



Eye movement pattern of attention bias to emotional stimuli in women with high premenstrual symptoms

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ABSTRACT

Background and objectives: Premenstrual Syndrome (PMS) refers to a group of symptoms linked to the menstrual cycle. Women with PMS have cognitive mode of rumination, which leads to their attention bias to emotional stimuli. This study investigated the biases for emotional information in women with high premenstrual symptoms (HPMS) compared with women with low premenstrual symptoms (LPMS).

Methods: A total of 38 women with HPMS and 44 women with LPMS completed self-report questionnaires and a free viewing task with eye-tracking technology.

Results: The questionnaire results indicate that women in the HPMS group had higher levels of rumination than those in the LPMS group. The eye-tracking results show that women in the HPMS group had an orientation bias towards negative emotional stimuli in the early cognitive process. In the late cognitive process, women in the HPMS group had accelerated attentional disengagement to positive emotional stimuli and difficult attentional disengagement to negative emotional stimuli. Further correlation analysis revealed positive relationships between the scores of initial fixation latency bias of positive pictures in premenstrual phase and the scores of symptom rumination in both groups and between the scores of initial fixation latency bias of positive pictures in premenstrual phase and the scores of brooding in HPMS group.

Limitations: This study used a retrospective questionnaire to assess the symptoms of PMS.

Conclusions: Women with HPMS had impaired attentional engagement and disengagement to emotional stimuli compared with women with LPMS, and it may be related to their cognitive mode of rumination.

1. Introduction

Premenstrual syndrome (PMS) refers to a series of physiological, emotional, and behavioral symptoms among the women of reproductive age. These symptoms appear periodically in the luteal phase, with remission generally occurring within 3 days after the onset of menses, and interfere with daily functioning (Yonkers, O'Brien, & Eriksson, 2008). PMS is characterized by a combination of symptoms such as irritability, depression, anxiety, and breast tenderness (Qiao et al., 2012).

Studies have found that women with PMS have a cognitive mode of rumination (Craner, 2014; Craner, Sigmon, Martinson, & McGillicuddy, 2014; Craner, Sigmon, & Young, 2015). Rumination is a negative cognitive style, which refers to recurrent negative thinking about the causes and various possible negative consequences, without proactive problem-solving (Nolen-Hoeksema, 1991). Hunter (2003) proposed a cognitive model for women with PMS by arguing that negative cognitive

appraisal of premenstrual changes may help explain the pathogenesis of PMS. Studies have shown that women with PMS reported a higher level of trait rumination than women without PMS (Craner, Sigmon, & Young, 2015), and that the level of trait rumination predicted the severity of PMS (Craner, 2014). Participants in the PMS group also showed more ruminant responses to negative emotions than those in the control group in a laboratory setting (Craner, Sigmon, & Young, 2015). The cognitive model of rumination may play an important role in elaborating the cognitive-emotional process in women with PMS (Takano & Tanno, 2008).

Recent studies found that attention biases (ABs) are associated with rumination (e.g., Armstrong & Olatunji, 2012; Kaiser et al., 2018). ABs are defined as a tendency to attend to a certain type of stimulus over others during emotional information processes (Beckwe & Deroost, 2016). ABs are driven by two components: attentional engagement and attentional disengagement (Posner, Inhoff, Friedrich, & Cohen, 1987).

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Attentional engagement refers to the selection and initial orientation of attention toward stimuli in the early cognitive process, whereas attentional disengagement refers to the withdrawal of attention from stimuli in the late cognitive process (Hollingworth, 2008). ABs may be caused by faster or more frequent initial orientation of attention to related stimuli, or impaired attentional disengagement. The impaired attentional disengagement leads to difficulty in diverting the attention away from the related negative stimuli and in the maintenance of related positive (Clarke, MacLeod, & Guastella, 2013). In addition to the static level of attentional engagement and disengagement involved in the ABs, the dynamic processes underlying attentional engagement and disengagement are also involved in the ABs to information, manifested as returning to stimuli repeatedly (Roy-Charland, Plamondon, Homeniuk, Fleisch, & Stewart, 2017).

Rumination is characterized by biased attentional processing of negative information (Owens & Gibb, 2016). For example, individuals with higher levels of trait rumination showed more ABs toward negative information (Koster, Derakshan, & Raedt, 2011). Studies have also shown that rumination and ABs are interrelated and affected by mood status such as anxiety and depression. High-anxiety individuals had stronger ABs under the condition of inducing rumination than that of inducing distraction, whereas low-anxiety individuals showed no ABs (Essmann & de Jong-Meyer, 2008). Depressed individuals with a high level of trait rumination were associated with difficulty in attentional disengagement from depression-related information (Grafton, Southworth, Watkins, & MacLeod, 2016). The difficulty of disengagement from depression-related information was found to be associated with trait rumination, but not state rumination (Donaldson, Lam, & Mathews, 2007). Armstrong and Olatunji (2012) reported that anxious individuals showed increased initial attention to threat stimuli, but no difficulty to disengage from threat stimuli. Conversely, depressed individuals did not show any increase in the initial attention to threat stimuli. Although these studies only focused on the static level of ABs, they all revealed that the affecting disorders were associated with different characteristics of altered ABs, which were closely related to rumination.

One most recent study further investigated ABs with regard to the emotional information of women with PMS (Eggert, Kleinstäuber, Hiller, & Witthöft, 2017). Researchers used the emotional Stroop paradigm with emotional words, pictures, and faces and found that participants in the PMS group had ABs toward negative emotional information. Compared to those in the control group, participants in the PMS group showed greater emotional Stroop effect to picture and facial stimuli. However, no significant difference was observed between the PMS and control groups on Stroop effects to word stimuli. With respect to the facial stimuli, researchers also found a type of paradox effect (Stroop facilitation) in the PMS group; i.e., emotional stimuli accelerated the speed of cognitive processing. An earlier study indicated that emotional Stroop tasks could not distinguish between the attentional engagement or disengagement of ABs (Jansen, Nederkoorn, & Mulkens, 2005). It is unclear whether the contradiction of the Stroop effect to different stimuli can be attributed to the acceleration of attentional engagement or the impaired attentional disengagement. Because the traditional AB paradigms heavily rely on the speculative cognitive process by measuring the reaction time; the components and the process of ABs cannot be directly observed. Additionally, it also ignores the dynamics of attentional processing involved in the ABs (Roy-Charland et al., 2017). Because eye-tracking technology has been used in the research of attentional engagement and allows for direct and continuous measurements of overt visual attention, researchers recently proposed that eye-tracking technology could provide an important supplement to reaction time measures (Armstrong, Sarawgi, & Olatunji, 2012).

Based on previous research, this study used the paired emotional picture-viewing paradigm with eye-tracking technology to examine the components, process, and dynamics of emotional information's ABs by comparing women with high premenstrual symptoms (HPMS) and women with low premenstrual symptoms (LPMS). As mentioned above,

the symptoms of PMS include both depression and anxiety. Therefore, we hypothesized that the eye movement patterns in women with HPMS would be different in patients with anxiety and depression. We further hypothesized that, compared with women with LPMS, women with HPMS would have accelerated attentional engagement toward negative emotional stimuli and reduced attentional engagement in the orientation to positive stimuli in the early cognitive process. However, they would have difficulties in attentional disengagement from negative emotional stimuli and in the maintenance of positive stimuli in the late cognitive process. Moreover, women with HPMS would return their attention back to negative stimuli more frequently than those with LPMS. Besides, ABs were associated with the cognitive mode of rumination in women with HPMS. The differences in attentional patterns would occur only during the premenstrual period, not in the postmenstrual period.

2. Methods

2.1. Participants

PMS Scale (PSS; Zhao, Wang, & Qu, 1998) was used in this study for sample selection through posters or online advertisements. According to the clinical cutoffs of PSS, those with scores higher than 10 (i.e., moderate or severe symptoms) were divided into the HPMS group, and those with scores lower than 6 (i.e., no symptoms) were divided into the LPMS group. In addition, all participants were required not to have any of the following situation: pregnancy, breastfeeding, current use of hormonal compounds, oral contraceptives, or psychotropic drugs, history of alcohol, drug abuse, and no Axis I psychiatric disorders that were ascertained using the Chinese version of Mini International Neuropsychiatry Interview, based on DSM-IV and ICD-10 (Si et al., 2009).

The sample consisted of 45 women with HPMS and 45 women with LPMS; 3 women dropped out. As suggested by previous eye-tracking studies (Garner, Mogg, & Bradley, 2006), the trials were excluded if the gaze was not directed at the region of the fixation target during the picture onset, eye movements away from the central region occurred within 80 ms of picture onset, or no eye movements were made during the trial. Using the criteria, the data of an additional 5 participants were excluded in data analysis, because more than 20% of their eye movement data was unqualified. After removing the unqualified trials, the ratio of the initial fixation of all the participants in the effective interest area was 88.19% of the total trials.

In the finalized sample, there were 38 women with HPMS (mean age = 21.34 years, SD age = 2.23 years) and 44 women with LPMS (mean age = 21.80 years, SD age = 2.15 years) in the final analysis. The PSS scores were significantly higher in the HPMS group (mean PSS = 15.16, SD PSS = 3.75) than the LPMS group (mean PSS = 3.16, SD PSS = 1.54, $p < .001$). No significant difference in age was found between participants in the two groups ($p = .35$).

The effect sizes in the meta-analyses of anxious versus nonanxious individuals were medium, as suggested by an eye tracking study ($g = 0.47$; Armstrong & Olatunji, 2012) and studies on RT measures ($d = 0.41$; Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & Van Ijzendoorn, 2007) of ABs. Therefore, we used a moderately optimistic expected effect size of $f = 0.25$ (Cohen, 1988; Quan, 2003), which was in combination with a power of $1 - \beta = 0.80$, $\alpha = 0.05$, and an assumed correlation between the repeated measures of 0.5. G^* power analysis revealed a required total sample size of 34 (Faul, Erdfelder, Lang, & AG, 2007). This study was approved by the Ethics Committee of the sponsoring university. All the participants provided their written informed consent in accordance with the guidelines of the Declaration of Helsinki.

2.2. Questionnaire measures

2.2.1. PMS scale (PSS)

The symptoms of PMS were assessed using the Chinese version of the

PSS (Zhao et al., 1998). The PSS consisted of 12 items related to emotional and physical symptoms, such as excitability, depression, anxiety, and abdominal bloating. All the items were scored using a 4-point Likert scale (from 0 “no symptoms” to 3 “symptoms seriously affecting life, study and work, needing treatment”). Total scores of 6–10 indicated mild symptoms, 11–20 indicated moderate symptoms, and scores greater than 20 indicated severe symptoms. The Chinese PSS has demonstrated good reliability and validity (Wu, Liang, Wang, Zhao, & Zhou, 2016; Zhao et al., 1998). In this study, the internal consistency of the PSS was good ($\alpha = 0.85$).

2.2.2. Ruminative response scale (RRS)

The severity of the rumination was assessed using RRS (Han & Yang, 2009). The scale consists of 22 items, including three dimensions: symptom rumination, brooding, and reflective pondering. The items were scored using a 4-point Likert scale, ranging from “never” to “always.” A higher score indicated a greater level of rumination. The Chinese RRS has shown good reliability and validity and has been widely used for evaluating rumination (Han & Yang, 2009). In this study, the internal consistency of the total scale was good ($\alpha = 0.95$).

2.3. Materials and apparatus

We selected 16 positive, 16 negative, and 32 neutral pictures from the International Affective Picture System (1999) based on valence and arousal, which have been localized in the study by Liu, Xu, and Zhou (2009). Each emotional picture was paired with a neutral picture twice. The detailed information about the pictures and apparatus is presented in the supplementary materials.

2.4. Procedure

All the participants were tested twice throughout their menstrual cycles, once in the premenstrual phase (1–7 days before the onset of menstruation) and once in the postmenstrual phase (1–7 days after the onset of menstruation). First, the test date was estimated based on the self-reported date of the last menstrual cycle and the average length of two menstrual cycles. Then, the test date was further confirmed from the estrogen and progesterone levels in a saliva specimen that was collected on the day of the experiment. The phase was randomly assigned during which the participants first came to our laboratory. In the first test, 20 women participated in the premenstrual phase; 18 women in postmenstrual periods participated in the HPMS group; 23 women participated in the premenstrual phase and 21 women in the postmenstrual phase in the LPMS group.

After arriving at the laboratory, the participants read the instructions for the study, signed an informed consent form, and completed all the relevant questionnaires at the first test. After providing a saliva specimen, the participants seated themselves 60 cm from the monitor, stabilized their head on a chin rest of the eye-track recorder, and adjusted the position of the eye tracker to ensure that their eye position was as high as the center of the monitor. After satisfying the standard of 9-point calibration, the participants were asked to classify the fixation point (“X” or “O”) by pressing the corresponding labeled key—a task included to further obscure the purpose of the study, and they were also instructed to maintain natural viewing of different pictures between the fixation point (Armstrong, Olatunji, Sarawgi, & Simmons, 2010). The task consisted of 12 practice trials and 64 experimental trials. Each trial began with a fixation point (“X” or “O”) to ensure that participants were centrally fixated before the display of each picture pair. The presentation time of the fixation point was the response time of the participant or for a maximum of 700 ms. A pair of pictures (negative–neutral or positive–neutral) appeared immediately after the fixation point, with a presentation time of 3000 ms followed by a random intertrial interval (ITI) of 1,500, 2,000, or 2500 ms. The type of fixation point, type of picture pair, and ITI duration were randomly selected in each trial. Each

emotional picture appeared once on the left and once on the right. In the second test, participants repeated this process without completing questionnaires.

2.5. Hormone assays

The saliva specimens were sent to the biochemical laboratory at Multi Sciences Biotech Co., Ltd. (Hangzhou, China) for the analysis of estrogen and progesterone levels. The collection and analysis method of saliva specimens is presented in the supplementary materials.

2.6. Eye movement data: selection and preparation

Eye movement events (saccades, fixations, and blinks) were defined using BeGaze 1.0 software from SMI. Areas of interest were defined as the area of each picture. Five dependent variables were calculated using the eye movement indexes, as used in previous studies (Garner et al., 2006; Mogg, Millar, & Bradley, 2000; Roy-Charland et al., 2017), see Table 1. Attentional engagement bias was measured using directional bias scores and initial fixation latency bias scores. Attentional disengagement bias was measured using initial fixation duration bias scores and dwell time bias scores. The dynamic attentional processes were measured using the number of saccades bias scores.

2.7. Data analysis

The estradiol and progesterone data of 82 participants were analyzed using a two-way mixed analysis of variance (ANOVA): 2 (phase: premenstrual, postmenstrual) \times 2 (group: HPMS, LPMS). We analyzed the data of questionnaires using independent sample t tests.

Then, a series of 2 (valence: positive, negative) \times 2 (phase: premenstrual, postmenstrual) \times 2 (group: HPMS, LPMS) ANOVA was conducted to explore the differences between the two groups on attentional indices to emotional pictures during the two phases of menstrual cycle. Bonferroni follow-up tests were used to further analyze significant interactions.

A correlation analysis for each group was performed to explore the relationship between the scores of RRS and the indexes of ABs in the premenstrual phase. Notably, the correlations were separately computed for the HPMS and LPMS groups because there might be significant group-related differences in some indices of ABs and some dimensions of RRS which might cause a situation that a significant correlation for a full sample might be due to the group-related differences in these variables. Therefore, we computed the correlations separately for the HPMS and LPMS groups, as suggested in previous studies (e.g., Hou et al., 2020).

Table 1
Calculation method of five dependent variables.

Dependent variables	The calculation method
Directional bias scores (%)	Number of trials in which the emotion of interest captured the initial fixation \div Total number of valid trials containing the emotion of interest (Garner et al., 2006)
Initial fixation latency bias scores (ms)	Latency of initial fixation of the emotional pictures–Latency of initial fixation of the corresponding neutral pictures (Mogg, Millar, & Bradley, 2000)
Initial fixation duration bias scores (ms)	Time of initial fixation of the emotional pictures–Time of initial fixation of the corresponding neutral pictures (Mogg, Millar, & Bradley, 2000)
Dwell time bias scores (ms)	Dwell time of the emotional pictures–Dwell time of the corresponding neutral pictures; Dwell time = The sum of fixation time and saccade time in the area of interest (Mogg, Millar, & Bradley, 2000)
Number of saccades bias scores	Number of saccades of the emotional pictures–Number of saccades of the corresponding neutral pictures; Number of saccades = Number of fixations in and out of the interest area (Roy-Charland et al., 2017)

3. Results

3.1. Hormone level results

The salivary estradiol and progesterone levels in the two groups are shown in Table 2, and the details of results are presented in Supplementary Materials. The results are consistent with the description of hormonal changes in the menstrual cycle (Wactawski-Wende et al., 2010), indicating that the test time of the two groups satisfies the experimental requirements.

3.2. Questionnaire results

The questionnaire results show that the scores on the PSS of the HPMS group (15.16 ± 3.75) are significantly higher than those of the LPMS group (3.16 ± 1.54), $t(80) = 19.45, p < .001$.

On the RRS, the HPMS group (28.24 ± 6.89) scored significantly higher in the dimension of symptom rumination than in the LPMS group (23.50 ± 5.87), $t(80) = 3.36, p = .001$. The HPMS group (12.68 ± 3.17) scored significantly higher in the brooding dimension than the LPMS group (11.27 ± 2.89), $t(80) = 2.11, p = .04$. However, no significant difference was observed on reflective pondering between the HPMS group (11.37 ± 3.17) and the LPMS group (10.80 ± 3.30), $t(80) = 0.80, p = .43$.

3.3. Internal consistency of eye movement indexes

The internal consistency among all the eye movement indexes showed low-to-medium reliabilities in this study on the free viewing task of different valence pictures, see Table 3.

3.4. Attentional engagement: directional bias scores

Analyses showed that only the main effect of valence was significant, $F(1,80) = 9.09, p = .003, \eta^2 = 0.10$. All other main or interaction effects were not significant. The directional bias score of the positive picture was significantly larger than that of the negative picture ($p = .01, 95\%CI [0.91, 4.79]$), see Table 4. The directional bias score had no difference between the two groups, $F(1,80) = 3.25, p = .08, \eta^2 = 0.04$.

3.5. Attentional engagement: initial fixation latency bias scores

The results show a nonsignificant three-way interaction. However, a significant valence × group interaction emerged, $F(1,80) = 11.33, p = .001, \eta^2 = 0.12$. A simple analysis showed that the initial fixation latency bias scores of negative pictures in the HPMS group was lower than that of the LPMS group ($p = .001, 95\%CI [-185.75, -48.66]$). No significant group difference was observed in the initial fixation latency bias scores of positive pictures. In the within-group comparison, no significant difference was observed in the initial fixation latency of the positive and negative pictures in the LPMS group, but the initial fixation latency of positive pictures was significantly longer than that of the negative pictures in the HPMS group ($p < .001, 95\%CI[70.61, 209.28]$), see Table 4.

Table 2

Hormonal levels in the premenstrual and postmenstrual phases of the HPMS and the LPMS groups (M ± SD).

Hormone	HPMS Group (n = 38)		LPMS Group (n = 44)	
	Premenstrual	Postmenstrual	Premenstrual	Postmenstrual
Estradiol	154.19 ± 112.18	111.29 ± 77.26	165.75 ± 162.48	96.52 ± 64.33
	855.65 ± 586.80	425.79 ± 277.96	940.52 ± 628.32	445.82 ± 266.00

Note: The units of estradiol and progesterone are both pg/mL.

Table 3

Internal consistency of each eye movement indexes of different valence pictures for the free viewing task.

Eye Movement Indexes	Positive	Positive—Neutral	Negative	Negative—Neutral
Directional bias (%)	.61	.41	.48	.50
Initial fixation latency	.40	.47	.61	.50
Initial fixation duration	.50	.39	.37	.36
Number of saccades	.58	.64	.56	.43
Dwell time	.61	.42	.47	.50

3.6. Attentional disengagement: initial fixation duration bias scores

Analysis showed a significant three-way interaction of valence × phase × group, $F(1,80) = 9.63, p = .003, \eta^2 = 0.11$. As shown in Fig. 1, Bonferroni post hoc analyses revealed that the initial fixation duration bias scores of the positive pictures in the HPMS group were significantly lower than those in the LPMS group ($p = .04, 95\%CI [-57.71, -1.07]$), and the negative pictures in the HPMS group was significantly higher than those in the LPMS group ($p = .03, 95\%CI [3.39, 66.06]$) during the premenstrual phase. In the postmenstrual phase, the initial fixation duration bias scores of the positive pictures in the HPMS group were significantly higher than those in the LPMS group ($p = .03, 95\%CI [-185.75, -48.66]$), while no group difference was observed in those of negative pictures ($p = .61, 95\%CI [-22.57, 37.99]$). Regarding the differences between the two phases of menstrual cycle, analyses revealed that the HPMS group had lower initial fixation duration bias scores of positive pictures in the premenstrual phase than that in the postmenstrual phase ($p = .01, 95\%CI [-71.77, -8.22]$). Their initial fixation duration bias scores of negative pictures had no difference in the two phases. The LPMS group had higher initial fixation duration bias scores of positive pictures in the premenstrual phase than those in the postmenstrual phase ($p = .04, 95\%CI [1.74, 60.80]$). Their initial fixation duration bias scores of negative pictures had no difference in the two phases.

3.7. Attentional disengagement: dwell time bias scores

The results show that only the main effect of phase was significant, $F(1,80) = 5.70, p = .02, \eta^2 = 0.07$, and the other main or interaction effects were not significant. The dwell time bias score of premenstrual phase was significantly larger than that of postmenstrual phase ($p = .02, 95\%CI [10.14, 105.46]$), see Table 4. The dwell time bias score had no difference between the groups, $F(1,80) = 0.30, p = .59, \eta^2 = 0.004$.

3.8. Dynamic measure: number of saccades bias scores

Analyses showed that only the main effect of valence was significant, $F(1,80) = 5.99, p = .02, \eta^2 = 0.07$, and the other main or interaction effects were not significant. The number of saccades bias scores of the positive picture was significantly larger than that of the negative picture ($p = .02, 95\%CI [0.02, 0.25]$), see Table 4. The number of saccades bias scores had no difference between the groups, $F(1,80) = 0.42, p = .52, \eta^2 = 0.01$.

3.9. Correlation analysis results

Correlation analysis revealed significant positive correlations between the initial fixation latency bias scores of positive pictures in premenstrual phase and the scores of symptom rumination in both the groups and between the initial fixation latency bias scores of positive pictures in the premenstrual phase and scores of brooding in the RSS in

Table 4
Eye movement data of the HPMS and LPMS groups in the premenstrual and postmenstrual phases (M ± SD).

Eye Movement Data	Valence	HPMS Group (n = 38)		LPMS Group (n = 44)	
		Premenstrual	Postmenstrual	Premenstrual	Postmenstrual
Directional bias scores (%)	Positive	55.86 ± 7.18	54.87 ± 7.98	53.76 ± 10.00	53.92 ± 8.90
	Negative	53.92 ± 12.41	53.45 ± 14.79	49.35 ± 11.16	50.29 ± 10.05
Initial fixation latency bias scores	Positive	-81.53 ± 177.76	-36.11 ± 171.79	-84.95 ± 141.06	-118.50 ± 184.48
	Negative	-218.42 ± 203.10	-179.11 ± 223.15	-76.03 ± 159.31	-87.10 ± 164.63
Initial fixation duration bias scores	Positive	-15.83 ± 78.98	24.16 ± 82.51	13.56 ± 48.11	-17.72 ± 84.35
	Negative	5.47 ± 76.86	-14.72 ± 82.93	-29.25 ± 65.74	-22.43 ± 53.53
Number of saccades bias scores	Positive	.17 ± .33	.06 ± .35	.18 ± .30	.21 ± .31
	Negative	.06 ± .45	-.01 ± .45	.06 ± .64	-.05 ± .42
Dwell time bias scores	Positive	161.29 ± 234.16	149.39 ± 199.54	181.62 ± 234.41	156.78 ± 233.31
	Negative	215.29 ± 508.20	89.76 ± 396.67	129.78 ± 421.98	60.83 ± 446.90

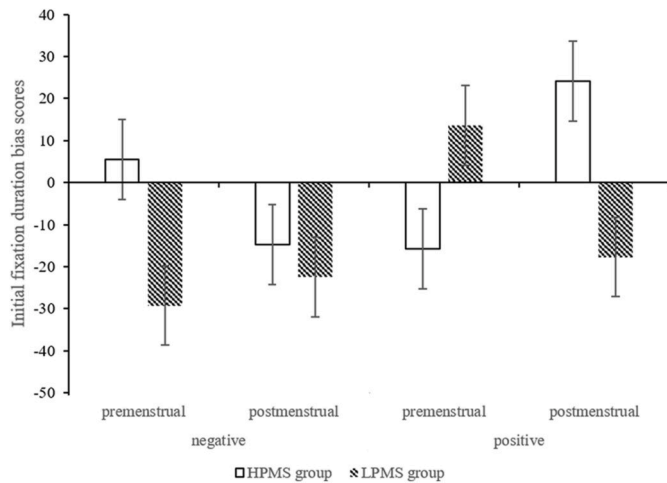


Fig. 1. Initial fixation duration bias scores of the PMS and control groups in the premenstrual and postmenstrual phases.

HPMS groups (see Table 5).

4. Discussion

This study used a free viewing paradigm combined with eye-tracking technology and self-reporting questionnaires to examine the differences in the ABs to emotional information and cognitive characteristics between women with HPMS and women with LPMS. It was found that the

HPMS and LPMS groups showed different eye movement patterns of ABs to different emotional information. In the attentional engagement of early cognitive processing, participants in the HPMS group had a biased orientation toward negative information from the results of the initial fixations latency bias, indicating that the participants in the HPMS group captured negative emotional information more quickly than those in the LPMS group. By further analyzing the results of the initial fixation duration bias, it was found that the participants in the HPMS group had significantly longer attentional maintenance for negative pictures and shorter attentional maintenance for positive pictures than those in the LPMS group in later cognitive processing. These findings revealed women with HPMS had a deficient attentional disengagement toward negative emotional information and accelerated attention disengagement from positive emotional information.

However, unlike the findings of initial fixation duration, we did not find a significant group difference in the dwell time bias between the HPMS and LPMS groups. This different result can be attributed to the fact that the second shift in gaze lacked clear predictions for attentional disengagement at the static level. Duration of gaze on the picture fixated second might be influenced by its emotional content and the PMS severity of the participants. Besides, it was also influenced by the emotional content of the preceding picture, due to priming effects or motive to return to the initially fixated picture. Because the immediately preceding stimulus was a neutral central fixation cue, the index of attentional disengagement during gaze on the initially fixated picture might be relatively pure (Caseras, Garner, Bradley, & Mogg, 2007). Therefore, the impaired attentional disengagement was only presented at the initial fixation duration. Furthermore, our study showed no significant differences in the number of saccades bias at the dynamic level between the two groups. The finding is consistent with a previous study

Table 5
Correlation between RSS and the indexes of ABs in each group.

	HPMS group (n = 38)			LPMS group (n = 44)		
	RSS_symptom ruminaton	RSS_brooding	RSS_reflective pondering	RSS_symptom ruminaton	RSS_brooding	RSS_reflective pondering
Directional bias scores_positive	-.061	-.127	-.119	-.232	-.147	-.301
Directional bias scores_negative	-.060	-.115	-.129	-.065	.002	-.107
Initial fixation latency bias scores_positive	.443**	.363**	.305	.350*	.229	.286
Initial fixation latency bias scores_negative	-.244	-.230	-.208	.132	.150	.180
Initial fixation duration bias scores_positive	-.015	.033	.052	.159	.118	.135
Initial fixation duration bias scores_negative	.058	.213	.224	-.194	-.123	-.048
Number of saccades bias scores_positive	-.304	-.212	-.216	-.271	-.186	-.256
Number of saccades bias scores_negative	-.144	-.178	-.170	.057	.129	.075
Dwell time bias scores_positive	-.300	-.307	-.208	-.098	-.042	-.081
Dwell time bias scores_negative	.247	.295	.248	-.123	-.083	-.136

Note: *p < .05, **p < .01, ***p < .001.

(Dias Da Silva, Ruzs, & Postma-Nilsenová, 2018). The study also found no differences in the number of saccades between the rumination and control groups. The finding is consistent with the study that the control group and the level of state rumination or trait rumination could not be used to predict the number of saccades (Dias Da Silva et al., 2018). These findings indicate that a dynamic process was not involved in rumination, but the impaired attentional engagement and disengagement was involved in rumination.

In addition, the results of self-reported questionnaires show that the level of rumination in the HPMS group was higher than that in the LPMS group. This finding is consistent with previous studies in which women with PMS increased their rumination to negative consequences (e.g., Craner, Sigmon, & Young, 2015). Moreover, this study further found a positive correlation between the brooding of RSS and the initial fixation latency bias scores of positive pictures in the HPMS group during premenstrual phase, i.e., the higher the level of brooding, the harder for the women with HPMS attend to positive stimuli during the premenstrual phase. These results provide a preliminary evidence for our hypothesis that ABs are associated with the cognitive mode of rumination in women with HPMS.

In general, the current results support the hypothesis that women with HPMS had a specific eye movement pattern of ABs, which was reflected in the attentional engagement bias to negative emotional information in the early cognitive processing, and impaired attentional disengagement to negative and positive emotional information in the later cognitive processing. As hypothesized, this pattern of ABs is similar to the eye movement patterns that have been demonstrated in individuals with anxiety and depression using the free viewing paradigm (Armstrong & Olatunji, 2012). In the early cognitive processing, the women with HPMS had a similar eye movement pattern as anxiety patients in previous studies (Garner et al., 2006). Specifically, the ABs of anxiety patients were reflected in the acceleration of early detection toward threat stimuli (Garner et al., 2006), while the ABs of women with HPMS in our study were reflected in the faster detection of the negative pictures. Moreover, in the later cognitive processing, it was found that the pattern of ABs of the women with HPMS in our study is similar to that of depressed patients in previous studies, i.e., the depressed patients had impaired attentional disengagement toward both negative and positive emotional information (Caseras et al., 2007; Eizenman et al., 2003; Kellough, Beevers, Ellis, & Wells, 2008). However, our finding shows that women with HPMS did not have a reduced attentional engagement to positive information during the early cognitive processing, which is slightly different from the conclusion of the meta-analysis in populations with depression by Armstrong and Olatunji (2012). The reason for the difference can be attributed to different materials and time of presentation selected for the study.

This study also revealed that both directional bias and latency to initial fixation bias for the positive pictures of women with HPMS were not different from the women with LPMS. However, the women with HPMS could not maintain a longer attention toward positive pictures. The duration of attentional maintenance toward negative pictures of the women with HPMS was significantly longer than that of the women with LPMS. Therefore, we speculate that the women with HPMS could notice positive information, but most likely they had deficits to process positive signals deeply. The longer time for attentional maintenance could be attributed to the fact that the negative information was similar to their cognitive characteristics.

It is important to note that regardless of the premenstrual or postmenstrual phases, participants in the HPMS group had an accelerated detection towards negative emotional information than that in the LPMS group in the early cognitive processing. During the late cognitive processing, however, the differences in attentional disengagement to negative stimuli between the HPMS and LPMS groups occurred only in the premenstrual phase, and the differences disappeared in the postmenstrual phase. Furthermore, compared to the participants in the LPMS group, the accelerated attentional disengagement to positive

stimuli in women with HPMS group also occurred only in the premenstrual phase. Instead, during the postmenstrual phase, the time taken for maintaining positive stimuli was shorter in women with LPMS than that with HPMS. Our findings are largely consistent with earlier studies that the abnormal state was only reflected in the premenstrual phase (Hou et al., 2020; Andreano, Touroutoglou, Dickerson, & Barrett, 2018).

This study further found that the difficulty in maintaining attention on positive stimuli or disengaging from negative stimuli only appeared in the premenstrual phase in women with HPMS. This phenomenon could be related to the cyclic changes in ovarian hormonal levels that produced cyclic alterations in connectivity between the intrinsic networks of the brain because of complex neuroendocrine systems (such as serotonin and tetrahydroprogesterone activity). These alterations produced specific temporal windows within the menstrual cycle when internetwork connectivity was increased. The increased internetwork connectivity is associated with increased stress reactivity and better memory for unpleasant, arousing events (Andreano et al., 2018), leading to increased rumination (Li & Graham, 2017). We think that this mechanism might also explain why the ABs only occur in the premenstrual phase. Specifically, the attention maintenance to positive stimuli of the HPMS group rebounded after menstruation, and even surpassed LPMS group, also indicating that participants in the HPMS group had a greater emotional volatility before and after menstruation.

There are several limitations of this study. First, this study used a retrospective questionnaire to assess the symptoms of PMS. There may be some recall bias in the retrospective questionnaire. Second, the content of picture materials used in the task is not related to PMS. We will add PMS-specific materials in future research to validate the findings using stimuli more closely associated with the cognitive characteristics of women with PMS. Third, there is a possibility of Type I error because of no multiple comparison correction in correlation analysis. Finally, although the low-to-medium effect sizes of ABs in this study (~ 0.12 for within-between factors' interaction effects) were consistent with the effect size observed in anxious versus no anxious individuals in Bar-Haim et al.'s (2007) review of RT measures and that observed in Armstrong and Olatunji (2012)'s meta-analysis of eye tracking of ABs, and the effect size was stronger than people with chronic pain (e.g., Chan, Suen, Jackson, Vlaeyen, & Barry, 2020; Jones et al., 2021; Todd, van Ryckeghem, Sharpe, & Crombez, 2018), caution is still advised before drawing conclusions.

In summary, the findings of our study suggest that women with HPMS have an orientation bias toward negative emotional information in the early cognitive processing, difficulties in maintaining positive emotional information, and disengaging from negative emotional information in the late cognitive processing.

Contribution of the individual authors

Lirong Chen: Conceptualization, Methodology, Software, Formal analysis, Writing - Original Draft. **Lulu Hou:** Investigation. **Renlai Zhou:** Conceptualization, Methodology, Writing - Review & Editing, Supervision, Funding acquisition.

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Declaration of competing interest

The authors declare that they have no conflict of interest.

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Appendix A. Supplementary data

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