 1019 ms; P<0.001). The interaction between motivation type and menstrual cycle was significant [F(1,26)=6.32, P=0.020, η_p^2 =0.20, *95% CI*: 0.01, 0.43], and the simple effect indicated that in the mid-luteal phase, the avoidance motivation is faster than approach motivation (P = 0.002). The interaction between emotion type and motivation type was significant [F(1,26)=38.97, P<0.001, η_p^2 =0.60, *95% CI*: 0.32, 0.73]. Simple effect analysis revealed that the approach response (895ms) was significantly faster than the avoidance response (1021ms) in the face of positive stimuli (P<0.001). And the avoidance response (909ms) was significantly faster than the approach response (1030ms) in the face of negative stimuli (P < 0.001). The triple interaction of menstrual cycle, emotion type, and motivation type was significant [F(1,26)=4.55, P=0.043, η_p^2 =0.15, *95% CI*: 0, 0.38]. Simple effect analysis found that women in the mid-luteal phase (824 ms) had significantly shorter responses to avoid negative stimuli than women in the late follicular phase (991 ms, P < 0.001) (See Fig. 3b).

The relationship between estradiol/progesterone levels and reaction time

Correlation analysis showed that estradiol levels correlated negatively with reaction times to a positive stimulus approach in early follicular phase [r=-0.41, P = 0.035; see also Fig. 4a]. Estradiol levels correlated negatively with reaction times to a positive stimulus approach in late follicular phase [r=-0.45, P = 0.019; see also Fig. 4b]. It revealed that the higher the estradiol level, the shorter the reaction time to approach positive stimulation.

Correlation analysis showed that progesterone levels correlated negatively with response times to negative stimulus avoidance in late follicular phase [r=-0.41,

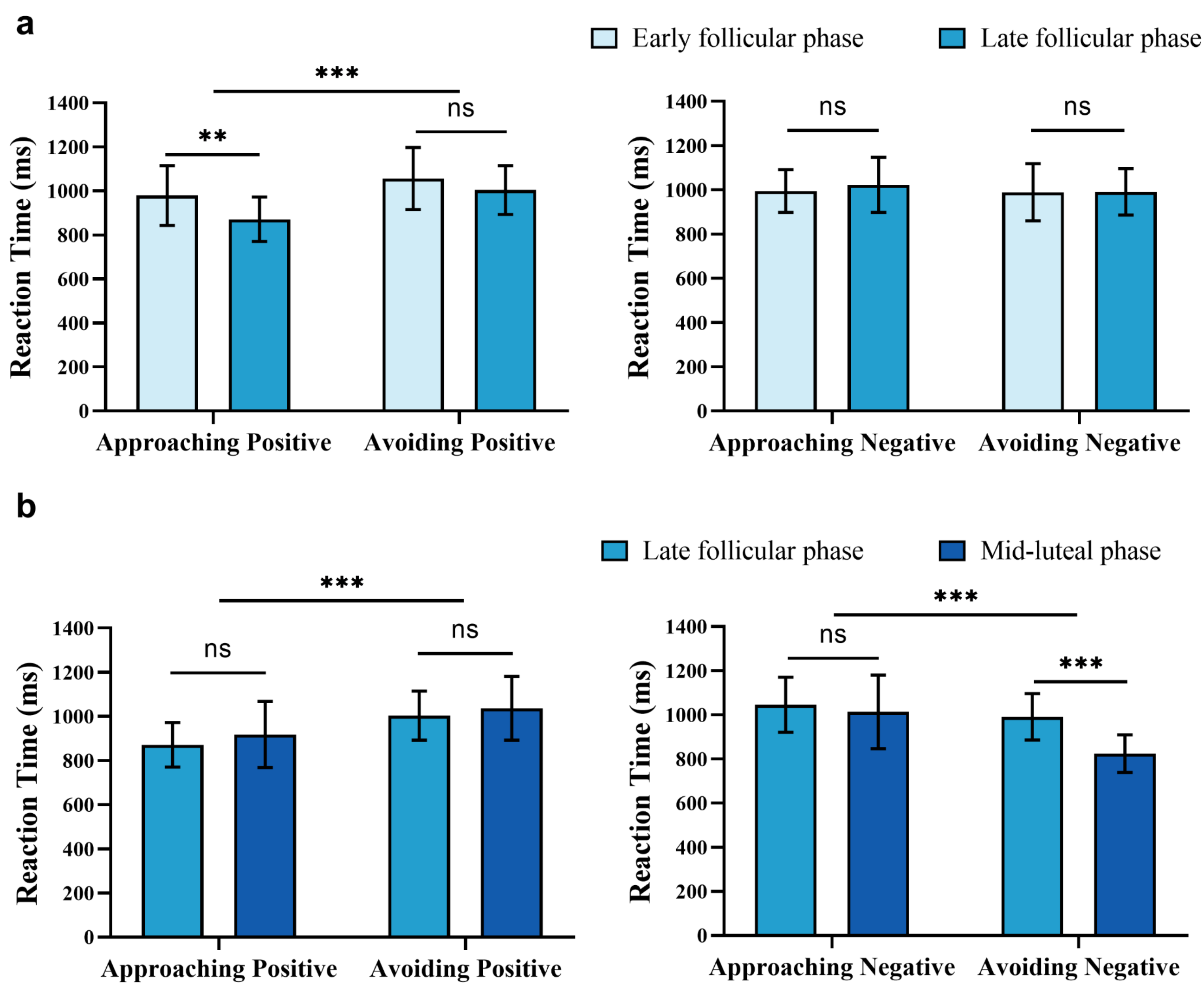

Fig. 3 Differences in reaction time across menstrual cycle phases. (**a**) Reaction time of the improved "manikin task" across the early follicular phase and late follicular phase. (**b**) Reaction time of the improved "manikin task" across the late follicular phase and mid-luteal phase. Error bars represent 95% confidence interval (*95% CI*) of the mean. *** $P<0.001$; ** $P<0.01$

$P=0.036$; see also Fig. 4c]. Progesterone levels correlated negatively with response times to negative stimulus avoidance in mid-luteal phase [r=-0.44, $P=0.021$; see also Fig. 4d]. It revealed that the higher the progesterone level, the shorter the reaction time to avoid negative stimulus.

ERPs results

ERP results on approach-avoidance behavior between early and late follicular phases

A 2(menstrual cycle phase: early follicular phase, late follicular phase)×2(emotion type: positive, negative)×2(motivation type: approach, avoidance) repeated measures ANOVA was performed to evaluate the peak value of P1, P2, N2 and the mean amplitude of LPP.

P1 Repeated measures ANOVA for P1 component peak value showed no significant main effects of menstrual cycle [$F(1,26)=0.07$, $P=0.801$, $\eta_p^2=0.01$, *95% CI*: 0, 0.10], emotion type [$F(1,26)=1.14$, $P=0.296$, $\eta_p^2=0.04$, *95% CI*: 0, 0.25], or motivation type [$F(1,26)=0.23$, $P=0.636$, $\eta_p^2=0.01$, *95% CI*: 0, 0.17], and no significant menstrual cycle, emotion type, and motivation type interaction [$F(1,26)=0.91$, $P=0.349$, $\eta_p^2=0.03$, *95% CI*: 0, 0.23].

P2 Repeated measures ANOVA for P2 component peak value showed no significant main effect of menstrual cycle

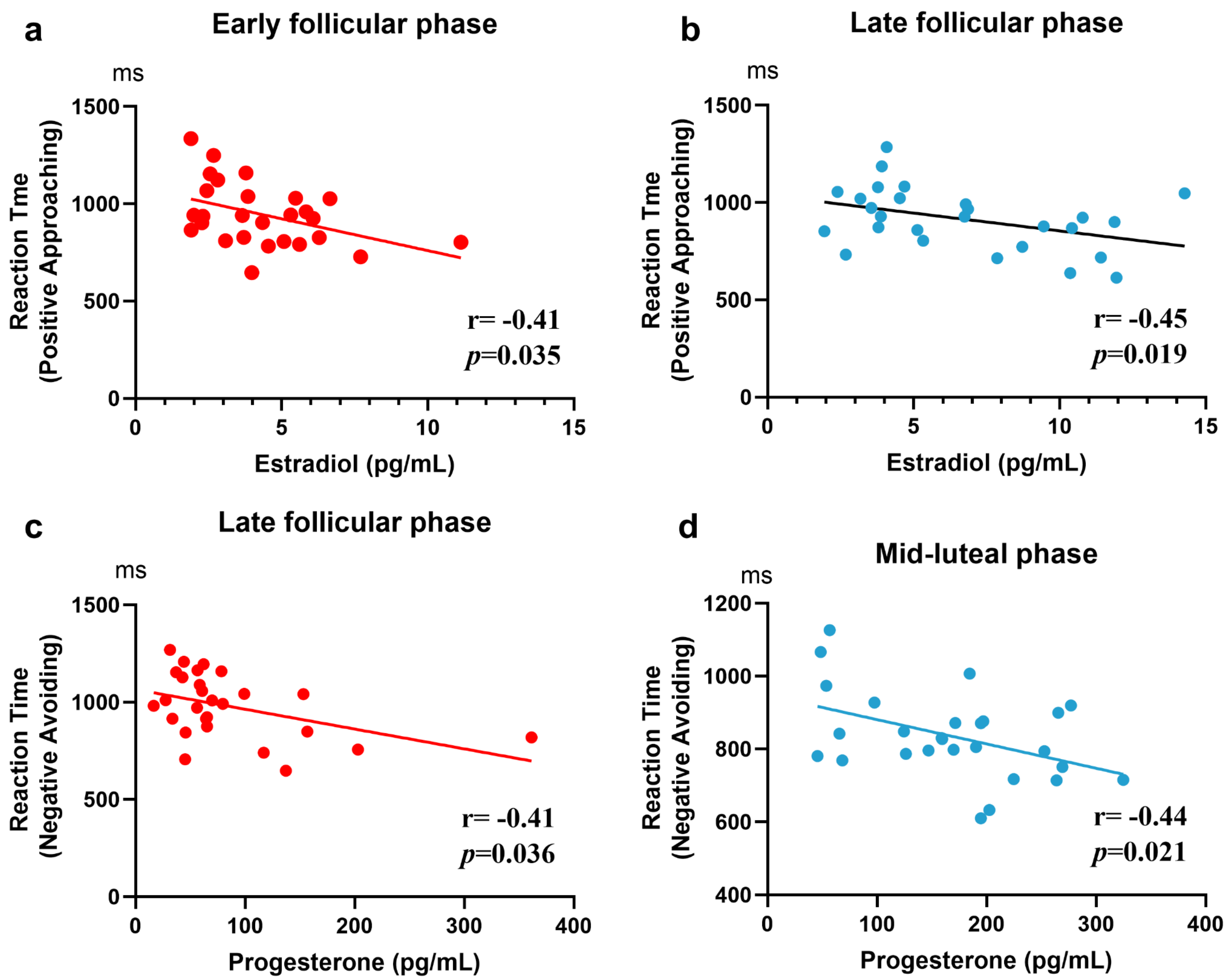

Fig. 4 Correlation analysis between estradiol / progesterone level and reaction time of approach-avoidance behavior. Correlation scatter plots between the level of estradiol and reaction time of positive-approaching in early follicular phase (**a**) and late follicular phase (**b**). Correlation scatter plots between the level of progesterone and reaction time of negative-avoiding in late follicular phase (**c**) and mid-luteal phase (**d**)

[F(1,26) = 1.29, P = 0.267, η_p^2 = 0.05, *95% CI*: 0, 0.26], emotion type [F(1,26)=0.01, P=0.928, η_p^2 =0.01, *95% CI*: 0, 0.02], and motivation type [F(1,26)=0.02, P = 0.894, η_p^2 =0.01, *95% CI*: 0, 0.03]. The triplex interaction of menstrual cycle, emotion type, and motivation type was significant [F(1,26)=4.43, P=0.045, η_p^2 =0.15, *95% CI*: 0, 0.38], and women in the late follicular phase induced higher P2 amplitudes (3.90 μV) when avoiding positive stimuli than women in the early follicular phase (1.89 μV, P = 0.007), see Fig. 5a.

N2 The main effect of emotion type was significant [F(1,26) = 5.92, P = 0.022, η_p^2 =0.19, *95% CI*: 0.01, 0.42], and the N2 amplitude induced by negative emotional stimuli (-4.56 μV) was significantly higher than that induced by positive stimuli (-3.85 μV, P=0.022). The main effect of motivation type was significant [F(1,26)=9.28, P = 0.005, η_p^2 =0.26, *95% CI*: 0.03, 0.49], and the N2 amplitude induced by avoidance motivation (-4.65 μV) was significantly higher than that induced by approach motivation (-3.76 μV, P = 0.005). The interaction between menstrual cycle and motivation type was significant [F(1,26)=26.57, P<0.001, η_p^2 =0.51, *95% CI*: 0.21, 0.67], the simple effect indicated that the N2 amplitude induced by approach motivation in the late follicular phase (-3.16 μV) was significantly lower than that in the early follicular (-4.35 μV, P = 0.001), and the N2 amplitude induced by avoidance motivation in the late follicular phase (-5.14 μV) was significantly higher than that in the early follicular

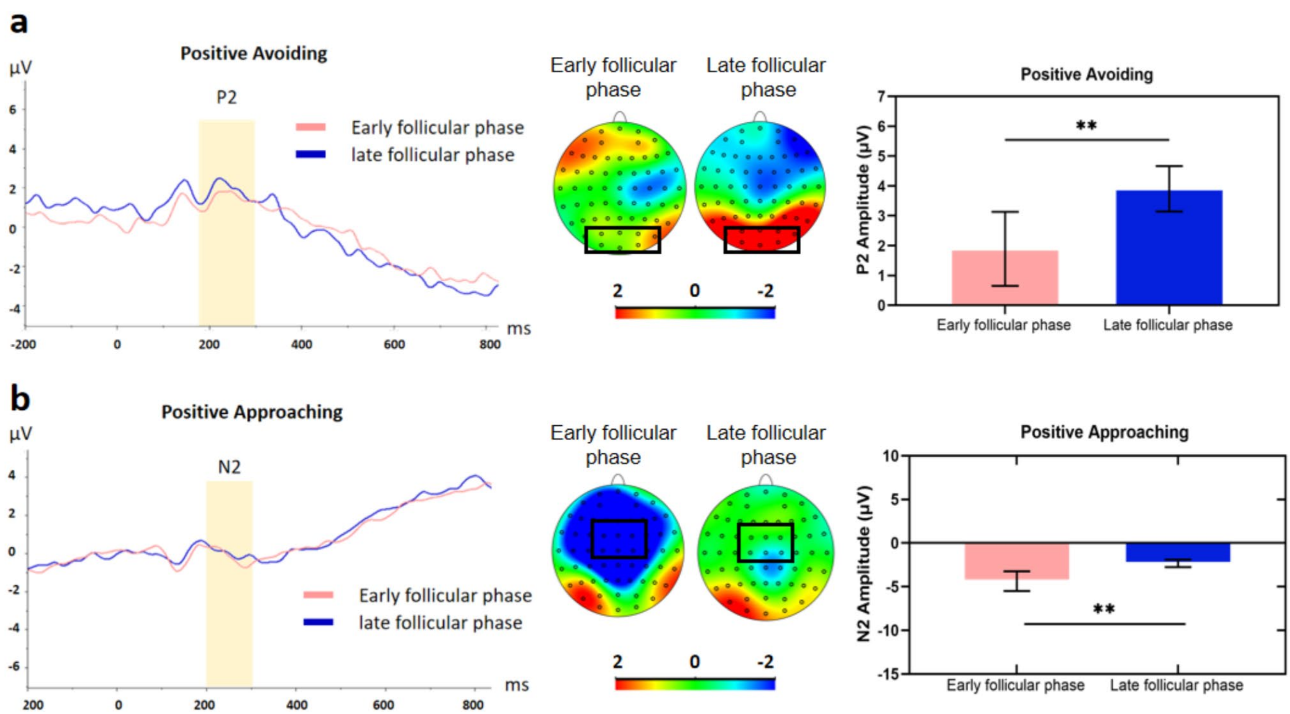

Fig. 5 The amplitude and topography of P2, N2 for avoiding/approaching positive stimuli across two cycle phases. (**a**) Grand average ERP waveforms, scalp topography maps, and average amplitudes of P2 for avoiding positive stimuli during the early follicular, and late follicular phases recorded across electrodes POz, PO3, PO4, Oz, O1, and O2. (**b**) Grand average ERP waveforms, scalp topography maps, and average amplitudes of N2 for approaching positive stimuli during the early follicular, and late follicular phases recorded across electrodes Fz, FC3, FCz, FC4, and Cz. Error bars represent 95% confidence interval (*95% CI*) of the mean. ** $P < 0.01$

(-4.16 μV, P=0.007). The triplex interaction of menstrual cycle, emotion type, and motivation type was significant [F(1,26)=5.04, P=0.034, η_p^2 =0.16, *95% CI*: 0, 0.40]. Women in the late follicular phase (-2.34 μV) induced a significantly smaller N2 amplitude when approaching positive stimuli than women in the early follicular phase (-4.37 μV, $P = 0.002$). Women in the late follicular phase (-4.95 μV) induced a significantly higher negative N2 wave when avoiding positive stimuli than women in the early follicular phase (-3.76 μV, $P = 0.004$). No other main effects and interactions were significant (see also Fig. 5b).

LPP Repeated measures ANOVA for LPP component amplitude showed no significant main effects of menstrual cycle [F(1,26) = 0.58, $P = 0.454$, η_p^2 = 0.02, *95% CI*: 0, 0.21] (see also Fig. 6b), emotion type [F(1,26)=2.16, P=0.153, η_p^2 = 0.08, *95% CI*: 0, 0.30] (see also Fig. 6a), or motivation type [F(1,26)=0.49, $P = 0.489$, η_p^2 = 0.02, *95% CI*: 01, 0.20], and no significant menstrual cycle, emotion type, and motivation type interaction [F(1,26) = 0.13, P=0.727, η_p^2 = 0.01, *95% CI*: 0, 0.15].

ERP results on approach-avoidance behavior between late follicular and mid-luteal phases

A 2(menstrual cycle phase: late follicular phase, mid-luteal phase)×2(emotion type: positive, negative)×2(motivation type: approach, avoidance) repeated measures ANOVA was performed to evaluate the peak value of P1, P2, N2 and the mean amplitude of LPP.

P1 Repeated measures ANOVA for P1 component peak value showed that a significant main effect for emotion type [F(1,26) = 12.91, $P = 0.001$, η_p^2 = 0.33, *95% CI*: 0.06, 0.54], but not for menstrual cycle phase [F(1,26)=1.94, P=0.175, η_p^2 = 0.07, *95% CI*: 0, 0.29] and motivation type [F(1,26)=0.99, $P = 0.329$, η_p^2 = 0.04, *95% CI*: 0, 0.24]. Further analyses indicated that positive stimuli (2.36 μV) induced greater P1 amplitudes than negative stimuli (1.49 μV). The triplex interaction of menstrual cycle, emotion type, and motivation type was significant [F(1,26)=4.39, P=0.046, η_p^2 = 0.15, *95% CI*: 0, 0.38], and women in the

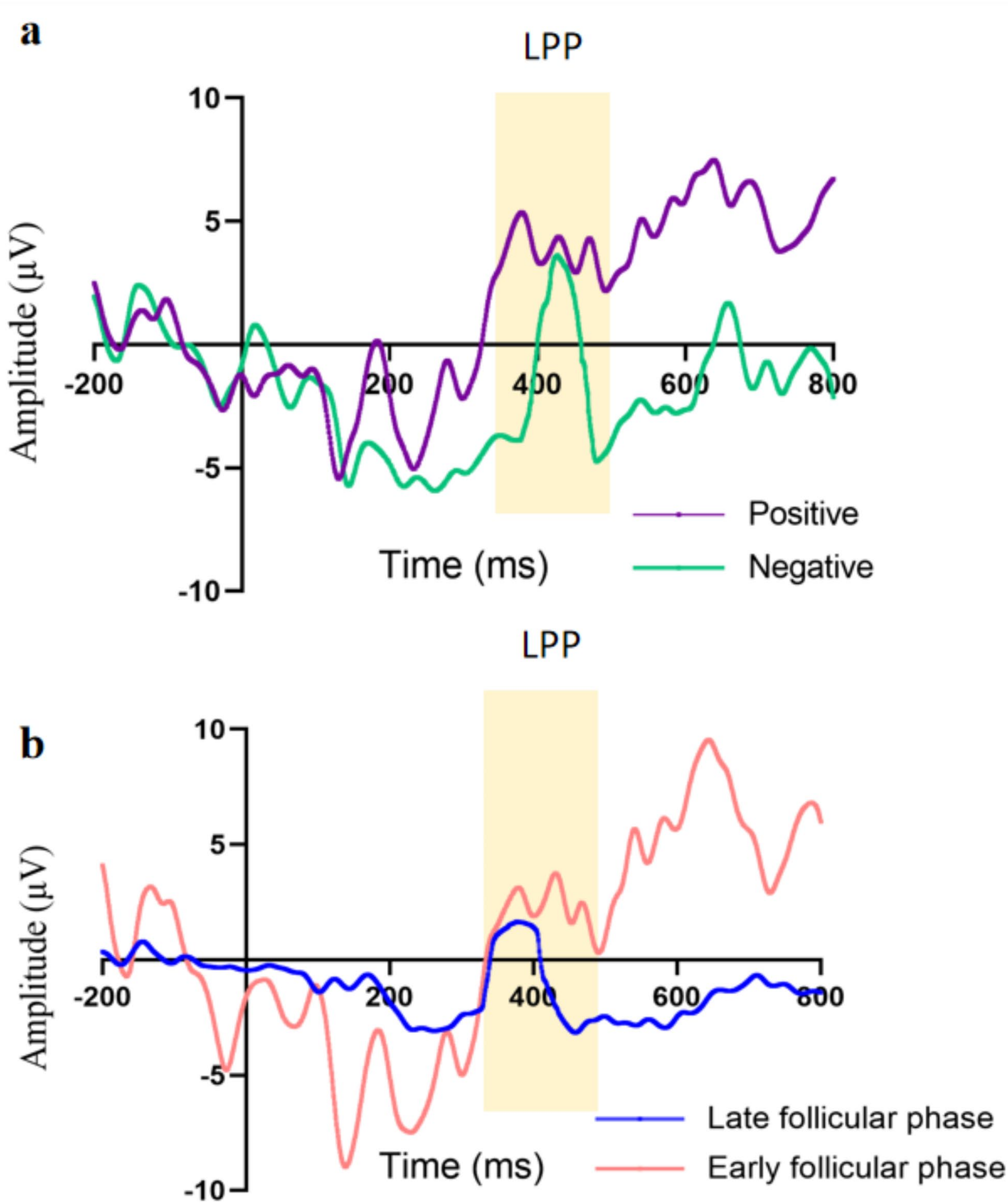

Fig. 6 Grand average ERP waveforms of LPP for emotion type (**a**) and menstrual cycle phase (**b**) recorded at electrodes CP1, CP2, and CPZ

mid-luteal phase stimulated smaller P1 amplitudes (0.77 μV) when avoiding negative stimuli than women in the late follicular phase (2.02 μV, $P=0.002$) (see also Fig. 7a).

P2 Repeated measures ANOVA for P2 component peak value showed no significant main effect of menstrual cycle [$F(1,26)=0.18$, $P=0.676$, $\eta_p^2=0.01$, *95% CI*: 0, 0.16], emotion type [$F(1,26)=2.81$, $P=0.105$, $\eta_p^2=0.10$, *95% CI*: 0, 0.33], and motivation type [$F(1,26)=0.38$, $P=0.543$, $\eta_p^2=0.01$, *95% CI*: 0, 0.19]. The interaction between emotion type and motivation type was significant [$F(1,26)=6.65$, $P=0.020$, $\eta_p^2=0.20$, *95% CI*: 0.01, 0.43]. Positive stimulus approach induced smaller P2 amplitudes (2.95μV) than positive stimulus avoidance (3.90 μV, $P=0.043$).

N2 The main effect of emotion type was significant [$F(1,26)=9.79$, $P=0.004$, $\eta_p^2=0.27$, *95% CI*: 0.03, 0.49], and the N2 amplitude induced by negative emotional stimuli (-4.45 μV) was significantly higher than that induced by positive stimuli (-3.44 μV, $P=0.004$). The main effect of motivation type was significant [$F(1,26)=5.81$, $P=0.023$, $\eta_p^2=0.18$, *95% CI*: 0.01, 0.41], and the N2 amplitude induced by avoidance motivation (-4.21 μV) was significantly higher than that induced by approach motivation (-3.68 μV, $P=0.023$). The interaction between menstrual cycle and motivation type was significant [$F(1,26)=17.69$, $P<0.001$, $\eta_p^2=0.41$, *95% CI*: 0.12, 0.60], The simple effect indicated that the N2 amplitude induced by approach motivation in the mid-luteal phase (-4.20 μV) was significantly higher than that in the late follicular phase (-3.16 μV, $P=0.012$), and the N2 amplitude induced by avoidance motivation in the mid-luteal phase (-3.28 μV) was significantly lower than that in the late follicular (-5.14 μV, $P=0.003$). The interaction between emotion type and motivation type was significant [$F(1,26)=24.99$, $P<0.001$, $\eta_p^2=0.49$, *95% CI*: 0.19, 0.66]. Positive stimulus approach induced smaller N2 amplitudes (2.56 μV) than positive stimulus avoidance (-4.33 μV, $P<0.001$). The triplex interaction of menstrual cycle, emotion type, and motivation type was significant [$F(1,26)=4.92$, $P=0.036$, $\eta_p^2=0.16$, *95% CI*: 0, 0.39]. Women in the mid-luteal

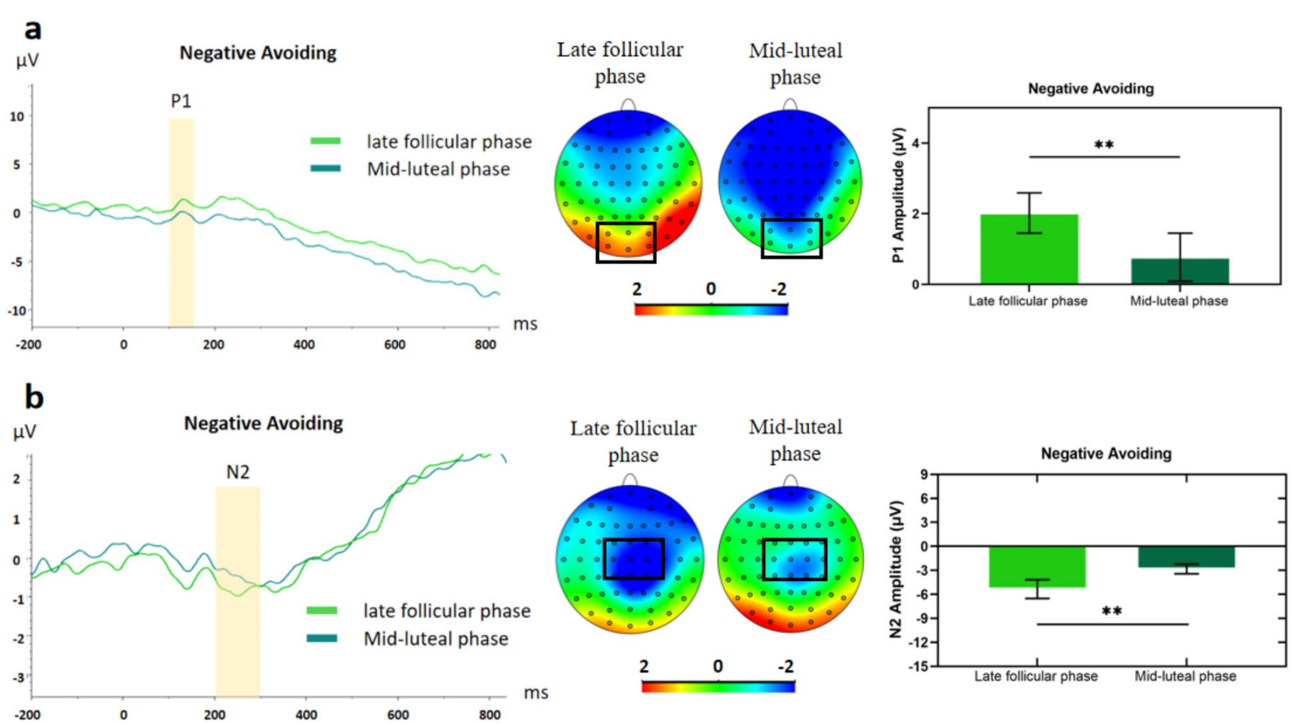

Fig. 7 The amplitude and topography of P1, N2 for approaching/avoiding emotional stimuli across two cycle phases. (**a**) Grand average ERP waveforms, scalp topography maps, and average amplitudes of P1 for avoiding negative stimuli during the late follicular, and the mid-luteal phases recorded across electrodes PO7, PO8, Oz. (**b**) Grand average ERP waveforms, scalp topography maps, and average amplitudes of N2 for approaching positive stimuli during the late follicular, and the mid-luteal phases recorded across electrodes Fz, FC3, FCz, FC4, and Cz. Error bars represent 95% confidence interval (*95% CI*) of the mean. ** $P<0.01$

phase (-2.84 μV) induced a significantly smaller N2 amplitude when avoiding negative stimuli than women in the late follicular phase (-5.34 μV, *P*=0.001) (see also Fig. 7b). Women in the mid-luteal phase (-5.62 μV) induced a significantly higher negative N2 wave when approaching negative stimuli than women in the late follicular phase (-3.98 μV, *P*=0.008). No other main effects and interactions were significant.

LPP Repeated measures ANOVA for LPP component amplitude showed no significant main effects of menstrual cycle [$F(1,26)=0.88$, $P=0.358$, $\eta_p^2=0.03$, *95% CI*: 0, 0.23] (see also Fig. 8b), emotion type [$F(1,26)=2.26$, $P=0.15$, $\eta_p^2=0.08$, *95% CI*: 0, 0.30] (see also Fig. 8a), or motivation type [$F(1,26)=1.15$, $P=0.294$, $\eta_p^2=0.04$, *95% CI*: 0, 0.25], and no significant menstrual cycle, emotion type, and motivation type interaction [$F(1,26)=0.01$, $P=0.959$, $\eta_p^2=0.01$, *95% CI*: 0, 0.02].

Discussion

The effect of menstrual cycle phases with different Estrogen levels on approach-avoidance behavior and its ERP characteristics

Analysis 1 mainly explored the relationship between female estradiol levels and approach-avoidance behavior, how female approach-avoidance behavior was affected by the menstrual cycle and its neurophysiological characteristics. The results confirmed the hypothesis that estradiol levels were negatively correlated with the reaction time of women's positive-approaching behavior, indicating that higher estradiol levels in women predicted the higher efficiency of their positive-approaching behavior. Women in the late follicular phase induced a smaller N2 wave than those in the early follicular phase when they approached positive stimulation.

The behavioral results were consistent with the results of Li's study in 2022, which found that estradiol levels were negatively correlated with the response time to approach positive stimulation. Women in late follicular phase with high estradiol levels approached positive stimulation more quickly [5]. Furthermore, one study focused on the pathways by which ovarian hormones affected the behavior activating system (BAS) and the behavior inhibiting system (BIS), and showed that at the behavioral level, estradiol levels were negatively correlated with BIS scores when progesterone levels were low. For this reason, the higher the estradiol level, the weaker the function of the BIS [41]. As for the explanation of behavioral results, from an evolutionary perspective, Darwin (1871) pointed out that women in the late follicular phase had a high risk of conception. And individuals would undergo a series of changes in appearance and behavior to obtain resources closely related to spouses and offspring during the late follicular phase, so as to maximize their benefits [42]. Therefore, it may be an evolutionary consequence that women in the late follicular phase approach positive stimuli more quickly and engage in more profit-seeking behaviors, which will be more conducive to access to high-quality resources and create favorable conditions for possible conception and breeding of offspring. From a neurobiological perspective, researchers have found that the dopaminergic system in the brain of ovulating women is more sensitive to positive stimulation, and estrogen plays a key role in regulating it [43]. Dopamine is a neurotransmitter associated with reward and pleasure, and elevated estrogen increases the activity of dopaminergic neurons, which may prompt women to more actively approach positive stimulation to obtain more rewarding experiences.

The ERP results also provided electrophysiological evidence for the behavioral results, which showed that women in late follicular phase had smaller N2 amplitude when they approached positive stimulation. In the SRC effect, when both the intuitive response and the instructed response tendencies were simultaneously activated, the fronto-central N2 ERP as indicator of early response inhibition on the level of response representations prior to response selection [13, 14, 44, 45]. The results showed that women in late follicular phase approached positive stimulation with stronger automatic processing and weaker inhibitory processing than women in the early follicular phase, which led them to approach positive stimulation more quickly. Previous research supports this finding. For example, during the late follicular phase, females demonstrated a greater desire for rewards such as genetic drugs, money, and high-calorie food. Compared with mid-luteal women, they were less likely to self-control behaviors such as smoking cessation and diet control [46]. Moreover, N2 is a good neural index of attentional shifts [14] and is also sensitive to dynamic changes in attention resources [47]. Therefore, the N2 result of this study reflects that women in the late follicular phase will more quickly and effectively shift their attention to approaching positive stimuli and spend less attention and cognitive resources than women in the early follicular phase.

In addition, the possible underlying reason of this result might also be related to emotional states. Van's research has found that when women were in the late follicular phase with high estradiol levels, they showed more positive and pleasant emotional states in response to positive stimulation, and their emotional receptivity score was higher [48]. A significant reduction in depressive symptoms had also been observed in postmenopausal

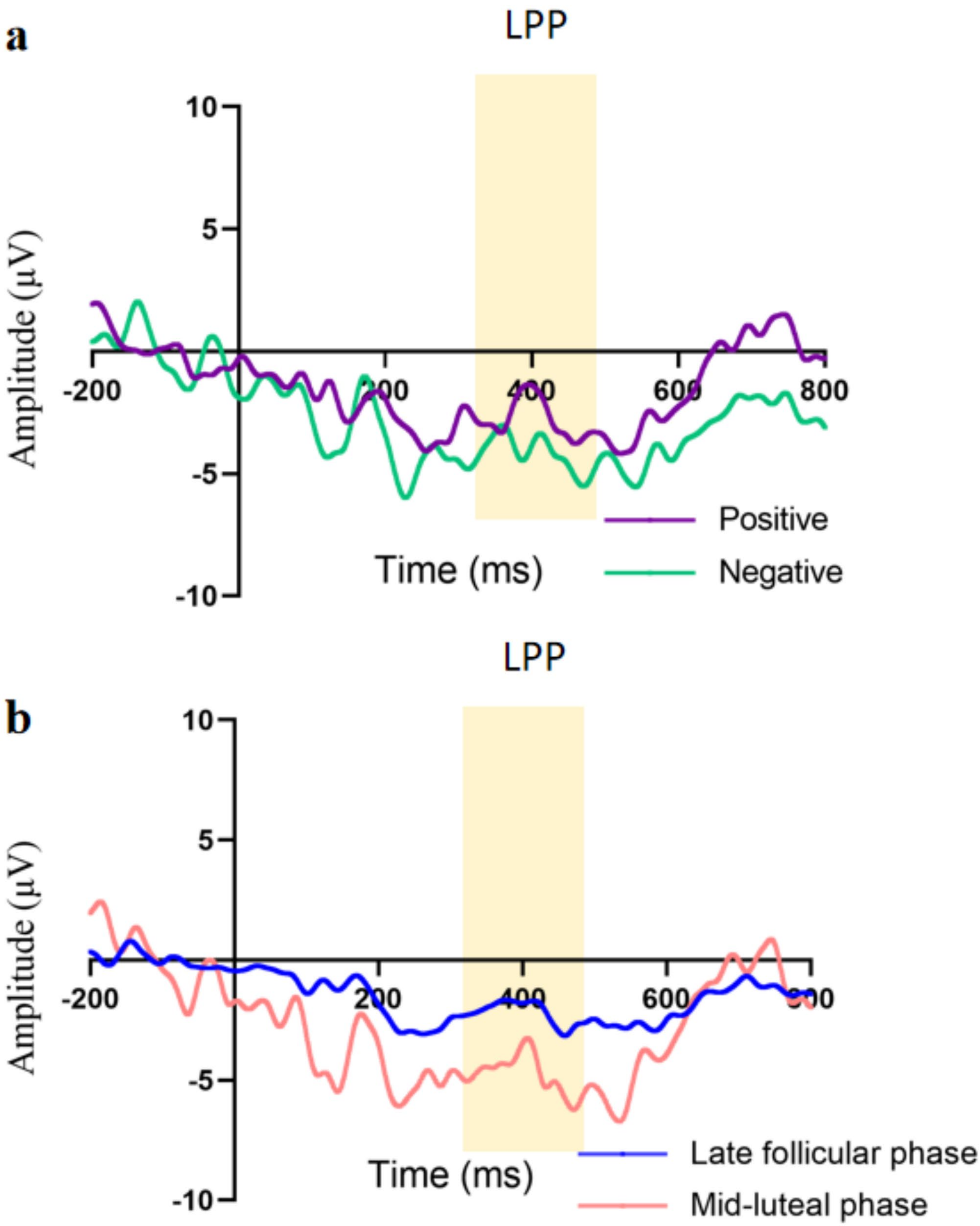

Fig. 8 Grand average ERP waveforms of LPP for emotion type (**a**) and menstrual cycle phase (**b**) recorded at electrodes CP1, CP2, and CPZ

women by injecting them with exogenous estradiol [49]. Therefore, women in the late follicle phase may feel more positive and friendly emotional states in response to positive stimuli than those in other phases, thus making the approach motivation stronger and activating the behavioral approach system more effectively. This conjecture needs to be further explored in the future.

ERP results did not find the main effect and interaction of menstrual cycle, emotional type and motivation type in LPP components. Previous studies (2017) also found that LPP had no significant difference in menstrual phase [20]. The LPP component not only reflects the deep processing and classification of stimuli [17, 50], also reflects how much psychological resources people invest [18]. Therefore, the results of this study reflect that the influence of estradiol levels on the motivational processing of emotional stimuli does not require in-depth processing and does not require excessive consumption of psychological resources. The reason for the non-significant difference in LPP may be related to the fact that the task in this study required rapid decision making, which may inhibit later cognitive processing.

The effect of menstrual cycle phases with different progesterone levels on approach-avoidance behavior and its ERP characteristics

Analysis 2 mainly explored the relationship between female progesterone level and approach-avoidance behavior, how female approach-avoidance behavior was affected by the menstrual cycle and its neurophysiological characteristics. The results confirmed the hypotheses that the women in the middle luteal phase avoided negative stimuli more quickly than women in other phases, and progesterone level was negatively correlated with the reaction time of female harm-avoidance behavior. The higher the level of progesterone could predict the higher the efficiency of their harm-avoidance behavior. Women in the middle luteal phase induced smaller P1 and N2 waves than those in the late follicular phase when they avoided negative stimuli.

The behavioral results showed that women in the high progesterone phase (mid-luteal phase) had stronger and faster avoidance motivation and avoidance behavior to the stimuli with negative stimuli. This was consistent with the results of Li's study in 2022, which found that progesterone levels were negatively correlated with the response time of harm avoidance behavior, and women in the mid-luteal phase with high progesterone avoided negative stimuli faster [5]. The results were supported by a number of previous studies, which found that during the luteal phase, the physiological changes in a woman's body to prepare for a possible pregnancy were accompanied by psychological changes caused by hormonal fluctuations. Psychological changes observed include increased social surveillance [51], increased vigilance against physical threats [12], and sensitivity to infectious sources [52, 53]. For example, women were more likely to show an aversion to certain foods during the luteal phase, especially those foods that might be a source of pathogens [54]. This strong motivation to avoid harm during the luteal phase of high progesterone levels may be related to protecting one's own health.

The ERP results provide deeper electrophysiological evidence for the behavioral results, which showed that P1 amplitude induced by women in middle luteal phase was significantly smaller than that of women in late follicular phase when they avoided negative stimuli. P1 was in the first stage of emotional processing, which reflected the automatic or rapid processing of emotional information [55]. The results revealed that women in the middle luteal phase processed habitual motivations such as avoidance of negative stimuli more quickly than women in other cycles, and that integration occurred in the early stages of emotional processing. In addition, women induced smaller N2 waves during the middle luteal phase when they avoided negative stimuli than during other phases. Changes in prefrontal and central N2 ERP were associated with early response inhibition processes [13, 14]. Therefore, ERP N2 results suggested that women in the middle luteal phase had weaker inhibitory processing of avoidance of negative stimuli than women in the late follicular phase, which led to faster avoidance behavior of negative stimuli. Moreover, N2 is a good neural index of attentional shifts [14] and is also sensitive to dynamic changes in attention resources [47]. Therefore, the N2 result of this study reflects that women in the mid-luteal phase will more quickly and effectively shift their attention to avoiding negative stimuli and spend less attention and cognitive resources than women in the late follicular phase.

Behavioral and ERP results were also supported by the 'parental investment theory', which suggested that women in the mid-luteal phase devoted more thought to creating a more stable and secure environment for their children [56]. Many studies have also confirmed that women in the luteal phase were more involved in paying attention to threats around them to keep themselves and their children away from material deprivation and danger [12]. Therefore, women's faster motivation to avoid negative stimuli during the mid-luteal phase was also related to their evolutionary nature to protect their unborn babies from harm.

As for the reason of the relationship between progesterone levels and harm avoidance behavior, studies have also shown that exogenous injections of progesterone could increase the level of negative emotions in women in the early follicular phase and menopause [57]. Therefore, women in the middle luteal phase may feel more negative emotional states in response to negative stimuli than in other phases, which leads to their stronger avoidance motivation and faster avoidance behavior to negative stimuli.

Similar to the results of experiment 1, ERP results does not find the main effect and interaction of menstrual cycle, emotional type and motivation type in LPP components, which reflects that the influence of progesterone level on the motivational processing of emotional stimuli does not require in-depth processing and does not require excessive consumption of psychological resources. In a study that explored the process of inhibition in emotional regulation tasks, there was also no significant difference in LPP between menstrual cycle phases [20]. The reason for the non-significant difference in LPP may be related to the fact that the task in this study required rapid decision making, which may inhibit later cognitive processing.

Strengths and limitations

Approach-avoidance behavior was crucial to human survival and development, and female motivational behaviors for favorable and unfavorable things adjusted with hormonal changes to better protect themselves and future offspring. The innovation of this study was that ERP technology was used for the first time to study the characteristics and electrophysiological mechanism of female avoidance behavior in different menstrual cycles. The findings of this study may provide greater insight to women regarding the physiological influences of the menstrual cycle on their personal growth and security. This study also expanded the research on the neural mechanism of the effect of female ovarian hormone on psychological behavior, and the discovery of the cognitive mechanism of the effect of sex hormone level on female approach-avoidance behavior lays the foundation for further exploration of its complex mechanism in the future.

However, our study was limited by several factors. First, sex hormone secretion is affected by both physiology and psychology, and there were individual differences in the regularity of each woman's menstrual cycle, saliva detection could only determine its sex hormone levels after the experiment. We relied on the reciprocal method and luteinizing hormone tests that are not perfectly accurate in determining the highest progesterone point of the mid-luteal phase; female participants were in or near the mid-luteal phase. In addition, we did not measure prolactin and oxytocin, which also increase in the late follicular phase [58] and should be considered and controlled in future studies. In terms of statistical methods, we acknowledge that while repeated-measures ANOVA is common in ERP studies, mixed-effects models could be considered in future research to better handle inter-individual variability. Finally, insufficient sample size is also one of the shortcomings of our study. In the future, it is suggested that researchers increase the sample size to increase the representativeness and applicability of the conclusions to the whole population.

Conclusion

In this study, event-related potential (ERP) technology was used to explore the specific manifestation and electrophysiological mechanism of the influence of menstrual cycle on female approach-avoidance behavior. The results not only found that the levels of estradiol and progesterone were related to the efficiency of female approach-avoidance behavior. Women in the late follicular phase approached positive stimuli more quickly, and N2 amplitudes were the smallest for impulsive benefit-approach reaction. Women in the mid-luteal phase avoided negative stimuli more quickly, and P1/N2 amplitudes were the smallest for impulsive harm-avoidance reaction. The findings of this study provide electrophysiological evidence that changes in female ovarian hormones can predict changes in social behavior. Future research could focus on women's health, safety and development in more fields, such as female athletes and female employees, and explore more influencing factors.

Abbreviations

ERPs	Event-Related Potentials
EEG	Electroencephalography
SRC	Stimulus- Response Compatibility
MN	Moderately Negative
HN	Highly Negative
RISM	Prospective Record of the Impact and Severity of Menstrual symptoms
DASS	Depression, Anxiety and Stress Scale
STAI	State-Trait Anxiety Inventory
PANAS	Positive Affect and Negative Affect Scale
IAPS	International Affective Picture System
VEOG	Vertical Electromyography
HEOG	Horizontal Electromyography
ICA	Independent Component Analysis
BAS	Behavior Activating System
BIS	Behavior Inhibiting System

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Author contributions

Authors DL, and XW designed the study. DL, CX, and XW participated in the conception of the study. DL managed and conducted the statistical analyses and interpreted the data. DL and XW wrote the first draft, and DL, CX, and XW revised it to make the final manuscript. All authors have approved the final version of the manuscript.

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Data availability

The datasets generated for this study are available on request to the corresponding author.

Declarations

Ethics approval and consent to participate
This study was approved by the Ethics Committee of Shanghai University of Sport [102772022RT120], and it was conducted in accordance with the ethical standards of the Declaration of Helsinki. All methods were carried out in accordance with relevant guidelines and regulations of Shanghai University of Sport. Participants were informed that their names and institution names would be kept confidential and their privacy rights were protected. Participants were included in the process on a voluntary basis and informed consent was obtained from all participants.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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