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The impact of ovarian hormones on binge eating episodes and related behavioral, motivational, and emotional components

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Abstract

Introduction: Binge Eating Disorder (BED) is characterized by the excessive consumption of food within a limited time frame, surpassing what most individuals would consume under similar circumstances. These episodes are accompanied by a sense of loss of control, leading to significant emotional distress. This dysfunctional eating pattern may be associated with two motivational subsystems: wanting (i.e., the drive to eat) and liking (i.e., sensory pleasure). According to epidemiological studies conducted in the United States, the prevalence of BED is 1.25% in women and 0.42% in men. These differences could be explained by the hormonal fluctuations that occur throughout the different phases of the menstrual cycle. Objective: To provide a brief review compiling published research on the impact of ovarian hormones (i.e., estradiol and progesterone) on binge eating episodes, emotional responses, motivational components (i.e., liking and wanting), and loss of control. Discussion: Estradiol exerts anxiolytic and anorexigenic effects, thereby reducing binge episodes. In contrast, elevated levels of progesterone increase both food intake and negative emotional responses. Regarding motivational components, higher estradiol levels decrease wanting and increase liking, which could be explained by an increase in taste detection thresholds. Progesterone tends to produce the opposite effect. While inhibitory control increases with progesterone and decreases with estradiol, this relationship can be reversed when the stimulus has a sexual nature.

Keywords Ovarian hormones, estradiol, progesterone, binge eating disorder

1. Introduction

Binge Eating Disorder (BED) is characterized by recurrent episodes of excessive consumption of palatable foods within a short period, in quantities significantly greater than what most individuals would consume under similar circumstances. During these episodes, individuals experience a loss of control, leading to significant emotional distress. For diagnosis, these episodes must occur at least once a week for a minimum of three months and be accompanied by at least three of the following symptoms: eating rapidly, feeling excessively full, eating large amounts without physical hunger, eating alone due to embarrassment about the quantity consumed, and experiencing feelings of disgust, depression, or shame after the binge [1]. Epidemiological studies conducted in the United States report a prevalence of BED of 1.25% in women and 0.42% in men [2]. These differences between women and men (e.g. [3, 4]) may be explained by variations in ovarian hormones during different phases of the menstrual cycle.

The menstrual cycle is a natural process in women of reproductive age, regulated by complex hormonal interactions aimed at preparing the body for a potential pregnancy. While the average duration is 28 days, healthy cycles can range from 21 to 37 days. It is typically divided into six phases: early follicular (days 1-5), late follicular (days 6-12), ovulation (days 13-15), early luteal (days 16-19), mid luteal (days 20-23), and late luteal (days 24-28) [5].

The early follicular phase begins with menstruation, during which the uterine endometrium sheds and is expelled through the vagina as part of the menstrual bleeding. This process typically lasts for an average of 5 days and is influenced by low levels of estradiol and progesterone. In the late follicular phase, which typically spans from day 6 until ovulation, ovarian follicles mature and the endometrium prepares for potential

implantation. While progesterone levels remain low, estradiol gradually increases, reaching its peak just before ovulation (day 12). Ovulation occurs around days 13 to 15 of the cycle, when an egg is released from the ovary. Gradually, estradiol levels begin to decrease, while progesterone levels increase [5].

After ovulation, during the early luteal phase, the empty follicle transforms into the corpus luteum, which secretes estradiol and progesterone to prepare the endometrium for the potential implantation of the fertilized egg. This phase typically occurs between days 16 and 19. In the mid-luteal phase, the corpus luteum continues to produce estradiol and progesterone in significant amounts. This phase is crucial for maintaining the endometrium in a prepared and receptive state in case fertilization occurs. The duration of this phase spans from days 20 to 23. Finally, in the late luteal phase, if fertilization and pregnancy do not occur, the corpus luteum begins to degenerate, and estradiol and progesterone levels drop abruptly. This hormonal decline leads to the onset of the next menstrual cycle, marked by the disintegration of the endometrium and the beginning of menstruation. The duration of this phase spans from days 24 to 28 (see [6]).

In rodents, a polyestric estrous cycle of approximately 4 to 5 days occurs, consisting of four phases: proestrus (12-14 hours), estrus (25-27 hours), metestrus (6-8 hours), and diestrus (55-72 hours). These phases can be identified through morphological changes in vaginal cellular tissue. During proestrus, estradiol levels reach their peak, preparing for estrus, the phase in which ovulation occurs and estradiol levels begin to decline. Subsequently, in metestrus, progesterone levels increase, and in diestrus, progesterone reaches its highest point before decreasing again toward the next cycle (see [7-9]).

Some animal studies provide evidence that estradiol produces anorexigenic effects on food intake [10, 11], which decreases binge eating episodes [12]. In contrast, lowering estradiol levels through ovariectomy increases overeating [13, 14]. In humans, elevated estradiol levels have been found to be associated with greater dietary restriction [15]. Moreover, recent evidence suggests that abnormal ovarian hormone production—including elevated androgens in women with polycystic ovary syndrome—may contribute to binge eating behaviors [16, 17], highlighting the importance of considering hormonal abnormalities in the context of binge eating. Considering the above, the aim of this short review was to investigate the influence of ovarian hormones (i.e., estradiol and progesterone) on overeating episodes, emotional responses, motivational components (i.e., liking and wanting), and loss of control.

2. Methodology

This manuscript is a narrative review that synthesizes studies and theoretical contributions on the influence of ovarian hormones on eating behavior and related motivational, behavioral, and emotional processes. The selection of references was guided by the relevance of the works to the topic and the author's expertise in the field, rather than by a systematic search strategy. Both human and animal studies were considered to provide a broad and integrative perspective.

2.1 Overeating episodes and emotional responses

In everyday life, individuals make comparisons between expected and obtained rewards. When there is a negative discrepancy, an aversive emotional state known as frustration arises. Frustration is defined as an emotional, behavioral, and neurobiological response triggered by the reduction or omission of the quantity or quality of an appetitive stimulus, in the presence of an expectation of a larger reward (see [18]). Studies in rats have shown a substantial increase in intake in animals that re-encounter the reinforcer after its omission [19, 20] or devaluation [21]. Moreover, the increase in intake is dependent on and specific to the prior state of frustration, as less frustrating emotional states eliminate this effect, while situations of greater frustration exacerbate it [19].

Ovarian hormones may modulate feeding by regulating aversive emotional responses, as it has been observed that rats in estrus phase do not exhibit overeating episodes following previous frustration experiences [20]. Furthermore, ovariectomized rats exposed to an aversive emotional frustration event display binge eating episodes, which dissipate upon estradiol administration. This phenomenon is also observed in non-ovariectomized rats during the diestrus and proestrus phases of the ovarian cycle, but disappears during the estrous phase. Additionally, ovariectomized rats exhibit increased activity in various brain anatomical structures associated with the regulation of emotional responses, such as the central nucleus of the amygdala, the paraventricular nucleus of the hypothalamus, and the nuclei of the dorsal and ventral bed nuclei of the stria terminalis [14].

In humans, an increase in emotional eating [22], body dissatisfaction, and desire for thinness [23] has been reported during the mid-luteal phase compared to the follicular/ovulatory phase. These behaviors decrease with estradiol and increase with progesterone [22, 23]. Additionally, food consumption in response to aversive emotions increases in the presence of both hormones, suggesting that progesterone antagonizes the anorexigenic effects of estradiol [15].

2.2 Dopaminergic alterations in binge eating disorder

Throughout the menstrual cycle, hormonal fluctuations exert direct and opposing effects on the dopaminergic system, which is altered in Binge Eating Disorder (BED) [24-26]. While estradiol increases dopaminergic activity [27-31], progesterone tends to reduce it [32].

In women with binge eating episodes, the relationship between ovarian hormones and dysregulated eating is more pronounced compared to women without this disorder [33]. This could be explained by an increased

sensitivity to reward during the late luteal phase [34], making women with BED more prone to anticipate the reinforcing effects of excessive intake over a short period.

Elevations in dopamine may contribute to the initiation of binge eating behavior, but a downregulation can occur once a sustained pattern of overeating is established (see [35]). Some data suggest that overeating normalizes general aspects of dopaminergic signaling [36]. As a result, excessive intake of appetitive stimuli may reflect the need to reactivate a hypofunctional reward circuit [37, 38]. In this regard, treatments with dopaminergic agonists, such as lisdexamfetamine, improve dopaminergic and noradrenergic neurotransmission [39, 40] and reduce overeating in both rats [41, 42] and humans [43].

2.3 Inhibitory control

This alteration in the dopaminergic system could be related to the loss of control [44] experienced during binge episodes [1]. The ability to inhibit behavioral responses is fundamental in this context, as higher inhibition control allows individuals to resist immediate gratifications and suppress impulses, guiding them to adopt more adaptive behavior patterns in response to changes in the environment, thereby influencing the effectiveness of their behavioral decisions [45, 46].

While some studies report that women have greater inhibitory control than men [47, 48], other works report opposing results [49], or even indicate no significant differences between the sexes [50, 51]. This disparity in the literature could be explained by variations in ovarian hormones during the menstrual cycle, which may influence the ability to inhibit impulsive responses.

Swalve, Smethells, & Carroll [52] evaluated the effects of progesterone on impulsivity in a Go/No-Go task with reinforcement using sucrose pellets. The Go component was indicated by a light on the lever. During this stimulus, rats could press the lever to receive a sucrose pellet according to a variable interval schedule. The No-Go component was marked by an intermittent light on the lever. During No-Go stimuli, not pressing the lever resulted in the delivery of a pellet under a differential reinforcement of other behaviors (DRO) schedule of 30 seconds. If the rat pressed the lever during this phase, the DRO timer would reset to zero, delaying access to reinforcement and serving as a measure of motor impulsivity. The findings indicated that progesterone significantly decreased the total number of DRO resets in both male and female rats, suggesting a decrease in motor impulsivity due to sucrose pellets.

In humans, similar results were found when evaluating inhibitory control in women across three phases of their menstrual cycle and comparing it with men. Women were less efficient at inhibiting prepotent (i.e., dominant or automatic) responses during their follicular phase compared to their luteal phase. Additionally, women showed less efficient inhibitory control than men during their follicular phase, but not during their luteal phase [53].

Griskova-Bulanova et al. [54] evaluated the effect of estradiol and progesterone levels on inhibition in a Go/NoGo task, using electrophysiological measures in women. Participants performed a probabilistic auditory Go/NoGo task while the amplitudes and latencies of the N2 and P3 peaks were measured through electrodes placed on the Fz, Cz, and Pz regions. Hormonal levels of estradiol and progesterone were measured from saliva samples and correlated with electrophysiological responses. The findings showed that higher levels of estradiol were associated with a prolonged Go-P3 latency, suggesting a delay in the inhibition of Go responses. Furthermore, higher estradiol levels were associated with a more negative N2 amplitude over the frontal regions in both conditions, indicating greater attention or activation related to Go and NoGo stimuli. In contrast, higher progesterone levels were associated with a shortened NoGo-P3 latency, indicating that progesterone facilitates the inhibition of NoGo responses. These results suggest that estradiol and progesterone modulate inhibition differently in Go/NoGo tasks, affecting both response activation and suppression. Thus, estradiol appears to be related to a delay in the inhibition of responses, while progesterone facilitates the inhibition of NoGo responses.

In contrast to these findings, when processing stimuli related to the opposite sex, greater performance is observed during the follicular phase, suggesting an interaction between hormones and specific stimuli. This aligns with the hypothesis that women may have greater inhibitory control during phases when pregnancy is more likely, possibly related to evolutionary adaptations [55].

2.4 Motivational components

Other components linked to ovarian hormones include *wanting* (i.e., the willingness to eat) and *liking* (i.e., the sensory pleasure of eating [56]). *Wanting* refers to the motivational incentive value that, without directly involving sensory pleasure, anticipates and directs behavior toward pleasurable situations. This component is associated with dopaminergic circuits (e.g. [57]). On the other hand, *liking* corresponds to the hedonic or affective response, the brain activity that generates the sensory pleasure derived from a reinforcing stimulus. In this component, the opioid (e.g. [58]), endocannabinoid (e.g. [59]), and GABAergic (e.g. [60]) systems predominate.

A precise measure of *wanting* or incentive salience is the *breakpoint*, defined as the point at which an animal stops pressing a lever to receive a reward. This measure of the effort the subject is willing to exert to obtain the reinforcer is estimated through a progressive ratio schedule (e.g. [61, 62]). In progressive ratio schedules, the number of responses required to obtain a reward gradually increases throughout the trial. For example, the animal might need to perform 4 responses to receive the first reinforcer, then 8 responses for the next one, 16 responses for the next, and so on. The *breakpoint* is reached when the animal is unable to complete

the required number of responses within the set time limit or when its response rate decreases significantly, indicating the subject's ability to continue performing the task (e.g. [63]).

In a previous study, sex differences in the breakpoint under a progressive ratio schedule were investigated, along with changes in extracellular dopamine in the nucleus accumbens using intracerebral microdialysis. Although no significant differences were found between male rats, intact females, and ovariectomized females, females showed reduced lever-pressing behavior and consumption during the proestrus and estrus phases compared to diestrus and metestrus. Additionally, they exhibited increased extracellular dopamine levels in the shell subregion of the nucleus accumbens during the anticipation and consumption of the reward, suggesting lower sensitivity to reward-associated cues and reduced motivation to obtain the reward. These effects are attributed to estradiol, which peaks during proestrus and estrus and appears to reduce lever-pressing responses [64].

In a similar study, an effect of estradiol was found on lever pressing, food-seeking behavior, and the amount of food consumed. Specifically, these behaviors were reduced during the estrus phase compared to diestrus. Ovariectomy increases food intake, body weight, and wanting. Peripheral or intra-ventral tegmental area administration of estradiol reduced wanting but had no effect on chow intake, body weight, or locomotor activity [65].

On the other hand, *liking* can be assessed through the microstructure of consummatory behavior. Rats tend to perform bursts of licks when consuming a palatable solution. Each burst constitutes a time interval that varies according to the hedonic value of the reward. Longer or shorter intervals are associated with higher or lower hedonic value, respectively [66]. To measure these intervals of palatable food consumption, a lickometer is used. Each interval begins when the animal makes the first lick and ends when it pauses for at least 500 ms [67].

Stone et al. [68] evaluated flavor preference across the different phases of the estrous cycle, identified through vaginal cytology. The results showed an increase in the consumption of palatable foods 24–48 hours after peak estradiol levels. A more detailed analysis revealed that this increased intake reflects a general enhancement in palatability (i.e., higher preference for appetitive flavors and lower for aversive ones) during the metestrus phase compared to diestrus.

Another objective indicator used to assess *liking* is the orofacial response exhibited during the tasting of palatable or unpleasant stimuli. These taste reactivity behaviors appear to have evolved from a common ancestral source across humans, orangutans, chimpanzees, monkeys, rats, and mice [69, 70]. Orofacial behavior presents specific response patterns that can be categorized as typical of appetitive or aversive stimuli. The specific behavioral repertoire that constitutes each pattern varies according to the muscular and sensory capacities, as well as the dietary habits of the species under study. In rats, for example, appetitive patterns can be inferred by observing behaviors such as tongue protrusion, mouth movements, and forepaw licking. Aversive patterns include responses such as gaping (rapid, large-amplitude opening of the mandible with retraction of the corners of the mouth), chin rubbing (placing the mouth or chin in direct contact with the floor or wall of the chamber while projecting the body forward), and paw treading (forward and backward movements of the forepaws in synchronous alternation) (e.g. [71-75]).

Clarke and Ossenkopp [76] examined the effect of the estrous cycle on orofacial responses in female rats. The animals were tested either in the morning of estrus or metestrus, when estradiol levels are reportedly low, or in the morning of diestrus or proestrus, when estradiol levels are reportedly high [77]. The authors found that females tested during diestrus/proestrus displayed more appetitive responses than male rats, and fewer aversive responses compared to both male rats and females tested during estrus/metestrus. These findings are consistent with other measures of liking, such as lick counts. During estrus, a reduction in liking is observed only for low-concentration sucrose solutions [78].

In another study, the number of licks over a 10-second interval was evaluated in response to sucrose solutions of varying concentrations. Ovariectomized female rats treated with estradiol exhibited fewer licks to a low-concentration sucrose solution compared to male rats and ovariectomized females treated with vehicle. Their lick rate was similar to that observed when the animals received water. However, estradiol had no effect on the lick rate for higher-concentration sucrose solutions [79].

According to the authors, these results can be explained by two non-mutually exclusive hypotheses: estradiol may reduce the preference for less concentrated sucrose solutions or increase the detection threshold for diluted solutions.

To test these hypotheses, a conditioned taste aversion paradigm was conducted in ovariectomized rats by pairing a 0.2 M sucrose solution with a lithium chloride (LiCl) injection, which induces gastrointestinal malaise. Subsequently, the generalization of the aversion was assessed using 0.075 M and 0.025 M sucrose solutions during treatment with either estradiol or vehicle. Vehicle-treated rats generalized the LiCl-induced aversion to both sucrose concentrations. In contrast, estradiol-treated rats generalized the aversion to the 0.075 M solution but not to the 0.025 M solution. When estradiol was withdrawn from the system, both groups generalized the aversion to all sucrose concentrations.

These findings suggest that estradiol affects the ability to discriminate sucrose concentrations by increasing the taste detection threshold, and that its effects are transient [80]. However, this does not entirely rule out the possibility that estradiol also influences preference.

It is possible that estradiol operates through both mechanisms: altering concentration perception and modulating hedonic valuation by reducing the preference for low-value solutions.

3. Conclusion

Taken together, these findings suggest that ovarian hormones (i.e., estradiol and progesterone) are involved in variations in eating behavior, emotional responses, motivational components (i.e., liking and wanting), and inhibitory control (see Table 1).

First, estradiol exerts anorexigenic effects on food intake [10, 11, 15], which reduces binge eating episodes [12]. In contrast, elevated levels of progesterone tend to increase food intake [14]. These effects may interact with emotions of negative valence, as they tend to increase or decrease in response to elevated progesterone or estradiol levels, respectively [22, 23].

In rat studies, estradiol was shown to reduce anxiety, as measured in the open field. Rats treated with estradiol spent more time in the central quadrant, an indicator of reduced anxiety. In contrast, progesterone appears to counteract the anxiolytic effects of estradiol. Additionally, in the fear-potentiated startle test, estradiol increased the startle response at the beginning of the test, but this response quickly diminished, suggesting that estradiol intensifies learning and extinction processes of fear. The addition of progesterone to the estradiol treatment counteracts this effect, indicating that progesterone modulates the intensity of both anxiety and fear. Taken together, these findings suggest that estradiol and progesterone exert antagonistic effects on specific components of anxiety and fear [81].

In humans, women prone to anxiety exhibit a more intense panic cognitive response during the luteal phase, when progesterone levels are elevated, compared to the follicular phase, when these levels are lower [82]. A similar pattern was observed in non-clinical populations, where women reported higher levels of anxiety during the luteal phase compared to the follicular phase of the menstrual cycle [83]. Additionally, women with higher average progesterone levels throughout their menstrual cycle reported greater levels of anxiety compared to those with lower progesterone levels. In contrast, women with higher average estradiol levels throughout the cycle reported lower levels of anxiety [84].

Second, progesterone is associated with improved performance on various inhibitory control tasks [52-54]. Estradiol, on the other hand, appears to improve performance specifically when "No-go" stimuli have a sexual content [55]. These findings suggest that sex hormones not only influence the ability to inhibit automatic responses but also modulate the motivational relevance of stimuli, particularly in contexts where emotionally significant or incentive-driven signals are involved.

Table 1 Effects of Ovarian Hormones on Binge Eating, Emotional Response, Motivation, and Inhibitory Control.

Hormone	Effect on Binge Eating	Emotional Response	Motivational Component	Inhibitory Control
Estradiol	Decrease	Anxiolytic	Decrease Wanting, Increase Liking	Decrease Control
Progesterone	Increase	Negative emotions	Increase Wanting, Decrease Liking	Increase Control

Note: This table summarizes the effects of the main ovarian hormones, estradiol and progesterone, on binge eating episodes, emotional responses, motivational components (wanting and liking), and inhibitory control. Note that the relationship between hormones and inhibitory control may be reversed when the stimulus has a sexual nature.

Third, in addition to their influence on emotional and cognitive aspects, ovarian hormones also modulate motivational components. On the one hand, wanting tends to decrease with an increase in estradiol [64, 65], which is associated with elevated extracellular dopamine levels in the shell subregion of the nucleus accumbens [64]. On the other hand, the literature on liking presents more ambiguous findings. Some studies indicate that this component increases with high levels of estradiol [76] and decreases with high concentrations of progesterone [68]. However, other studies have found that estradiol is associated with a reduction in liking [78, 79]. One possible explanation is that estradiol affects taste sensitivity, decreasing the ability to discriminate solutions with low sucrose concentration, which would raise the threshold for taste detection [80]. In fact, in the studies reporting a decrease in liking, diluted sucrose solutions were used, and the responses of animals treated with estradiol were comparable to those observed when they were offered water [78, 79]. The direct effects of ovarian hormones on feeding could be explained, at least in part, by their influence on the dopaminergic system. Some studies suggest that overeating could be related to hypofunctional dopaminergic signaling, and excessive food consumption tends to normalize aspects of this dysfunction [36]. In this sense, since estradiol increases dopaminergic activity [27-31], it is coherent to observe a decrease in binge eating frequency induced by prior frustration events in the presence of elevated levels of this hormone [14, 20]. Considering that binge episodes tend to intensify during the mid-luteal phase of the menstrual cycle, it is plausible to think that this increase is due to the action of progesterone, which antagonizes the beneficial effects of estradiol [15], reduces dopaminergic activity [32], and increases sensitivity to emotional stressors [82]. In this context, an expectation might arise to seek

a pleasurable and familiar experience, such as excessive food consumption, to alleviate emotional distress. Usually, wanting is sensitive to current neurobiological and physiological states (see [85]), such as emotions. Peciña et al. [86] showed that corticotropin-releasing factor, a neurotransmitter related to stress, can enhance wanting similarly to dopamine. Additionally, some animal model studies suggest that progesterone might be associated with an increase in wanting [64]. Given that anxiety, stress, and binge episodes tend to increase during the luteal phase [87], it could be hypothesized that wanting would also be amplified during this phase of the menstrual cycle.

In summary, ovarian hormones have direct effects on feeding behavior, emotional responses, inhibitory control, and their motivational components. Although the available literature on these latter components does not specifically address binge episodes, it provides a foundation for understanding how they may be affected. Future studies could further explore the impact of ovarian hormones on liking, wanting, and inhibitory function, particularly in the context of binge eating disorder.

Author Contributions

The author did all the research work for this study.

Competing Interests

No conflicts of interest exist.

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