Do hormonal fluctuations during the menstrual cycle lead to enhanced emotional memory in naturally cycling women?

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Plain Language Summary

This research explored whether hormonal changes during the menstrual cycle influence emotional memory in women not using hormonal contraception. Emotional memory refers to how well we recall emotionally significant events, such as joy or fear. Women are twice as likely as men to experience stress-related and mood disorders, making it crucial to understand how hormones like estrogen and progesterone impact memory. The study reviewed eight research articles examining emotional memory across the two menstrual phases: the follicular phase (low progesterone) and the luteal phase (high progesterone). Most studies found better memory for emotional images, particularly negative ones, during the luteal phase when progesterone levels peak. However, one study reported better memory during the follicular phase, while two found no significant differences. Inconsistencies in how the phases were defined and the emotional content tested make it difficult to draw definitive conclusions. The findings suggest that hormonal fluctuations, especially elevated progesterone, may enhance memory for negative emotions during the luteal phase. These effects could help explain women's greater vulnerability to stress-related disorders. Further research is needed to confirm these findings and could inform personalized mental health treatments tailored to hormonal cycles.

Abstract

The menstrual cycle plays a crucial role in regulating female reproductive physiology and also influences cognition and emotion in naturally cycling women. This literature review examines the effects of fluctuating estrogen and progesterone levels on emotional memory during the follicular and luteal phases of the menstrual cycle. Using PsycINFO and PubMed databases, eight studies conducted between 2000 and early 2024 were identified that explored emotional memory in healthy, naturally cycling women. Five of these studies reported superior emotional memory during the luteal phase compared to the follicular phase. However, one study found better emotional memory during the follicular phase, while two others reported no significant differences between the phases. Of the studies that found superior emotional memory, many noted stronger memory for negative images, although the lack of positively valenced stimuli in some experiments made it difficult to draw conclusions regarding emotional valence. Additional methodological differences, particularly in variation in the definition of the follicular and luteal phases across studies, further comp-licated cross-study comparisons. Overall, while there is some evidence suggesting superior emotional memory (potentially only for negative stimuli) during periods of elevated progesterone in naturally cycling women, future research should address the methodological inconsistencies in the existing literature. These findings are important as enhanced emotional memory may be linked to the higher prevalence of stress-related disorders in females compared to males.

Publication Category

Student-Faculty Collaboration

Academic Context

This paper began as a literature review assignment for a Cognitive Psychology course. The undergraduates were keen to develop the paper and experience academic publication. Through CMU-Q's Summer Undergraduate Research Apprenticeship (SURA) with Jennifer Bruder, they expanded the paper and submitted to this journal for review.

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Introduction

It has been well established that women are significantly more likely than men to develop affective and stress-related disorders, with incidence rates sometimes nearly double those of men (Kessler et al., 1993; Maeng & Milad, 2015; Nolen-Hoeksema, 1987). Epidemiological studies have consistently demonstrated that the lifetime prevalence of mood and anxiety disorders is roughly twice as high in women compared to men (Bangasser & Valentino, 2014; McLean et al., 2011).

Previous research indicates that sex hormones, such as progesterone and estrogen, play a crucial role in modulating neural function and cognitive behaviors, including memory formation (Brinton et al., 2008; Frick, 2015; Korol & Pisani, 2015). Estrogen and progesterone receptors are widely distributed throughout the brain, particularly in regions involved in emotion and memory processing, such as the hippocampus, amygdala and prefrontal cortex (Brinton et al., 2008; Frick, 2012). The fluctuations of these hormones across the menstrual cycle impact various cognitive functions, including attention, learning and memory (Jacobs & D'Esposito, 2011; Sundström Poromaa & Gingnell, 2014).

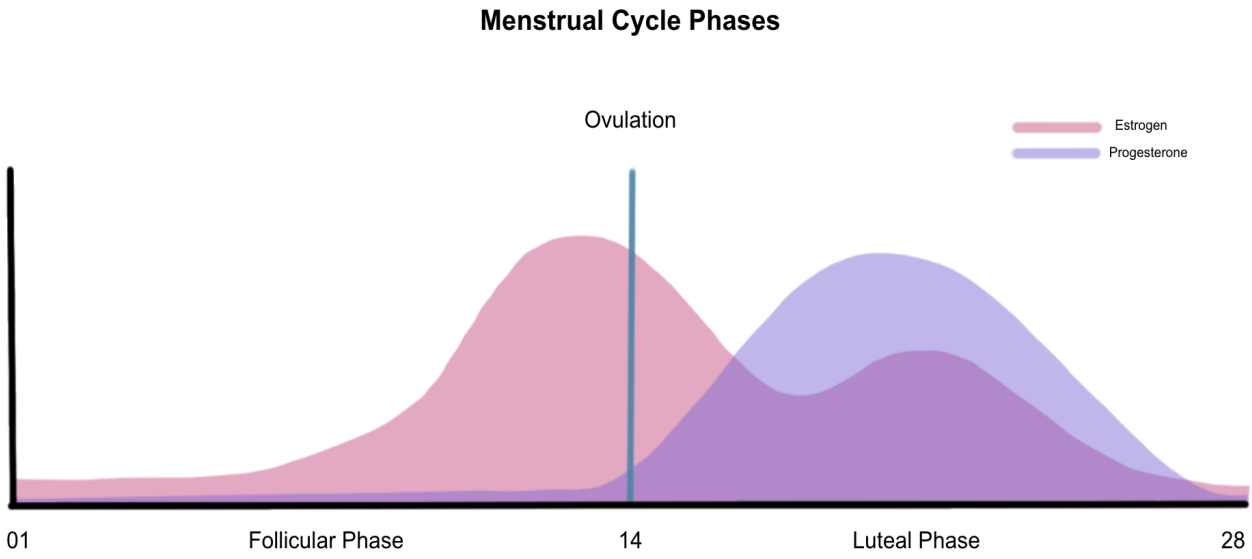
Since drastic hormonal fluctuations occur during the menstrual cycle, it is imperative to assess the impact of these fluctuations on cognitive functions like emotional memory (e.g., Bayer et al., 2014; Ertman et al., 2011; Nielsen et al., 2013). Understanding the relationship between hormonal changes and emotional memory processes may help elucidate the underlying mechanisms contributing to the heightened prevalence of affective disorders in women compared to men (Bangasser & Valentino, 2014; Maeng & Milad, 2015).

By deepening our understanding of these effects, we may uncover the underlying reasons for women's higher susceptibility to stress-related disorders and other mental health conditions compared to men, which could be instrumental in advancing effective, tailored treatments.

In line with this, the American Psychological Association defines emotional memory as memories that evoke an emotional response and can be implicit, for example, in the form of conditioned fear, or explicit, such as when individuals re-experience the original emotions engendered by an event (e.g., terror when describing an accident, joy when describing a close family member's wedding) (*APA Dictionary of Psychology*, n.d.).

The menstrual cycle of naturally cycling (NC) women is dominated by fluctuating levels of estrogen (also referred to as estradiol or E2) and progesterone (also referred to as P4) (see Figure 1). These hormonal shifts define two distinct phases of the menstrual cycle. The first phase, the follicular phase, spans approximately the first half of the menstrual cycle (days 1-14). It begins on the first day of

FIGURE 1. MENSTRUAL CYCLE PHASES



menstruation and includes the (approximately) 7 days of menstruation followed by days 8-14 which are marked by steadily increasing levels of estrogen peaking prior to ovulation. Throughout the follicular phase progesterone levels remain constant and low. On day 14 ovulation occurs and the menstrual cycle transitions into the luteal phase (days 15-28). The luteal phase is dominated by progesterone which peaks during the mid-luteal phase (approximately days 20-23). Estrogen remains present during the luteal phase and also peaks during the mid-luteal phase but is less abundant than progesterone (Thiyagarajan et al., 2024).

Other hormones also fluctuate throughout the cycle, in particular follicle stimulating hormone and luteinizing hormone (Reed & Carr, 2018).

Estrogen and progesterone have receptors in a network of brain centers which process emotion and memory, therefore making it plausible that emotional memory abilities in women may fluctuate throughout the menstrual cycle (Brinton et al., 2008). Indeed, it has been shown that after the initial contact with an emotional stimulus, emotional arousal leads to enhanced hippocampal consolidation via the amygdala, which also acts to enhance attentional processes via higher cortical areas. A prefrontal-parietal network is further involved in attaching valence to the stimulus (Davis & Whalen, 2001; Pessoa, 2008).

Estrogen and progesterone affect cellular mechanisms in these areas during both encoding and consolidation of memories of emotional information. The interplay between estrogen and progesterone is complex. For example, the presence of estrogen increases neural transmission in the hippocampus while down-regulating neuronal excitability in the amygdala (Foy et al., 1999; Womble et al., 2002). Moreover, estrogen and progesterone engage some cellular processes in the hippocampus antagonistically, where it is thought that estrogen exerts beneficial effects on memory that are reversed by progesterone. Although these two hormones act in opposition in the hippocampus, their combined presence in the prefrontal cortex offers some neuroprotection (Djebaili et al., 2004; Foy et al., 2008; Hill et al., 2009; Kritzer & Kohama, 1998).

Since emotional memory relies on the interaction of these brain structures, predicting how hormonal fluctuations in NC women will affect memory function during the menstrual cycle is challenging.

This paradigm is further complicated by the impact of hormones on different types of emotions experienced during the span of the menstrual cycle. Thus far, we have discussed emotional memories and stimuli as a single category; however, research indicates that positive and negative emotions are processed differently in the human brain (Vaish et al., 2008). Studies suggest that memory for negative emotional information may be experienced and retained differently—and perhaps more effectively—than for positive or neutral information (Kensinger, 2009). Therefore, differences that may emerge in emotional memory capabilities in women during the menstrual cycle may further be related to the content of the emotional memories, where negative memories may receive superior processing at certain times.

Despite the presence of estrogen and progesterone hormone receptors in brain regions associated with memory and cognitive functions (Bayer et al., 2014), the role of these hormones in emotional memory remains under-explored. This review seeks to synthesize the limited research on how hormonal fluctuations during the menstrual cycle may influence emotional memory in NC women, thereby highlighting a significant gap in the literature.

Methods

Literature Search

The PsycINFO and PubMed databases were searched in late 2023 and early 2024 for peer-reviewed studies published since 2000. A combination of Boolean operators, including 'AND', 'OR' and parentheses, was utilized alongside key terms to obtain precise results. The terms "menstruation" and "neuro" were truncated using an asterisk (*).

In both databases the following search strings used were:

Emotional Memory" AND Menstrua*
"Emotional Memory" AND "Menstrua* Cycle",
"Emotional Memory" AND "Menstrua* Phase",
"Emotional Memory" AND (Estrogen OR Progesterone) ,
"Emotional Memory" AND (Estrogen OR Estradiol OR Progesterone),
"Emotional Memory" AND (Follicular OR Luteal),
"Emotional Memory" AND Menstrua* AND (Neuro* OR Brain)

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Results

The initial search for PsycINFO for all the search strings yielded 275 articles (including repetitions) whereas the initial search for PubMed yielded 918 articles (including repetitions). Articles that were repeated due to the use of different search strings were removed. The remaining articles were scanned for their relevance to our search criteria. We found that the majority of the remaining articles were not directly relevant to our study, and therefore excluded during the initial screening. Several reasons for exclusion were as follows: the articles focused on unhealthy women (e.g., those with PTSD or traumatic memories), involved the use of hormonal contraceptives and did not include NC women, did not directly pertain to emotional memory as defined for this review, or primarily concentrated on other types of memory, such as working memory. Some of the articles were focused on monitoring the activity of other hormones like cortisol which didn't directly relate to the menstrual cycle hormones (i.e. progesterone or estrogen). As a result of this screening process, and after evaluating the relevance and significance of each article, eight unique articles were shortlisted from the two databases for inclusion in this review (see Table 1).

Discussion

In this review, we aimed to summarize the research on emotional memory in naturally cycling (NC) women across the menstrual cycle. Our literature search identified 8 relevant studies that explored this topic (see Table 1).

The following paragraphs present the support for and against superior emotional memory during the menstrual cycle in NC women, while also highlighting gaps and unresolved questions in the literature.

Emotional Memory During the Follicular Phase

Evidence for enhanced emotional memory during the follicular phase is notably supported by the study conducted by Bayer et al. (2014). They found that women in the early follicular phase (days 0-4) exhibited superior recollection memory specifically for negative images compared to their performance during the luteal phase (days 18-28). This indicates that lower hormone levels in the early follicular phase may facilitate better memory for emotionally charged content.

Interestingly, when participants expressed lower confidence in their recollections, no significant differences were observed between positive and negative images across the follicular and luteal phases. However, it is crucial to note that memory for emotional items consistently outperformed memory for neutral items, regardless of the participants' confidence levels.

This study stands out in the review as the only one employing a within-subjects design and incorporating a neuroimaging component. The neuroimaging results revealed that improved memory formation for emotionally arousing images was linked to increased activity in the hippocampus during the low-hormone early follicular phase compared to the high-hormone luteal phase. Furthermore, emotional encoding was influenced by a network involving the hippocampus, amygdala and anterior cingulate cortex, highlighting the complex interplay of brain regions in processing emotional memories.

Emotional Memory During the Luteal Phase

Altogether, 5 studies found enhanced emotional memory during the luteal phase (days 15-28). This phase, characterized by high levels of progesterone mid-phase (days 20-23), was associated with better recall of emotional, particularly negative, stimuli. Felmingham et al. (2012) showed that NC women with high progesterone levels in the mid-luteal phase had better recall of threatening images when under stress. Likewise, Wassell et al. (2015) observed that NC women in the mid-luteal phase exhibited enhanced emotional memory for visual (but not verbal), peripheral elements of negative images compared to women in the follicular phase. Ertman et al. (2011) also found a positive correlation between increasing progesterone levels and superior memory for emotionally negative stimuli during the luteal phase. Nielsen et al. (2013) found that women in the luteal phase displayed enhanced memory for emotional memories, particularly for gist recall, compared to NC women in the follicular phase. Both Ertman et al. (2011) and Nielsen et al. (2013) included women throughout the luteal phase, thus their sample consisted of women with varying levels of progesterone.

Only one study, Pompili et al. (2016) compared emotional memory in the peri-ovulatory luteal phase (days 12-16) to the early follicular phase (days 1-4). The peri-ovulatory phase is characterized by both lower estrogen and progesterone levels. This study found enhanced emotional memory for positively valenced stimuli in the peri-ovulatory luteal phase of NC women in a between-subjects design. It is interesting to note that the authors did not find superior memory for negative images as compared to the studies in the mid-luteal phases characterized by high progesterone levels. These findings suggest that superior emotional memory for negatively valenced stimuli may be

driven by high levels of progesterone. In line with this, Felmingham et al. (2012) found that progesterone levels, rather than estrogen, were more closely associated with enhanced emotional memory, implying that the follicular phase, with its lower progesterone levels, might not enhance emotional memory. In support of this conclusion, Ertman et al. (2011) also suggested that the follicular phase does not confer a specific advantage for memory recall of emotional content.

No Emotional Memory Differences

Not all studies reviewed found superior memory for emotional content in either of the menstrual phases. Ferree et al. (2011) had participants view films with violent content. The authors did not find significant differences in free recall of emotional content between the follicular and luteal phases. However, the authors did note that the participants who viewed the films in the luteal phase reported significantly more spontaneous intrusive recollections of the violent films compared to the NC women who viewed the films in the follicular phase. Similarly, Gamsakhurdashvili et al. (2021) found no differences in emotional memory performance between the follicular and luteal phases for either positive or negative images. This was the only study which tested memory after only a 24-hour delay, which may have resulted in less forgetting of the images. In addition, this study also employed several other measures (i.e. cold pressure tests, empathy and mood questionnaires) which may have impacted or interfered with encoding.

General Findings

Although all studies investigated emotional memory in the follicular and luteal phases, the summary in Table 1 reveals considerable variation of the criteria employed for assigning probands to the experimental groups. Some studies utilized sweeping definitions of the follicular phase (day 0-14) and the luteal phase (day 15-30) (e.g., Ertman et al., 2011; Ferree et al., 2011; Nielsen et al., 2013); whereas others used stricter criteria (i.e. limiting the follicular phase to days 1-4 or the luteal phase to days 20-23) when delineating the boundaries of these phases (see Table 1 for full details) (e.g., Bayer et al., 2014; Gamsakhurdashvili et al., 2021; Pompili et al., 2016; Wassell et al., 2015). Because there is a great deal of variation of the hormone levels within the follicular and luteal phases (see figure 1), it could be argued that stricter control of group assignment would result in an improved understanding of the influence of a particular phase within the cycle on memory. For example, in the follicular phase estrogen levels are relatively low in days 1-7 and begin to peak rapidly until day 12 (Andreano & Cahill, 2010) and then sharply decline toward the end of the follicular phase. Studies that include women in days 1-14 in the follicular group would therefore have women with low and very high estrogen levels. A study like Ertman et al. (2011) would be improved by dividing women in early and late follicular groups (Andreano & Cahill, 2010; Bayer et al., 2014; Ferree et al., 2011).

In comparison, during the luteal phase, estrogen increases steadily but remains low in relation to the sharp increase in the follicular phase, peaking around day 21 and then gradually declining. Progesterone is low through the entire follicular phase and dominates the luteal phase through gradual but prominent increases which remain high approximately through days 20-23 before gradually decreasing. Research that classified participants broadly into the luteal group (i.e. Ertman et al., 2011; Ferree et al, 2011; Nielsen et al., 2013) would therefore include women with both low and high estrogen and progesterone levels in their study, making it difficult to ascertain the precise influence of progesterone on emotional memory.

Additional variation was found across studies with regards to the number of days between exposure to the stimuli and recall. Only one study tested memory after a 24-hour delay (Gamsakhurdashvili et al., 2021), three studies after 48 hours (Bayer et al., 2014; Felmingham et al., 2012; Wassel et al., 2015), while the others tested memory after one week (Ertman et al., 2011; Ferree et al., 2011; Nielsen et al, 2013; Pompili et al, 2016). These variations in testing delay may have contributed to some of the differences between study results, however this hypothesis would need to be tested in future research.

Conclusions regarding the influence of progesterone and estrogen on positive versus negative stimuli are also limited. When studies employed both positively and negatively valenced stimuli, under certain testing conditions, negative emotional content experienced some superiority over positive stimuli (Bayer et al., 2014; Gamsakhurdashvili et al., 2021) or positive content was found to be superior to negative content (Pompili et al., 2016). However, most of the studies reviewed did not include positively valenced stimuli (Ertman et al., 2011; Felmingham et al., 2012; Ferree et al., 2011; Wassell et al., 2015) or did not specify the valence (Nielsen et al., 2013), which limited the overall conclusions possible with regards to how valence may influence memory superiority for emotional content.

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Finally, there were some notable consistencies across many studies. These included participant numbers, the method of memory retrieval and the stimuli employed. The participant numbers were similar across all studies (ranging from n=18 to n=36) and free recall was the predominant memory measure, except for Bayer et al. (2014) and Ferree et al. (2011). Most studies reviewed utilized the International Affective Pictures stimuli set (IAPs) (Bayer et al., 2014; Ertman et al., 2011; Felmingham et al., 2012; Gamsakhurdashvili et al., 2021; Pompili et al., 2016; Wassell et al., 2015). Despite these consistencies, the researchers did not reach the same conclusions regarding emotional memory, suggesting that differences between the studies may not be attributed to stimuli or memory recall measures. These comparative strengths further suggest that the discrepancies across study results might be due to the variation in the criteria used between the studies to define the follicular and luteal phases.

Conclusion

In this brief review we examined evidence for and against superior emotional memory in NC women. Altogether, we isolated a total of 8 studies that met our inclusion criteria. We found mixed evidence for superior memory related to different phases of the menstrual cycle. The majority of evidence favored superior memory during the luteal phase, characterized by higher progesterone levels, compared to the follicular phase. Some of the research also suggested that superior emotional memory may be particularly relevant for negatively valenced stimuli.

Overall, several methodological differences across studies complicated comparisons and limited the conclusions that could be drawn regarding superior emotional memory in NC women. The largest comparative limitation is related to the large variation in the definitions of follicular and luteal phases between studies (from a few days to two weeks), where variations in progesterone and estrogen during the cycle would not be truly comparable and would likely have a large impact on the results. Although a general increase in emotional memory during the luteal phase is supported by the research, the majority of studies limited their experiments to negatively valenced stimuli, thus rendering it difficult to conclude if the effect is specific to particular types of emotional content or a general phenomenon.

This research is important because previous research has established that sex hormones, such as progesterone and estrogen, play a crucial role in modulating neural function and cognitive behaviors, including memory formation (Brinton et al., 2008; Frick, 2015; Korol & Pisani, 2015). Estrogen and progesterone receptors are widely distributed throughout the brain, particularly in regions involved in emotion and memory processing, like the hippocampus, amygdala and prefrontal cortex (Brinton et al., 2008; Frick, 2012).

The fluctuations of these hormones across the menstrual cycle have been shown to impact various cognitive functions (Jacobs & D'Esposito, 2011; Sundström Poromaa & Gingnell, 2014). Given the drastic hormonal changes that occur during the menstrual cycle, it is important to assess the impact of these fluctuations on cognitive functions like emotional memory (e.g., Bayer et al., 2014; Ertman et al., 2011; Nielsen et al., 2013).

Understanding the relationship between hormonal changes and emotional memory processes may help elucidate the underlying mechanisms contributing to the heightened prevalence of affective disorders in women compared to men (Bangasser & Valentino, 2014; Maeng & Milad, 2015). By deepening our understanding of these effects, we may uncover reasons for women's higher susceptibility to stress-related disorders and other mental health conditions, which could inform the development of more effective, tailored treatments.

Future studies can use this review to guide their criteria for study design, most importantly considerations of including both negatively and positively valenced stimuli and strictly defining inclusion criteria in cycle phases will be important for comparisons to past literature. As the majority of studies to date point to a key role for progesterone in mediating superior memory for negative images, future studies may want to include other comparison groups, such as early, mid and late luteal in addition to the follicular group, as well as male participants.

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TABLE 1: STUDIES THAT DISCUSS THE IMPACT OF THE MENSTRUAL CYCLE ON EMOTIONAL MEMORY.

Reference	Overarching research question	Participants and study design	Major outcomes	Comments on research gap and critique
Bayer et al., 2014	Do estrogen and progesterone impact recollection of negative, positive, and neutral stimuli during the follicular and luteal phases? Does memory performance relate to underlying neural activity during encoding?	N=22 healthy, NC females aged 19–33 years (M = 26, SD = 3.25) were tested during their early follicular (day 0-4) and the luteal phase (day 18-28); within-subjects design. Brain Imaging (fMRI); Subjects were shown negative, positive and neutral images (N=144) from the International Affective Pictures System (IAPS). Two days after encoding (in the scanner), memory recollection was assessed (accuracy and quality) outside the scanner.	Overall, recognition accuracy remained stable across cycle phases, and emotional stimuli were better remembered. However, recognition quality varied with menstrual cycle phases for negative images only. Emotional memory was enhanced during the follicular phase compared to the luteal phase. Both positive and negative images were associated with increased anterior hippocampal activity in the follicular phase.	Overall, suggests hormone-specific superior emotional memory is especially related to negatively valenced stimuli. The authors were careful to control for cycle phase, as variations in the cycle can lead to large differences amongst women. This is a strength of the study, as well as this study is one of the few to employ a within-study design across follicular and luteal phases. Other studies reported enhanced memory to negative images in the luteal phase. The authors do not address the discrepancy. Did not include males. Difficult to ascertain if enhanced memory is relative to only NC females in a cyclically dependent manner, or also enhanced to males.
Ertman et al., 2011	Do differing progesterone and/or estrogen levels during the follicular and luteal phases impact encoding and retrieval of negative vs neutral images?	N=60 healthy, NC women's menstrual cycle phases were estimated by self-report and confirmed by salivary assay of 17b-estradiol and progesterone. The women were divided into two groups: n = 36 follicular (day 0-14); n = 24 luteal (day 15-31); between-subjects design). Participants rated 120 negative and neutral IAPS images on arousal and valence. One week later they completed free recall and recognition memory tests.	Found better free recall of negative images in the luteal phase relative to the follicular phase of the menstrual cycle and a positive relationship between progesterone levels and free recall of negative images. No relationship with estrogen was found.	Cycle phase was very broadly defined (follicular day 0-14; luteal day 15-31) and therefore the findings might be influenced by interphase hormonal fluctuations. The study did not include positive images. Only free recall showed a relationship with progesterone and negative valenced material, but recognition memory was at a ceiling effect suggesting the information may have been to easy. The study cannot determine that recognition is not affected by menstrual hormones. Did not include males. Difficult to ascertain if enhanced memory is relative to only NC females in a cyclically dependent manner, or also enhanced to males.

Felmingham et al, 2012	Do differing progesterone levels during the early follicular and luteal phases impact the encoding and retrieval of negative (threatening) vs neutral images under stress?	Healthy women, aged 18-40, were classified into high progesterone, mid-luteal (n=30; days unspecified), and low progesterone, follicular (n=26; days unspecified) groups based on salivary readings (between-subjects design). Participants viewed neutral and threatening (negative) IAPS images, followed by a stress or control condition. Memory recall was tested two days later.	Women with high progesterone levels (luteal phase) recalled threatening images under stress better than women in the low progesterone (follicular) phase. In the non-stress conduction negative image recall did not differ between groups. Suggests that progesterone mediates cortisol responses to stress and enhances memory for negative content.	The study mainly focuses on progesterone, without isolating the effects of estrogen. Though the authors mention a mediating effect of progesterone on cortisol, the study did not examine the mechanism for this. The study did not include positive images. The specific menstrual cycle days for were not noted, suggesting the authors allowed a wide gap in days which may have influenced the results.
Ferree et al., 2011	Do the luteal and follicular menstrual cycle phases influence recall of negative valenced film material and/or the occurrence of the number of spontaneous intrusive recollections of the films?	NC women aged 18-33 were divided into two between-subject groups: follicular (n=19, day 1-13) and luteal (n=21, day 15-28). Participants viewed films that contained violence toward humans or animals and were tested for recall after one week and asked to estimate the number of spontaneous intrusive recollections of the films.	There were no recall differences found between the two groups. However, women in the luteal group reported significantly more spontaneous intrusive recollection events.	This study showed no effects on emotional memory for negative valenced stimuli across broadly defined follicular and luteal groups. The authors did report increased spontaneous recollection of the films in the luteal group which they discuss as important to consider for mental health (i.e. PTSD) understanding in women. This study employed a very broad definition of follicular and luteal phases and did not include positively valenced stimuli.
Gamsakhur-dashvili et al., 2021	Do differing progesterone and/or estrogen levels during the follicular and luteal phases impact encoding and retrieval of negative vs positive vs neutral images?	N = 24 NC females in the follicular phase (days 10-13); n = 24 NC females in the luteal phase (days 17-23) and n=24 women on oral contraceptives (days 6-20); between-subjects design. In the first session of the experiment, negative, positive and neutral IAPS images (n=20 for each stimulus) were presented (memory encoding) while recording mimic and skin-conductance responses. Additionally, participants were exposed to a post-encoding stressor (cold pressor test). After 24 h, surprise-free recall and empathy-related performance. For the purposes of this review, only the memory results are discussed.	The authors found overall enhanced memory for emotional images compared to neutral images and enhanced memory for negative images compared to positive images, but there were no group differences found between women in the follicular or luteal phases.	This study used a much narrower window to assign participants to the follicular and luteal groups than earlier studies, a factor which might be important for the null effect interpretation. The authors conducted many other tests after the emotional memory procedure, which may have affected encoding.

Nielsen et al., 2013	Does encoding of emotional content differ between the follicular and luteal phases for gist and detail recall in NC women compared to men?	N = 39 male and N= 59 NC female undergraduates aged 18–33. The NC women were further divided into a "follicular" group (n=28; day 1-14) or a "luteal" group (n=31; day 15-30) (between-subjects design). The participants viewed a brief, narrated, three-phase story containing neutral or emotionally arousing elements. One week later, participants were called for a surprise free recall test for story elements.	Women in the luteal phase, but not during the follicular phase of the menstrual cycle recalled more details from an emotional than a neutral story. Men, whose testosterone levels were elevated compared to all women, recalled more details about the gist of an emotional story, compared to a neutral story.	It is challenging to ascertain the nuances that may arise in emotional memory due to the valence (positive or negative) of emotional stimuli as the authors do not give any details on the emotional content of the stories subjects read. The researchers used a very broad window to assign participants to the follicular and luteal phases; more recent studies use more narrow windows to control for variations within these two broad menstrual phases.
Pompili et al., 2016	Do differing estrogen levels during the early follicular and periovulatory phases impact encoding and retrieval of negative vs positive vs neutral images?	N = 46 healthy, NC women aged 21-27. In a between-subjects design, participants were grouped into an Early Follicular (EF) group (n=20) (day 1-4) and a Periovulatory (PO) group (n=18) (day 12-16). Note, the periovulatory group overlaps with follicular and luteal day definitions in other studies. Participants viewed positive, negative and neutral (n=50 of each type) IAPS images during follicular and luteal phases, and free recall was tested one week later. EEG was also recorded during encoding.	Overall emotional images were recalled better than neutral images. Elevated estrogen levels in the PO group compared to the EF group were related to increased memory for positive images. Some evidence for enhanced memory for negative images in the EF group.	The use of the periovulatory phase makes comparison of this study's results challenging to the other studies in this review. The two groups of women did not differ in progesterone levels, rendering comparison between other studies also challenging.
Wassell et al., 2015	Does mental imagery strength interact with progesterone to influencethe recall of negative images?	NC undergraduate women divided into two between-subject groups. Late follicular women (n=20; day 8-13) and mid-luteal women (n=20; day 18-24) and 20 undergraduate men were assessed for the strength of visual imagery and shown negative and neutral IAPS images. They were asked to view these images with an emphasis on either visual (i.e. perceptual) or verbal (i.e. conceptual) characteristics. A surprise free-recall test was administered after 2 days.	Negative images processed for perceptual (visual) features were recalled better by women in the luteal group compared to the other groups. The results suggest that imagery interacts with valence during the luteal phase to enhance memory for negatively valenced images.	The study shows nuanced effects for negative stimuli, where only negative images processed for their visual features show enhanced memory. No implications about positive valenced material can be made. Strengths include a narrower window for defining the luteal and follicular phases and including a male control group.

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