

Effects of the Menstrual Cycle on Working Memory: Comparison of Postmenstrual and Premenstrual Phases

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Abstract: This study aimed to examine the effects on working memory of the postmenstrual and premenstrual phases. The subjects were 12 female students. Computer-based tasks formulated by the authors, using the working memory that actively retains the information as the index, were used for experiments of 60 min during the premenstrual and postmenstrual phases. Session order was counter-balanced. The results showed that there was a significantly lower error rate for working memory tasks in the premenstrual phase, suggesting that task performance was good. Mild premenstrual symptoms had no effect on working memory function of the premenstrual phase. Further, no clear difference in terms of phase was found for mental workload or change in heart rate variability, which are used to evaluate workload. For this reason, the estrogen sex hormone secreted from the ovaries in relation to the menstrual cycle is thought to be involved in the working memory function rather than the indefinite menstrual complaint.

Key words: Menstrual cycle, Postmenstrual phase, Premenstrual phase, Working memory, Performance

Introduction

With the low birthrate and aging of the population in Japan, women are making a marked contribution to the workforce and their range of employment continues to expand. However, women have physical and mental symptoms during the menstrual cycle, and the indefinite menstrual complaint extends to 150–300 kinds. In addition, it is also said that 80–90% of women are aware of their indefinite menstrual complaints¹. Within the menstrual cycle, the wide variety of symptoms that appears during the premenstrual phase is known as the premenstrual syndrome (PMS). It has been pointed out that this result in big losses for industry, with many workplace accidents, reduced work ability and increased error rates². Also, within the menstrual cycle, poor work performance

in the premenstrual phase is often reported^{3–5}.

The nursing profession, in which many women are employed, is complex and varied, with a sense of time-related urgency and the constant need to determine priorities. This means that many tasks use working memory. For example, a nurse may be listening to patient D's complaint while filling the drip bottles for patients A, B and C with medication, or in many cases she may have to interrupt what she is doing to answer a nurse call. Working memory has to function in these cases when humans carry out several tasks in parallel. In other words, working memory entails carrying out important work in order to reach a goal, while retaining information that is temporarily required and at the same time retaining and processing other information^{6, 7}. There are two views with regard to the functioning of working memory. One places emphasis on the active retention of information for a certain period of time; the other emphasizes the flexi-

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ble processing of the actively retained information. For the working memory in this study, we assign a focus to the function of the working memory in the meaning of the former.

There are few previous studies that discuss the working memory in relation to the menstrual cycle. Rosenberg and Park⁸⁾ have reported that higher performance is shown for language working memory on days 7 and 14 of the menstrual cycle rather than on days 0 and 21. Grigорова *et al.*⁹⁾ also have reported that reduced estrogen levels in premenopausal women are associated with deterioration in working memory. Meanwhile, no significant differences were seen between the control group and the PMDD (premenstrual dysphoric disorder) group in the context of Spatial Working Memory, but it has been reported that a significantly higher error rate was found in both groups for the premenstrual phase as compared to the postmenstrual phase⁵⁾.

However, not much is known due to the fact that in previous studies the ages of the subjects varied, different times during the menstrual cycle were measured, and task performance differed due to job characteristics. Further, a uniform viewpoint could not be obtained in regards to which phase of the menstrual cycle working memory function deteriorates. By focusing on the relationship with indefinite menstrual complaint, we hypothesized that working memory function deteriorates in the premenstrual phase when mood and physical complaints are strongly present.

Therefore, this study focused on task performance in order to evaluate the function of working memory, due to the fact that the amount of computer input work on medical wards has increased with the spread of electronic charts. In this study, a task was formulated from the viewpoint of active retention of information, with working memory as the index. This study aimed to gain fundamental knowledge for the purpose of managing women's occupational health and safety, by examining task performance capability from both subjective and physiological aspects in terms of the effects on working memory of the postmenstrual and premenstrual phases.

Methods

Subjects

The subjects were 12 healthy female students from the university of nursing with an average age of 21.6 ± 0.7 , and normal vision or corrected vision in both eyes averaging 1.0 ± 0.4 . Their average computer experience was 4.3 ± 1.4 yr, and all were right-handed. The subjects have measurement knowledge of and experience with measuring the basal body temperature. Only women with regular menstrual cycles and biphasic body temperature were

selected for the study through the prior screening. From three months prior to the start of the experiment, subjects measured their oral temperature every day to reconfirm that they had ovulatory menstrual cycles, as demonstrated by a biphasic body temperature curve. Subjects also kept a record of their menstrual cycles, which were on average 31.8 ± 5.8 d. It was further confirmed that the subjects had not taken hormones, oral contraceptives, headache medicine, or other reserve medicine within 24 h of the experiment, that they had never conceived a child, and that they are not currently suffering from any gynecological disorders. It was also confirmed that they received sufficient rest and avoided alcohol consumption the day before the experiment, and had not consumed caffeine on the day of the experiment.

Procedure

The experiment took place in individual rooms with ambient silence, between the hours of 2 pm and 6 pm. The temperature was $26.7 \pm 1.0^\circ\text{C}$ and humidity was $58.1 \pm 5.6\%$. For this study, task performance was measured twice, during the postmenstrual and premenstrual phases, respectively. In order to avoid the order effect during the two phases, the experiment was counterbalanced by having six women start during the postmenstrual phase and six during the premenstrual phase. The subjects filled in general information, answered self-recorded MDQ survey, and then were fitted with portable electrocardiographs (ECG) before the experiment. After resting for ten minutes, they practiced the tasks for two minutes, then rested for one minute, and then carried out the tasks for 60 min. After completing the tasks they rested for ten minutes, then answered the NASA-TLX.

Experimental tasks

The tasks used for this study are a modification of the dual-task method, which is an experimental task based on the working memory model of Baddeley and Hitch¹⁰⁾ that simulates "medication preparation work" that is part of the representative work of nurses. Subjects memorize the visually shown amount of medication while concurrently performing selection tasks relating to medication names for ten seconds. After ten seconds have passed, the working memory is then evaluated by measuring the correct recall (error rate) of the initially memorized amount of medication (Fig. 1). That is, tasks using the mouse to click on the computer (Dell Sharp 17" PC) were limited to 60 min considering the limit to VDT (Visual Display Terminals) work.

The first task entailed clicking on OK once that the amount in the medication bottle on Screen 1 was memorized. And the amount of medication is displayed randomly, in a bottle marked at 100 ml intervals from 100

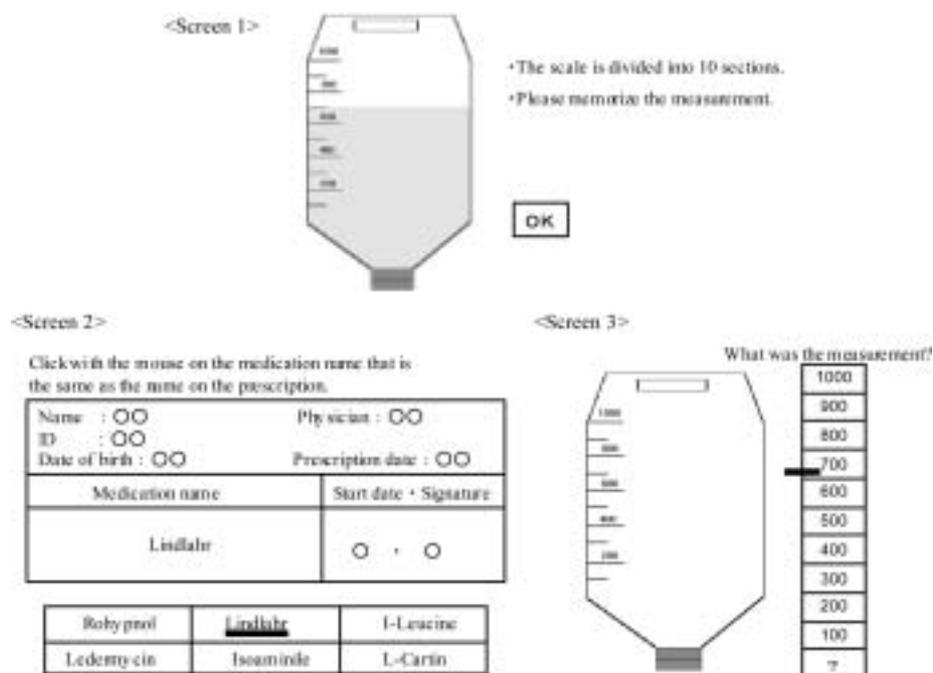


Fig. 1. Experiment task: working memory index.

The number on Screen 1 is memorized, the task on Screen 2 is performed for 10 s, and then on Screen 3 the memorized number is selected and clicked. Tasks on Screens 1–3 were carried out repeatedly for 60 min.

to 1,000 ml. The Screen 2 was used for a task that interfered with memory, namely selecting the same medication name as that shown on the prescription from among six medication names, all spelled using six letters, and clicking on it, at which point the next medication name was randomly displayed. This task was performed for ten seconds (Secondary task). On Screen 3, the subjects clicked on the amount memorized on Screen 1 (Primary task). If the subjects forgot or did not know, they input “?”. The above tasks on Screens 1–3 were carried out repeatedly for 60 min. There was no time limit for clicking on the numbers to be memorized on Screen 1 and the memorized numbers on Screen 3. Mouse clicking was done on a mouse pad (140 × 180 mm). The subjects were instructed to carry out the experiment tasks by clicking as quickly and as accurately as possible, and to keep their eyes lightly closed during the pre- and post-experiment rest period.

Subjective indices

MDQ

The questionnaire used was the MDQ (Menstrual Distress Questionnaire), developed in order to gain an understanding of catamenial symptom, i.e., physical and mental status, by Moos¹¹⁾, as translated into Japanese and rearranged into 48 questions by Kasamatsu *et al.*⁴⁾. It was simplified, so as to correspond to the Japanese lan-

guage, to a six-point scale, ranging from “don’t feel at all” at 0 point to “feel acutely” at 6 points. In addition, the MDQ 48 complaints are classified into 8 factors by Moos using factor analysis. The question was regarding the current state of the condition of the malaise in the menstrual cycle. The subjects respond by placing a mark in the appropriate segment of the six segments indicated along a straight line ranging from “don’t feel at all” at one end and “feel acutely” at the other. For these question items, the Krombach factor was 0.949 for the post-menstrual phase and 0.908 for the premenstrual phase, with high internal consistency for both phases, indicating reliability.

NASA-TLX

The NASA-TLX (NASA Task Load Index) was developed by the American National Aeronautics and Space Administration (NASA) and is a scale for subjective evaluation of mental workload¹²⁾. In this study, scale names and explanations from the Japanese version of the NASA-TLX by Haga and Mizukami¹³⁾ were used, and the Adaptive Weighted Workload (AWWL) proposed by Miyake and Kumashiro¹⁴⁾ was used for the overall evaluation points. Evaluation of this scale was done using a visual analogue scale whereby the subjects placed marks along 12 cm lines and raw scores were obtained by converting the distance from the extremes to points between 0 and 100.

Physiological indices

Heart rate variability

The Active Tracer AC-301 (GMS, weight approx. 87 g) was used for the electrocardiograph (ECG). The ECG was fitted to the subjects after they entered the room and were seated, relaxed and breathing normally. The portable ECG was placed on their chests (the positive electrode on the left chest V5, the negative electrode at the highest point of the sternum, and the ground on the right chest opposite the positive electrode) and measurement was done continuously until the end of the ten-minute rest period after task completion. In this study, heart rate variability (HRV) was obtained by autoregressive (AR) analysis of the RR intervals measured five minutes after the start of the rest period, before task start, at start, at 20 min, at 40 min, and for the first five minutes after completion. The autoregressive spectral analysis was performed at a sampling interval of 500 ms, and this was applied to the heartbeat interval data^{15, 16}. The respective percentages of low frequency component (LF) and high frequency component (HF) were calculated for LF of 0.04 to 0.15 Hz and HF of 0.15 to 0.5 Hz (LF and HF). LF/HF was also calculated as a percentage. Although breathing frequency was not controlled in this study, there was no significant difference in the mean breathing frequency, which was shown by the center frequency of respiratory sinus arrhythmia, among time or phase.

Measured phases of the menstrual cycle and measurement period

The experiment was carried out in both the postmenstrual and premenstrual phases. Measurement in the postmenstrual phase was done when the female hormones were stable (3–7 d after cessation of bleeding), and in the premenstrual phase when the symptoms of premenstrual syndrome (PMS) were most likely to appear (3–10 d before the onset of menstruation). Measurement of the basal body temperature was started in June 2005, subjects

reported the menstruation starting date, the measurement period was adjusted, and then the experiment was completed in a month and a half from September. The basal body temperature was measured until completion of the experiment.

Statistical analysis

SPSS12.0j was used for statistical analysis. Normality was indicated for working memory task results in both the premenstrual and postmenstrual phases, so a paired *t*-test was carried out. The Wilcoxon signed-rank test was performed for MDQ and NASA-TLX. For HRV, 2-way analysis of variance between premenstrual and postmenstrual phase was conducted, and the degree of freedom was adjusted using the Greenhouse-Geisser method to determine the existence of a main effect and interaction. The level of statistical significance was $p < 0.05$ for all tests.

Ethical considerations

This study was examined and approved by the Committee for Research Ethics and Safety of the Oita University of Nursing and Health Sciences.

Results

Working memory task results in the postmenstrual and premenstrual phases

The task results given as working memory index are shown in Table 1. Primary task: Compare the number of tasks completed in the postmenstrual and premenstrual phases, which showed there was no significant difference. The task error rate was significantly lower in the premenstrual phase than in the postmenstrual phase ($t = 2.200$, $p < 0.05$).

Secondary task: For the secondary task that interfered with the primary task, there was no significant difference between phases for the number of correct confirmations of the prescription and error rate.

Table 1. Working memory task performance in the postmenstrual and premenstrual phases

						(N=12)	
		Postmenstrual phase		Premenstrual phase			
		Mean	SD	Mean	SD	¹⁾ <i>t</i>	<i>p</i> value
Primary task	Number of tasks completed	266.9	23.7	273.3	12.6	-1.541	0.151
	²⁾ Task error rate (%)	8.7	6.9	6.5	5.4	2.200	0.050
Secondary task	Number of confirmations	1,377.9	235.2	1,407.8	164.4	-0.912	0.381
	³⁾ Error rate (%)	2.5	1.2	2.2	1.2	0.941	0.367

¹⁾ Difference in means of variables between at postmenstrual and premenstrual phases by paired *t*-test.

²⁾ $(1 - \text{Number of correct task answers} / \text{Number of tasks completed}) \times 100$.

³⁾ $(1 - \text{Number of correct answers} / \text{Number of confirmations}) \times 100$.

MDQ scores in the postmenstrual and premenstrual phases

Table 2 shows the MDQ for the postmenstrual and premenstrual phases. There was a significantly large number of complaints relating to the “water retention” factor, such as increased weight, rough skin, breast pain, and swelling in the premenstrual phase compared with the postmenstrual phase ($p < 0.05$). Conversely, under the “mood uplift” factor, the postmenstrual phase tended to show more energy and drive than the premenstrual phase ($p < 0.10$).

NASA-TLX scores in the postmenstrual and premenstrual phases

The results for the NASA-TLX after task performance are illustrated in Table 3. There was no significant difference between the premenstrual phase and postmenstrual phase. However, the items of “mental demand”, “physical demand”, “temporal demand”, “own performance”, “effort” and “frustration” all scored 60 points or higher for both phases. Also, the AWWL, or overall evaluation, exhibited scores near 80 points for both phases.

Changes in HRV in the postmenstrual and premenstrual phases

The change in HRV before and after task performance for both the postmenstrual phase and premenstrual phase is shown in Fig. 2. HF is low during task performance for both phases, and while LF/HF rose, after task completion it recovered to a value close to that prior to task start. The results of 2-way analysis of variance and multiple comparison (Table 4) show no difference in the HRV index between the postmenstrual phase and the premenstrual phase with only the time effect for HRV having a significant effect. In other words, HF declined significantly and the LF/HF rose significantly during task performance compared to pre-task but the interaction between the phase and the time were not significant.

Discussion

In this study, we hypothesized that working memory function deteriorates in the premenstrual phase when there are many indefinite menstrual complaints, the experiment

Table 2. Menstrual distress questionnaire (MDQ) scores in the postmenstrual and premenstrual phases

(N=12)

Scales	Postmenstrual phase		Premenstrual phase		¹⁾ <i>p</i> value
	Mean	SD	Mean	SD	
Pain	10.2	5.9	11.3	7.2	0.476
Concentration	9.5	7.3	9.5	6.4	0.789
Behavioral change	8.6	6.7	8.3	6.0	0.964
Autonomic reaction	2.4	2.5	2.3	3.2	0.721
Water retention	5.1	4.3	9.0	4.3	0.044
Negative feelings	10	10.3	9.8	9.2	1.000
Mood uplift	6.2	5.2	4.0	3.9	0.079
Control	2.1	2.0	2.3	3.8	0.916

¹⁾ Wilcoxon signed-rank test.

Table 3. NASA task load index (NASA-TLX) of postmenstrual and premenstrual phases

(N=12)

Factors	Postmenstrual phase		Premenstrual phase		¹⁾ <i>p</i> value
	Mean	SD	Mean	SD	
Mental demand	77.5	18.4	80.4	17.8	0.395
Physical demand	65.4	25.9	75.4	25.3	0.125
Temporal demand	63.8	24.9	66.3	24.7	0.859
Own performance	69.6	22.8	73.3	21.0	0.689
Effort	73.3	21.0	73.8	16.5	0.968
Frustration	71.7	20.0	60.4	28.6	0.423
AWWL ²⁾	76.2	16.5	77.8	10.8	0.754

¹⁾ Wilcoxon signed-rank test.

²⁾ Adaptive weighted workload.

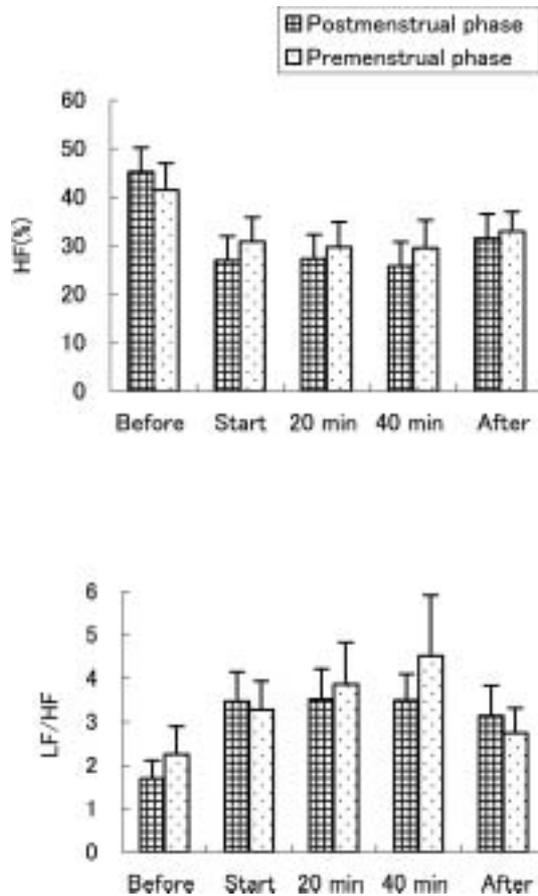


Fig. 2. Changes in HRV in the postmenstrual and premenstrual phases after task performance.

Before: Before task performance, Start: After task start, 20 min: 20 min late, 40 min: 40 min late, After: After task completion. Values are expressed as mean \pm SE.

was performed for 60 min using the working memory that actively retains the information as the index. The results showed that the task error rate was significantly lower in the premenstrual phase than in the postmenstrual phase. The results indicated that the task performance for the working memory function was good in the premenstrual phase.

We considered what effect was had on working memory function by the subjective complaint depending on the difference in the menstrual cycle phase. In this study, the Japanese translation of the MDQ by Kasamatsu *et al.*⁴⁾ was used, and the results were similar to those of previous studies, showing that there was a significantly large number of complaints relating to the “water retention” factor in the premenstrual phase compared with the postmenstrual phase. The symptoms of premenstrual syndrome (PMS) appeared to a slight degree but they had no effect on working memory function. In fact, the women made fewer errors on the task in the premenstrual phase compared with the postmenstrual phase.

Table 4. ANOVA in HRV in the postmenstrual and premenstrual phases

	(N=12)			
	ss III	^{1)df}	F	p value
LH/HF				
^{2)A} (Phase)	2.17	1	0.104	0.750
^{3)B} (Time)	60.106	2.212	3.682	0.029
A \times B (Time \times Phase) interaction	7.911	2.212	0.485	0.638
HF				
A (Phase)	61.404	1	0.061	0.808
B (Time)	4188.261	2.791	11.931	0.001
A \times B (Time \times Phase) interaction	268.736	2.791	0.766	0.509

¹⁾ *df* for postmenstrual and premenstrual phases was adjusted by Greenhouse-Geisser method.

²⁾ Postmenstrual and premenstrual phases.

³⁾ Before task performance, after task start, 20 min late, 40 min late, after task completion.

The NASA-TLX subjective index shows the mental workload, and generally shows the mental workload when a task is completed. After working memory tasks were repeated for 60 min, the overall evaluation “AWWL” of the workload for both phases showed a high mental workload evaluation of nearly 80 points out of 100 points. We¹⁷⁾ showed that this is a heavy mental workload of the same degree as seen in beginning assistants when assisting during childbirth. In other words, the mental workload is heavy during both phases and there was no difference between the phases of the menstrual cycle.

The effect of the workload and menstrual cycle phase on the autonomic nervous system was evaluated by looking at HRV. The results showed that HF and LF/HF ratio were not significantly different for both phases. It has been reported in previous studies, from results using HRV as the index, that sympathetic nervous activity is predominant in the high temperature phase (luteal) as compared to the low temperature phase (follicular) for the autonomic nervous function^{15, 18)}. In this study there was no interaction between the phase and the time, but in the time effect a significant decline in HF and a significant increase in LF/HF were observed, which indicate the cardiac sympathetic nerve activity is in an ascendant state during task performance.

From this, it was shown that the task performance for the working memory function was good in the premenstrual phase and that it was unrelated to the catamenial symptom. Further, mental workload and change in HRV, which are used to evaluate the workload, also showed no clear difference between the phases.

However, the menstrual cycle measurement phase was considered to investigate why the task performance was

good in the premenstrual phase. Estrogen values were not measured in this study, but it is known that production of estrogen is 10–200 pg/ml in the middle of the premenstrual phase and 10–80 pg/ml in the first half of the postmenstrual phase, with the premenstrual phase having a value up to 2.5 times higher. In this study, the basal body temperature was measured to ensure the experiment was performed accurately in the premenstrual and postmenstrual phases by confirming that the subjects demonstrated biphasic body temperature and by measuring the 3–7 d after cessation of bleeding in the postmenstrual phase. It has been reported that the high performance of the language working memory is likely related to the highly concentrated estrogen level^{8,9}. In addition, it has been reported that such tasks as language fluency and fine handwork (continuous handwork test) scored better during the estrogen high concentration phase³. The tasks of this study were also similar to language working memory and showed good results for the working memory function in the premenstrual phase when the production of estrogen is high. In other words, the estrogen sex hormone secreted from the ovaries in relation to the menstrual cycle is thought to be involved in the working memory function rather than the indefinite menstrual complaint. Regarding the higher error rate in the postmenstrual phase compared to the premenstrual phase, the subjects were instructed to carry out the tasks “as quickly and accurately as possible”, and as is shown by the results of both the NASA-TLX and HRV, this is thought to be due to the subjects trying their best during both phases. In other words, the results were not due to given less effort in the postmenstrual phase.

We would like to consider the working memory function as affected by the different menstrual cycle phases from the viewpoint of medical safety. On the front line of the nursing profession, more and more of the work requires cognitive task load, as medical technology develops and electronic media bring about a change to more complex and varied job content. In this context, medical accidents are more likely to occur, and one of the causes is human error. A relationship between human error and working memory function has been pointed out. Working memory involves control of concentration distribution, and when concentration capacity processing resources approach their limit, task performance is soon affected and errors occur¹⁹. This study showed that there was a higher error rate of working memory task in the postmenstrual phase than in the premenstrual phase. In other words, the distribution of processing resources to concentration capacity, which is working memory function, declines in the postmenstrual phase and this is hypothesized to more easily result in errors.

Meanwhile, in the case of PMS, it has been reported

that the autonomic nervous system becomes supersensitive^{20–22}. This study showed that PMS appeared to a slight degree and that the change in HRV showed a similar pattern in the premenstrual and postmenstrual phases and had no effect on working memory function. However, if the symptoms of PMS are strong and interfere with daily living, there may be deviation from the physiological range that increases the error rate. Further study of the case when the symptoms of PMS are strong needs to be conducted.

From the above, to prevent human error from occurring during nursing work, it is important for nurses to practice self-care through the understanding of error occurrence and psychosomatic changes due to the differences between the phases of the menstrual cycle, and for administrators to promote health education in the workplace from the viewpoint of occupational safety. Not only the postmenstrual and premenstrual phases, but all three phases including the menstruation phase should be examined in future study, and estrogen levels also should be measured. We would also like to investigate the other view of working memory, which is the processing of actively retained information.

Conclusion

This study aimed to examine the effects on working memory of the premenstrual and postmenstrual phases. The results indicated that the task performance for the working memory function was good in the premenstrual phase. Mild premenstrual symptoms had no effect on working memory function of the premenstrual phase. It was indicated that when the same tasks were performed during both phases, the sympathetic nerve was ascendant and that the mental workload was heavy after task performance.

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