Effects of Menstrual Cycle-Associated Oestradiol Variations on Procedural Learning in Women of Reproductive Age

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Abstract

Women's unique physiology and menstrual cycle-associated hormone variations are often not taken into account in psychological research. Findings from menopause and hormone treatment research point towards oestradiol having an impact on verbal skills and memory. Furthermore, menstrual cycle and neuroimaging studies suggest that oestradiol might have an additional benefit on motor and verbal learning, as well as modulating brain plasticity. Therefore, by employing a repeated measures design, this study aimed to investigate the effect of two menstrual cycle phases associated with high and low oestradiol on several aspects of cognition, including motor speed, verbal fluency, verbal learning, and memory. Moreover, a novel second hypothesis proposed that women in the late follicular phase (LFP) (high oestradiol phase) will experience a larger learning effect between the first and second sessions on the cognitive tests, in comparison to women in the early follicular phase (EFP) (low oestradiol phase). A series of mixed ANOVAs revealed a main effect of the LFP on a test involving motor and processing speed, as well as a procedural learning advantage when testing was started in the EFP on several tasks involving visual search, verbal learning and memory. These results hold important implications regarding women's learning potential during low estradiol phases, such as menstruation, where learning tasks involving these skills might be easier. The current study's findings lead to the conclusion that women's unique hormonal profiles should be considered in psychological studies, as women might have an implicit learning advantage on several cognitive tasks.

Key Words: *Menstrual Cycle; Oestradiol Variation; Reproduction; Estradiol; Cognition.*

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Introduction

Women represent around 50% of the adult population (Statista, 2024), yet their unique physiology is often not taken into consideration within psychological enquiry. Women have a unique hormonal profile operating on a regular monthly cycle that is defined by changing levels of sex steroids (Thiyagarajan et al., 2024). With approximately 26% of the female population being of reproductive age (UNICEF, 2018), the investigation of how women's cognition is affected by the changing levels of hormones is a topic worthy of exploration. Additional research is necessary to expand our understanding of women's unique physiology and how it impacts their cognitive abilities, in order to advance consideration and inclusion of women in psychological research.

Research on the function of gonadal hormones, commonly referred to as sex steroids (i.e., oestrogen and progesterone), has advanced significantly in recent years, especially in the ageing female population. There has been considerable emphasis on researching how cognitive decline can be mitigated during menopause, a period of women's lives where hormonal production ceases. There is evidence of cognitive changes being observed during the menopausal transition, particularly a reduction in verbal memory and verbal fluency skills (Kilpi et al., 2020; Reuben et al., 2021; Weber et al., 2014), potentially resulting from the decreased sex steroid production. Similarly, self-reported cognitive complaints regarding attention and working memory are also often associated with the menopausal transition (Reuben et al., 2021), which suggests that the decrease in sex steroids resulting from menopause might have an impact on not only verbal skills, but working memory as well. Women are often offered hormone replacement therapy (HRT) treatments to combat menopause-related complaints such as hot flashes and mood changes. With HRT treatment often utilising oestradiol supplementation (Flores et al., 2021), evidence points towards a potential positive relationship between oestradiol and cognition when HRT is used during the

menopausal transition (Sharma et al., 2023). Observational studies have found that HRT supplementation might also have neuroprotective qualities on cognition by delaying the onset of cognitive decline (Sherwin, 1988, 2003), indicating that oestradiol might serve as a protective factor for age-related cognitive diseases.

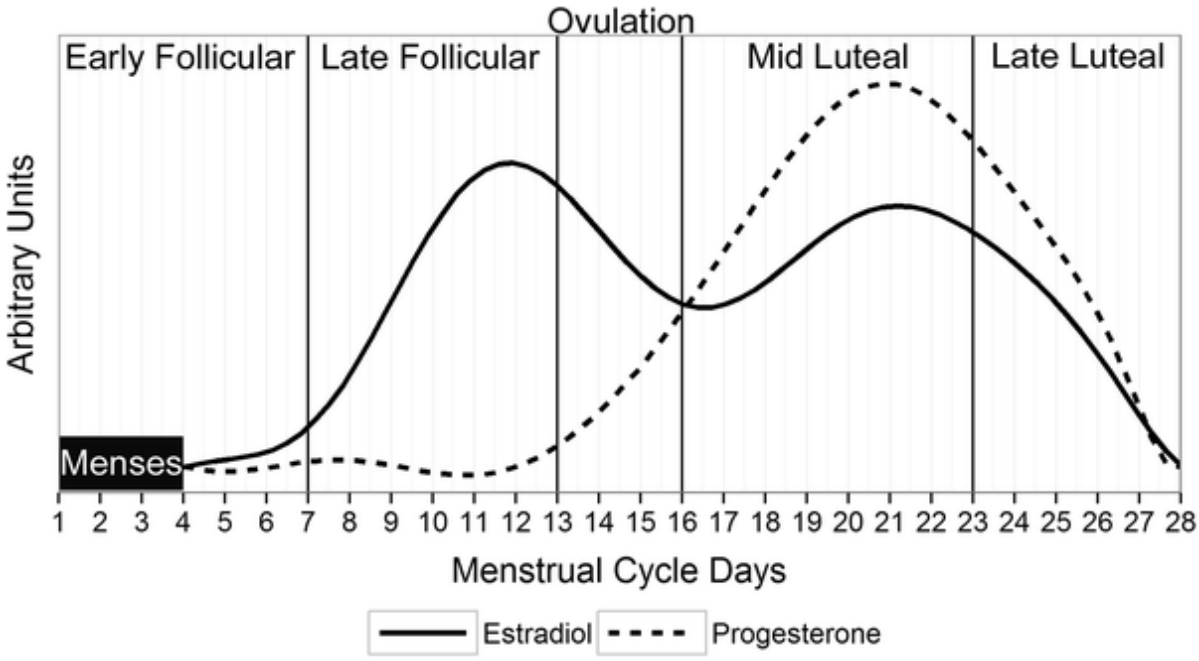
This is further supported by research exploring the relationships between the reduced production of sex steroids and the development of Alzheimer's Disease (AD). AD is characterised by a reduction in cognitive capacity, often manifesting as memory loss and verbal difficulties (Kumar et al., 2024). The prevalence of AD is often greater in women compared to men, which could be used to support this hormone link, as men do not experience the sharp hormonal decline that women do (Andersen et al., 1999; Farrer et al., 1997). Although women's longer life expectancy might be a moderator when considering these findings, women also experience greater age-related sex steroid loss in contrast to men (Rosario et al., 2011), which could strengthen the link between sex steroid loss and cognition. Oestradiol, specifically, has been a subject of interest as correlations have been identified between oestradiol's decline and the development of age-related neurodegenerative diseases, such as AD, in both animal and human studies (Pike, 2017; Rosario et al., 2011; Yue et al., 2005). Whilst the role of oestradiol is not fully understood, with other studies suggesting that a larger lifetime exposure to oestradiol could contribute to an increased risk of AD (Geerlings et al., 2001; Najar et al., 2020), it is clear that oestradiol might indeed play an important role in mediating aspects of cognition in older women.

Although there is plenty of evidence discussing oestradiol in the older population, less research has focused on how normal menstrual cycle-associated oestradiol changes might affect reproductive-aged women. It is well known that sex steroids fluctuate throughout the menstrual cycle (Thiyagarajan et al., 2024). The menstrual cycle can be divided into two main phases: the follicular phase, which starts with the onset of menstruation and ends with ovulation

(usually between days 1-14), and the luteal phase, which is the period between ovulation and the next menstrual phase (usually days 15-28). During the early follicular phase, oestradiol and progesterone are low. Oestradiol rises and peaks shortly before ovulation, while progesterone peaks shortly after, with elevated levels of both hormones being maintained throughout the luteal phase (See Figure 1). Early studies comparing men's and women's cognition have shown that women's performance is indeed dependent on their menstrual cycle phase (Hampson, 1990). For instance, it appears that higher hormone levels improve performance on verbal tasks (Sherwin, 2012), as well as tasks involving perceptual and manual speed when women are tested in the midluteal phase (Hampson, 1990).

Figure 1

Visualisation of hormonal variations during a 28-day menstrual cycle



Note. Theoretical pattern of oestradiol and progesterone changes in the corresponding menstrual cycle phase. Taken from Tenan et al. (2016).

Contemporary findings reveal a similar pattern, with studies finding that oestradiol is positively associated with verbal skills on several tasks such as categorical word generation and narrative production (Kheloui et al., 2021; Schultheiss et al., 2021). Novel findings have also emerged, showing that higher levels of oestradiol contribute to an array of cognitive advantages during testing. For instance, studies show that naturally cycling women perform better on learning tasks, such as motor learning (Ikarashi et al., 2020) during the late follicular phase (i.e., peak in oestradiol), as well as enhanced verbal implicit memory during high oestradiol phases (Maki et al., 2002). However, there is debate over the existence of hormonal influence, as well as its direction, with menstrual cycle studies often yielding mixed results. For instance, some authors argue that the effects of the menstrual cycle are only observable for mood and not for cognition (Sundström-Poromaa, 2018) or that there are no changes in cognition throughout the menstrual cycle at all, with meta-analyses concluding that results are inconsistent and critiquing small sample sizes (Jang et al., 2025). Leeners et al. (2017), for instance, found that the cognitive effects associated with the menstrual cycle disappear when non-cross-sectional methodologies are used and women are tested during two consecutive menstrual cycles instead of one.

The effects of oestradiol on the brain are perhaps better understood through neuroimaging research, in contrast to contradictory findings seen in menstrual cycle studies. Primarily, the discovery of oestradiol receptors in several brain regions associated with cognitive function, such as the hippocampus and prefrontal cortex, can be used to support oestradiol's hypothesised influence (Hara et al., 2015; McEwen et al., 2017). For example, animal studies have demonstrated a correlation between higher oestradiol levels and better performance on tasks measuring different aspects of memory, such as spatial memory and object recognition (Engler-Chiurazzi et al., 2016; Wallace et al., 2006). Furthermore, a review discussing recent neuroimaging studies across the menstrual cycle demonstrates multiple

positive associations between oestradiol, but not progesterone, and hippocampal volume (Beltz & Moser, 2020), pointing to potential memory and learning advantages associated with oestradiol. Namely, one study found that observations in the late follicular phase showed greater grey matter volume compared to the early follicular phase (Lisofsky et al., 2015). With Beltz & Moser (2020) considering oestradiol data from not only menstrual cycle studies, but also menopause and hormonal contraceptive use they concluded that despite oestradiol impacting verbal and memory skills, the interaction between oestradiol and other hormones is extremely complex. Several studies show that menstrual cycle-dependant oestradiol changes have an observable effect on brain structure and functionality (Catenaccio et al., 2016; Lisofsky et al., 2015; Sumner et al., 2018), leading authors to conclude that the influence of higher oestradiol levels might contribute to brain plasticity, indicating an increased learning potential in healthy reproductive-aged women in high oestradiol phases. The theoretical assumptions underlying these findings are that perhaps oestradiol has a role in regulating engagement between hippocampus and striatum learning strategies, indicating that it might have differing effects on learning potential and learning outcomes (Korol & Pisani, 2015).

Despite mixed evidence, there is a pattern that suggests oestradiol might provide an advantage to women's performance on some cognitive tasks. With a gap in the literature surrounding oestradiol's effects on cognition in young women, this study aimed to investigate the effects of menstrual cycle-associated oestradiol variations on reproductive-aged women's cognitive abilities, during low and high oestradiol phases. Specifically, during the early follicular phase (EFP) when oestradiol is low (cycle days 2-3) and the late follicular phase (LFP) when oestradiol levels are elevated (cycle days 11-14).

It is hypothesised that changing levels of oestradiol during the menstrual cycle will have an effect on women's performance on tasks measuring aspects of cognition impacted by oestradiol, such as memory and verbal fluency. Due to the wide range of available cognitive

tasks, this study will focus on tests which specifically measure information processing and motor speed, verbal fluency, verbal learning, and memory, aspects of cognition that have been shown sensitive to oestradiol decline in older population studies.

Secondly, it was hypothesised that women who start testing in the late follicular phase (LFP) first and are subsequently tested in the early follicular phase (EFP) after, will gain a larger procedural learning advantage, compared to women who start testing in the EFP first and are then tested in the LFP. With oestradiol being higher in the LFP compared to the EFP, this hypothesis is based on the assumption that oestradiol can have potential learning advantages as proposed by the literature.

Methods

Participants

A total of 20 female participants (Age: 20-28, M = 23.35, *SD* = 2.58) were recruited through the distribution of study posters (Appendix A) across the Loughborough University campus, as well as additional snowball sampling between January and March 2025. Inclusion criteria included being over 18 and of reproductive age (18-35), having a regular menstrual cycle (22-35 days) (Reed & Carr, 2018), no hormonal contraceptive use in the past 6 months (excluding emergency contraception), not currently pregnant or given birth in the past 6 months, and having no significant health concerns that might impact the menstrual cycle, such as endocrine conditions.

Participants were screened using the Health Screen Questionnaire (HSQ) for Study Volunteers. No significant health concerns were reported. All participants stated their last menstrual cycle to have been between 23-35 days (M=28.30, *SD*=3.60). One participant reported that their cycle was sometimes irregular, despite it being within the normal day range

(their scores did not differ compared to the other participants, so they were included in the analysis).

Materials

Trail Making Test (TMT, Reitan & Wolfson, 1985)

The Trail Making Test (TMT) (Appendix B) was employed in this study to measure several executive function skills, including attention and visual search. It is composed of two parts, consisting of 25 circles each, distributed on a piece of paper. In Part A, the circles are numbered 1-25, and in Part B, circles include both numbers (1-13) and letters (A-L). Participants were asked to connect the circles in ascending order. In part B, participants were asked to alternate between numbers and letters in ascending order (1-A-2-B, etc.). Participants were informed that they would be timed and were instructed to connect the circles as quickly as possible without lifting the pen from the paper. Time was measured in seconds, with shorter completion time indicating better attention and visual search skills. Reassurance was provided that if a mistake is made, the participant can correct it and continue the process, with the time taken to correct the mistake still being included in the total time taken to complete the test.

Symbol Digit Modalities Test (SDMT, Smith, 1973)

The Symbol Digit Modalities Test (SDMT) (Appendix C) assessed several aspects of cognition, including information processing speed, visual scanning and motor speed. Participants were presented with a reference key of 9 matched symbols and numbers, as well as a sheet of symbols with blank spaces where numbers should be entered. They were then asked to pair as many of the presented symbols with the corresponding numbers in a span of 90 seconds. The SDMT was scored by counting the number of correct matches, with a higher score indicating better processing and motor speed skills.

Verbal Fluency (Tombaugh et al., 1999)

A categorical verbal fluency task was used where participants were asked to name as many animals as they could in 60 seconds. Any animals were accepted as correct answers, including categories (e.g., brown bear, polar bear), but excluding mythical animals, such as dragons or unicorns. Higher numbers of animals named indicated higher levels of verbal fluency.

Hopkins Verbal Learning Test (HVLT, Brandt, 1991)

Form 1 of the Hopkins Verbal Learning Test (HVLT) (Appendix D), was used to measure participants' verbal learning and memory. Participants were instructed that a list of words would be read out to them and they were asked to recall as many of the words in any order after the investigator had finished reading them out. The list was read out with two second between each word. This procedure was repeated two more times immediately after with the added instruction to recall as many of the words including the ones they had named before. The total sum of words across the three trials was recorded as the final score of the HVLT, with a higher number of words recalled indicating greater verbal learning abilities.

Procedure

Women who expressed interest in participating were sent out a template email (Appendix E) providing them with an attached participant information sheet (Appendix F), inviting them to a Teams meeting. Participants were randomly allocated to the EFP-first group or LFP-first group based on a coin flip. During the Teams meeting, participants were sent a consent form (Appendix G) and the HSQ (Appendix H) and were asked to complete them during the meeting. The information from the participant's HSQ was used to set up the first

meeting or record the predicted date of their next menstrual cycle. For participants who had to wait for their next menstrual cycle to start, a reminder email was sent out on the predicted date to arrange the first meeting.

During the first experimental session, participants were asked to complete a physical copy of the consent form before testing. Testing started with the TMT, followed by the SDMT, the verbal fluency test and then the HVLT. After testing was completed, the date of the next session was arranged (i.e., if the first testing session was done on cycle day 2 the next session would be scheduled on days 11-14), or a prediction was recorded (i.e., if testing started on days 11-14, the predicted date of the next cycle would be recorded and a reminder email would be sent close to that date to schedule the next meeting). During the second experimental session, the same process and testing order were implemented, with a repeated visits form being completed instead of the consent form. Overall, each visit took 10-15 minutes total.

Arbitrary identifiers were assigned to participants (P1, P2 etc.) and were maintained throughout the study when keeping track of the participants' menstrual cycles. All physical data was associated with the relevant participant identifier and was kept in locked storage separate from the physical consent forms. The digital versions of the consent forms and HSQs were stored on Loughborough University's OneDrive server. Full ethical clearance was obtained from the Loughborough University Ethics Committee before the start of recruitment (LEON ID: 21049) (Appendix I).

Data Analysis

All data was initially recorded on Microsoft Excel and then entered and analysed using IBM SPSS version 28.0. A repeated measures design was used to measure performance during the early follicular phase (EFP) and the late follicular phase (LFP), to check for a main effect of cycle phase on attention, information processing speed, verbal fluency, verbal learning, and

memory. The starting phase served as a between-subjects factor to test for a learning effect dependent on starting phase. Therefore, five mixed methods ANOVAs were conducted to analyse performance on the different tests between the two phases.

Preliminary analyses were run to ensure no violations of assumptions. Two participants had abnormally large scores on the TMT-B due to making an error, not spotted and corrected in time by the investigator. These scores were confirmed as outliers in SPSS. In order to avoid violating the assumptions of normality within the data, these were replaced with the mean scores for the TMT-B. This decision was justified, since two other participants whose errors were pointed out by the investigator scored significantly lower in comparison to the two outliers. A Shapiro-Wilk test confirmed normality within the data distribution ($W(10) \geq .857$, $p \geq .07$) on all testing sessions, except for the HVLT completed during the LFP for participants who started testing in the LFP first ($W(10) = .830$, $p \geq .033$). The Levene's tests of Homogeneity of Variances showed no significant differences ($F(1,18) \geq .002$, $p \geq .091$) on all tests, except on the TMT-A during the EFP, and SDMT during the LFP, where p values were $p = .045$ and $p = .026$, respectively. Thus, indicating that there were significant differences on those two tests during the respective menstrual cycle phases. Box's Test of Equality of Covariance Matrices was not significant across all testing sessions ($p \geq .225$), indicating that intercorrelations within both groups were consistent. Sphericity was assumed as there were only two levels to menstrual cycle phase.

Results

Descriptive Statistics

The descriptive statistics for all employed measures during the study are displayed in Table 1.

Table 1

Mean Scores and SDs for Performance on All Cognitive Tests During the EFP and LFP

Tests	EFP		LFP	
	Mean	*SD*	Mean	*SD*
TMT-A	19.43	5.45	19.18	5.01
TMT-B	36.59	8.12	39.41	13.91
SDMT	58.85	7.06	61.35	7.10
Verbal Fluency	24.9	6.12	23.95	6.35
HVLT	29.35	4.44	30.10	3.04

Note. TMT scores are measured in seconds. SDMT scores correspond to the number of correctly symbol-digit pairs in 90 seconds. Verbal fluency scores represent the number of animal names produced in 60 seconds. HVLT scores represent the sum of correctly recalled words over the three trials.

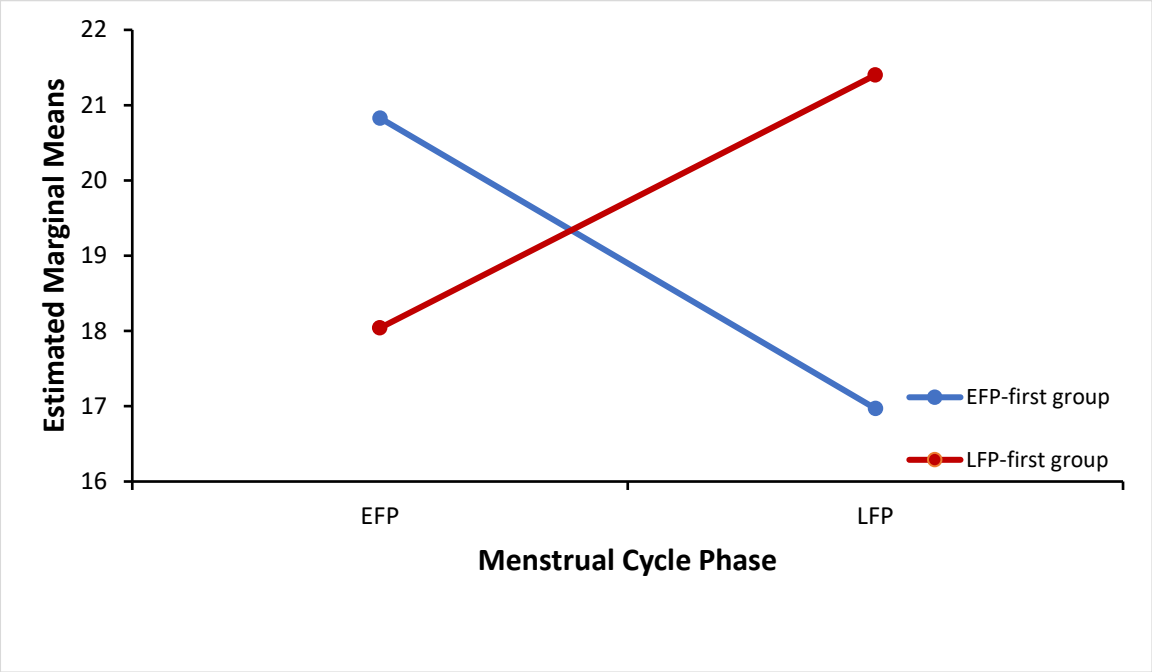
Cognitive Measures

Trail Making Test Part A (TMT-A)

The mixed ANOVA did not find a significant main effect of menstrual cycle phase on the time taken to complete the TMT-A. However, the interaction between the testing starting phase and menstrual cycle phase did reach statistical significance ($F(1,18) = 10.596$, $p = .004$, $\eta^2 = .371$), suggesting that there was a large effect size (Cohen, 1988) of starting phase on time taken to complete the TMT-A during the different menstrual cycle phases (Figure 2). Although both groups completed the task in less time during their second visit, the EFP-first group made a larger improvement in reducing the time taken to complete the test between their first (EMM = 20.83) and second visit (EMM = 16.97), compared to the LFP-first group's first (EMM = 21.40) and second visits (EMM = 18.04).

Figure 2

Interaction Between Menstrual Cycle Phase and Starting Phase on TMT-A Scores



Note. Estimated marginal means of response time in seconds on the TMT-A during the EFP and LFP.

Trail Making Test Part B (TMT-B)

The mixed ANOVA did not find a significant main effect of menstrual cycle phase on the time taken to complete the TMT-B, ($F(1,18) = .830$, $p = .374$, $\eta^2 = .044$), as well as any interaction effects ($F(1,18) = 2.793$, $p = .112$, $\eta^2 = .134$), indicating that this test might not be affected by menstrual cycle-associated oestradiol changes.

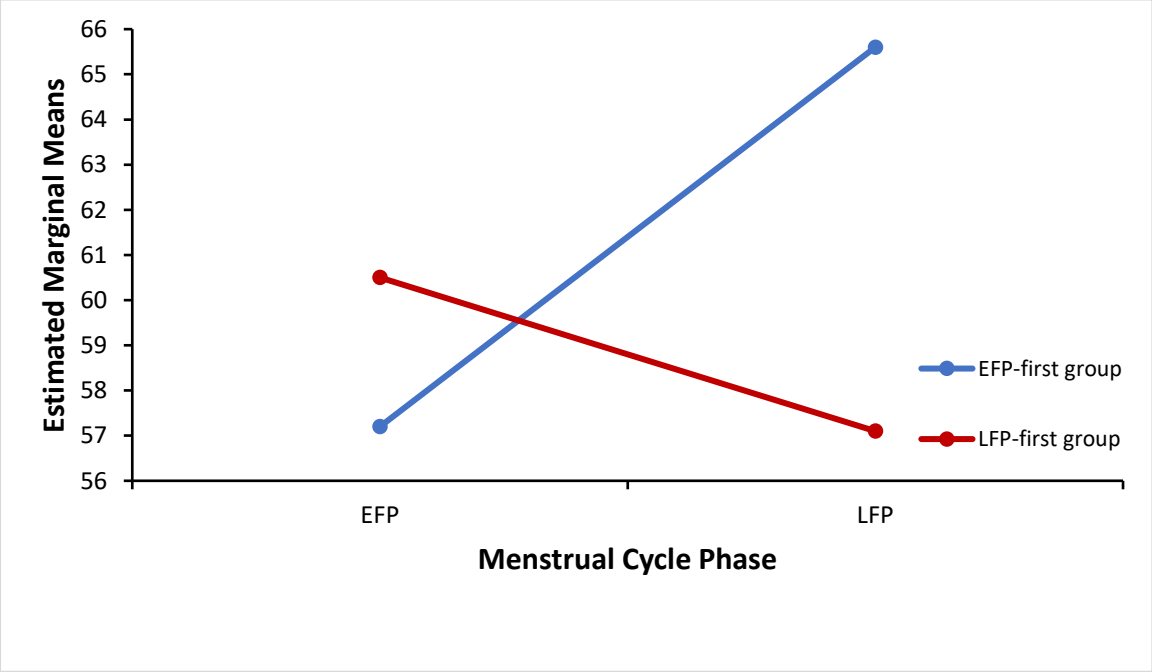
Symbol Digit Modalities Test (SDMT)

There was a significant main effect of menstrual cycle phase on SDMT performance ($F(1, 18) = 4.80$, $p = .042$, $\eta^2 = .211$), a large effect size according to Cohen (1988). This indicates that variations in processing and motor speed measured by the number of correct digit substitutions on the SDMT could be impacted by oestradiol variations during the EFP and LFP phases.

Performance was generally better during the LFP (EMM = 61.350) compared to the EFP (EMM = 58.850). Furthermore, a significant interaction was detected between menstrual cycle phase and the phase in which testing was started ($F(1, 18) = 26.73$, $p < .001$, $\eta^2 = .598$). Participants who started in the EFP, made a larger improvement between the EFP phase (EMM = 57.20) and the LFP phase (EMM = 65.6) compared to those who started in the LFP first (EMM =57.10) and (EMM = 60.50) (Figure 3).

Figure 3

Interaction Between Menstrual Cycle Phase and Starting Phase on SDMT Scores



Note. Estimated marginal means of correct number-symbol substitution on the SDMT in a 90-second time period during the EFP and LFP.

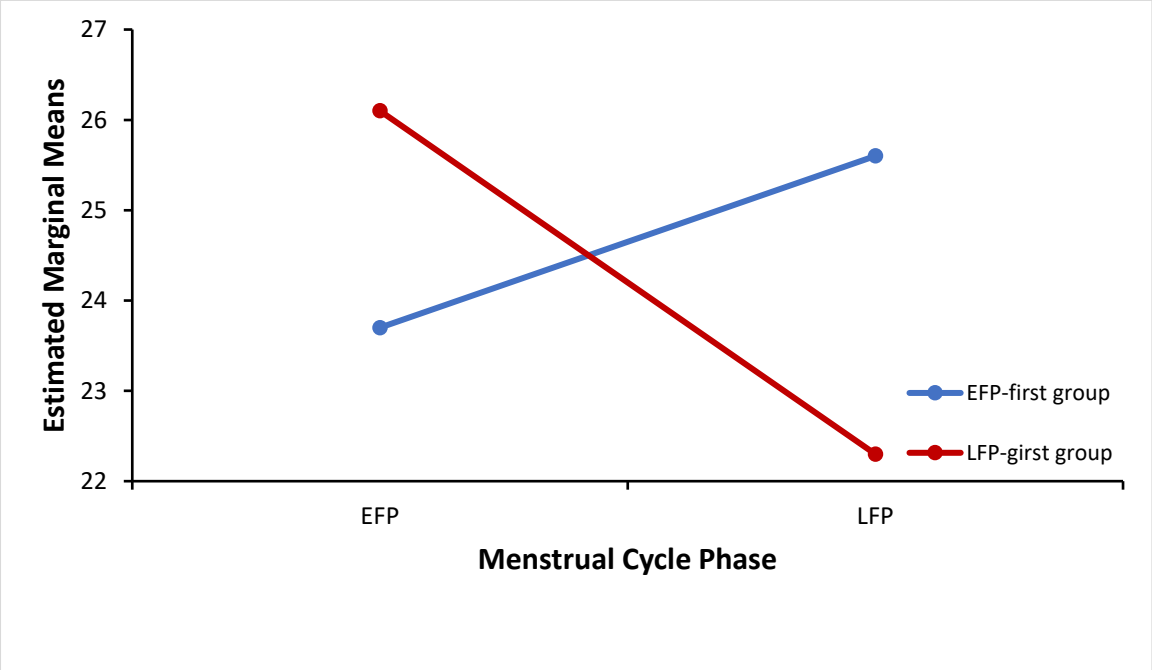
Verbal Fluency

No significant main effect was detected of menstrual cycle phase on verbal fluency ($F(1,18) = .891$, $p = .358$, $\eta^2 = .047$). However, there was a large interaction effect, according to Cohen (1988), between starting phase and menstrual cycle phase on the number of animal names

participants produced ($F(1, 18) = 8.02$, $p = .011$, $\eta^2 = .308$) (Figure 4). Estimate marginal means showed that although both groups were able to produce more animal names during their second visit, participants starting in the LFP made a larger improvement between their first visit (EMM = 22.30) and their second visit (EMM = 26.10), in contrast to the EFP-first group's visits (EMM =23.70) and (EMM = 25.60), respectively.

Figure 4

Interaction Between Menstrual Cycle Phase and Starting Phase on Verbal Fluency Scores



Note. Estimated marginal means of the animals named in 60 seconds during the EFP and LFP.

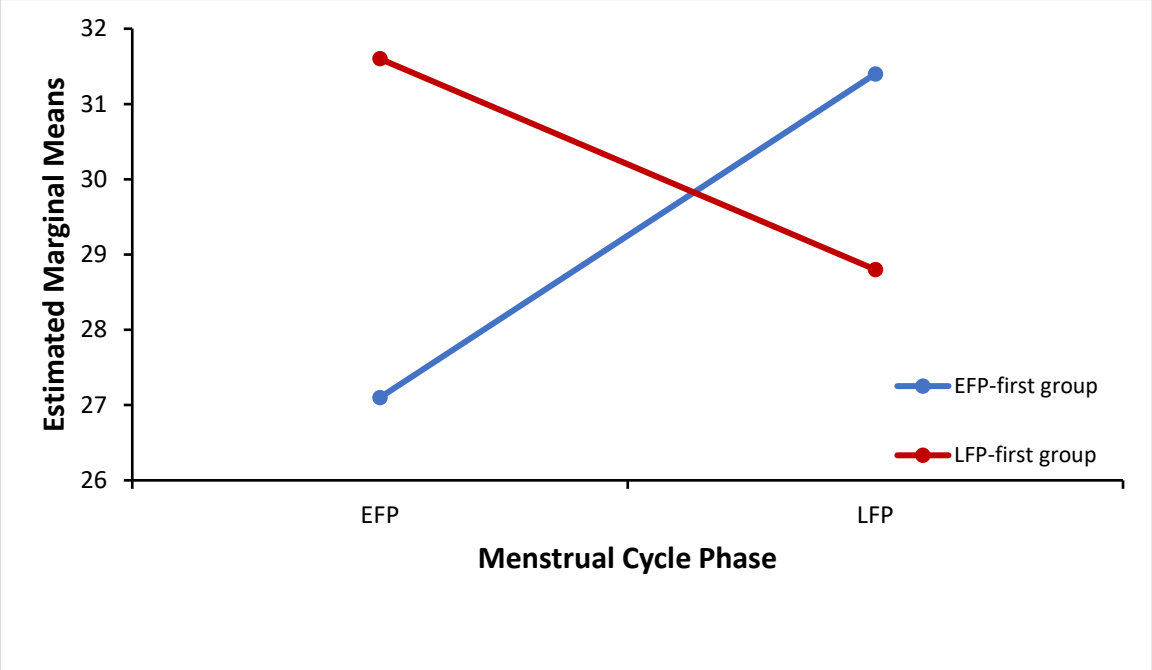
Hopkins Verbal Learning (HVLT)

A mixed ANOVA showed a significant interaction effect only, between starting phase and menstrual cycle phase on verbal learning and memory ($F(1, 18) = 29.52$, $p < .001$, $\eta^2 = .621$), Estimated marginal means showed that those in the EFP-first group recalled more words during their second visit (EMM = 31.40) compared to their first visit (EMM = 27.1). Although in comparison the LFP-first group were able to recall a larger number of words during their first

visit (EMM = 28.8), they did not make as much improvement on their second visit (EMM = 31.6), in contrast to the EFP-first group (Figure 5).

Figure 5

Interaction Between Menstrual Cycle Phase and Starting Phase on HVLT Scores



Note. Estimated marginal means of total words recalled on the HVLT during the EFP and LFP.

Discussion

This study sought to investigate the effects of menstrual cycle-associated oestradiol changes on women's cognitive abilities on a battery of tests measuring processing and motor speed, verbal fluency, learning, and memory. The current findings reveal that the effect of menstrual cycle phase can only be detected on the SDMT. To our knowledge, this was the first study to also test for a procedural learning potential as a result of menstrual cycle-associated oestradiol changes in healthy reproductive-aged women. The hypothesised learning effect was evident, however, its direction differed depending on the employed test, with an advantage being seen for the EFP-first group on the TMT-A, SDMT and HVLT.

Participants in the LFP, where oestradiol levels were assumed to be higher compared to the EFP, scored better on the SDMT than those in the EFP, thus supporting the first hypothesis. This finding indicates that higher oestradiol levels might be advantageous in tasks involving motor and processing speed, such as the SDMT. This is in line with earlier research that indicates women in high-oestradiol phases, such as the LFP and luteal phase, outperform those in low-oestradiol phases on tasks involving manual and perceptual speed (Hampson, 1990; Sherwin, 2012). Despite the use of a different test in the current study compared to Hampson (1990), who used six different tests measuring speed, the pattern of results is similar. This could mean that oestradiol's effects on motor and perceptual speed are significant and can be observed regardless of the tests used. It is, however, important to note that Hampson (1990) tested for these during the midluteal phase, instead of the LFP, where both progesterone and oestradiol are elevated (refer to Figure 1). This is an important distinction as the hormonal interaction in the midluteal phase makes it harder to distinguish the causality of the effects (Beltz & Moser, 2020).

Furthermore, a procedural learning effect were also observed on the SDMT. In contrast to other studies investigating motor learning, the current findings demonstrate a greater learning effect when testing was started during the EFP, instead of the LFP as seen previously (Ikarashi, 2021). Similar results were observed in the TMT-A and HVLT, where a larger learning effect was observed in the EFP-first group and not the LFP-first group, which is contrary to neuroimaging research that proposes high oestradiol phases to be associated with learning advantages (Beltz & Moser, 2020; Lisofsky et al., 2015). Since implicit procedural learning across the menstrual cycle has not been investigated previously, it is possible that the learning potential found in neuroimaging studies as a result of oestradiol changes during the menstrual cycle is too small to be translated into field studies, such as this one. Another possibility is that there is no learning effect on tasks specifically measuring attention and visual

search, such as the TMT, or motor learning and processing speed, such as the SDMT resulting from elevated oestradiol. This outcome would support the conclusion of Sundström-Poromaa (2018) in that the menstrual cycle does not have a significant impact on cognitive function.

With HVLT results following an identical trend, this largely contradicts findings from menopause and AD research that point towards verbal memory being most impacted by oestradiol changes (Kilpi et al., 2020; Reuben et al., 2021; Weber et al., 2014). The current findings suggest that the cognitive benefits associated with oestradiol, as seen during HRT, are perhaps only seen after there has been a substantial decline in oestradiol as a result of menopause or ageing, and such an impact does not occur during normal menstrual cycle hormonal variations. Furthermore, since this study did not investigate learning strategies, it might be the case that participants employed different strategies on the HVLT, which could be the reason for these conflicting outcomes (Korol & Pisani, 2015). For instance, a participant in the current study mentioned that they were able to identify the categories of the words used in the HVLT (e.g., animals, precious stones; See Appendix D) and were thus able to remember all words from one visit to the next, a strategy which might have not been used by all participants.

On the contrary, performance on the verbal fluency test showed a large learning effect in participants in the LFP-first group in comparison to the EFP-first group, thus supporting the second hypothesis and indicating that oestradiol might be advantageous in verbal learning, more so than verbal production or memory as seen in the HVLT. Despite contradicting previous findings that support better verbal fluency performance during high oestradiol phases (Maki et al., 2002; Sherwin, 2012), no difference in verbal fluency was detected between the two phases in the current study. A potential explanation for the difference in results in the current study might be that part of the sample were not native English speakers. Following the verbal fluency test, several participants reported having difficulty generating animal names in English, initially thinking of the names in their native language, thus needing additional time to translate

them. For instance, one participant produced the word steak instead of cow and expressed frustration in the inability to think of the right word in English after the 60 seconds were up.

It is important to consider a number of limitations in the present study that could have affected these findings. Firstly, since the sample was small, any variation in the results caused by extraneous circumstances, like a participant not having slept well, for instance, could potentially make a large difference in the study outcomes. Perhaps the most important limiting factor to consider is the lack of hormone measurements in the current study. This methodological lack is crucial in explaining the current results, as menstrual cycles are largely unique to each individual and they can be affected by a multitude of factors, including stress, exercise or changes in routine. Stress, for example, has been shown to cause irregular menstruation (Poitras et al., 2024), meaning that hormone profiles may be different than expected in the relevant phases. It is therefore impossible to confirm that participants experienced the hormonal peak of the LFP associated with cycle days 11-14 during the tested menstrual cycle. This might be a large part of the reason why no effects were observed on some measures, such as the verbal fluency test, where previous research points to better performance during high oestradiol phases (Maki et al., 2002; Sherwin, 2012). Likewise, this might be the reason why no learning effect was observed in the LFP-first group compared to the EFP-first group on the TMT, SDMT and HVLT.

With all of that considered, the present study merits valuable implications regarding the menstrual cycle's effect on cognition. Perhaps the most significant outcome from this study is the effect of the LFP on motor and processing speed. With these skills being dependent on oestradiol variations, this should be considered in psychological inquiry that utilises tasks involving motor and processing speed when sampling women. Furthermore, with a learning effect being observed in both the TMT-A, the SDMT, and the HVLT for the group who began testing in the EFP, this suggests that learning new skills that require motor speed, verbal

learning, or memory might be easier for women when started in the EFP. For instance, women might find it easier to learn a movement sequence needed for a sport or memorise certain phrases for an exam when they are in the EFP and oestradiol is at its lowest. However, these implications should nonetheless be interpreted with caution, as it is not certain how the skills measured using the current tests might translate to a real-life learning context. For example, learning a particular movement in a sport might require several different abilities beyond motor speed, and it is unclear how oestradiol would affect the way these interact.

Future research should focus on filling the methodological gaps presented in the current and previous studies. Hormone testing should be used in conjunction with distinct menstrual cycle phases to investigate the impact of oestradiol on young women's cognition, particularly the LFP. With the current study not being able to overcome the limitation of the cross-sectional design (Leeners et al., 2017), it will be beneficial for future studies to utilise repeated-measures over several menstrual cycles to examine whether the current effects of oestradiol on cognition can be replicated. Furthermore, seeing how such findings are applied and how these effects are translated in women's experiences with daily cognitive tasks during high and low oestradiol phases would be an important factor in progressing research of women's health and unique physiology.

Overall, research examining the effects of menstrual cycle on cognition remains extremely mixed, with the current study providing no clearer picture. However, despite limitations, this study was able to contribute to the understanding of how two oestradiol-associated menstrual cycle phases affect several cognitive abilities. Specifically, the positive effect of elevated oestradiol associated with the LFP on processing and motor speed has significant implications for women's performance in psychological tests, but also potential real-life applications to activities, such as sports. Furthermore, findings revealed that the hypothesised learning effect of the LFP was reversed, and participants who started testing in

EFP first showed a larger learning effect on tasks involving motor speed, verbal learning and memory, indicating that women might have a learning advantage during low oestradiol phases.

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