

Attention-related potentials over the menstrual cycle. Indicators of the phase-related variations in visual data processing

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The ambiguous evidence on variations in cognitive functioning during the menstrual cycle may be verified by neurophysiological studies. Integrated behavioural and electrophysiological data were collected from 12 healthy women examined four times within the cycle. Variations in event-related potentials (ERPs) suggested weakened selective attention in the menstrual phase, whereas pre-menstrual sessions revealed increased excitability to non-important stimuli and the highest speed of information processing. Those significant electrophysiological variations were accompanied by few respective behavioural changes, which pointed at ERPs as very sensitive indicators of phase-related alterations in visual processing and attention.

Key words: menstrual cycle, attention, event-related potentials

Introduction

In spite of numerous evidence on changes in emotions during the menstrual cycle, there is still a lack of unequivocal proofs on parallel variations in cognitive (psycho-motor) functioning. Such opinions [1, 2, 3] seem to deny the subjective experience of many women.

On the other hand, some studies on evoked (EP) or event-related potentials (ERP) suggest cycle-dependent changes in both sensory [4, 5] and cognitive [6, 7] stage of data processing.

It is still under consideration, to what extent the “rough” neurophysiological measures may reflect the cognition. However, these are the only objective measures of the data processing in its’ real time (i.e., in the moment in which the processing-related features really occur following the given stimulus). In particular, there are some ERP parameters which reflect speed of information processing (latencies of successive ERP components) or selective attention (processing negativity).

The latter concept [8] has been introduced by Näätänen following studies based on attentional task in auditory modality. This describes a negative potential, which develops following those target stimuli, which are defined with respect to their selected physical properties (high vs. low tones, received in right vs. left ear, etc.). It peaks at about 150 ms after the onset of the stimulus, overlapping the N100 (N1) component, and gradually weakens with an increasing post-stimulus latency. Processing negativity reflects an increased sensitivity in a sensory channel responsible for encoding the determined physical parameter, hence, it is an electrophysiological expression of attention selectively oriented to the given physical properties of stimuli.

The aim of the presented study was to clarify the hypothesis of variations in cognitive functions during the menstrual cycle by integration of the ERP parameters and behavioural data, collected during the performance of the Continuous Attention Test – the task demanding an engagement of attention, working memory and executive functions.

Subjects and methods

The subjects were 12 healthy, right-handed adult women (mean age 27.2 with standard deviation \pm 4.5) with natural and regular menstrual cycle. Current use of contraceptive drugs as well as any associated hormonal, neurological or psychiatric abnormalities were criteria for exclusion. Each woman was examined 4 times, during the consecutive sessions corresponding to the 4 phases:

- menstrual (A) – in the 3rd to 5th day of the menstrual cycle,
- pre-ovulatory (B) – in the 11th to 13th day,
- mid-luteal (C) – in the 18th to 23rd day,
- pre-menstrual (D) – in the 26th to 28th day of the cycle.

In case of a length of the cycle different than 28 days, these ranges were recalculated under the assumptions of the respective shifts during the follicular phase and a uniform 14-day-long luteal one. Regardless of these estimations, each session was preceded by hormone-level tests for estradiol, progesteron, FSH, LSH, prolactine and HCG.

During each session, the subjects performed the Continuous Attention Test (CAT) [9]. The CAT consisted of consecutive, quasi-randomly appearing visual stimuli of 3 sorts. Attended (non-target and target) CAT stimuli were geometrical patterns (the target was defined as a direct repetition of any standard pattern) while unattended (ignored) stimuli were digits. As behavioural measures of performance, index of errors [10], including both omissions and commissions, as well as mean reaction time were assessed. In order to avoid artifacts related to learning, the phase during which a woman entered the study was chosen at random.

Event-related potentials (ERP's) elicited by CAT stimuli were recorded during the session at 21 scalp leads referenced to the linked mastoids. ERP's were averaged off-line, separately for each of the three conditions (ignored, non-target, target). The ERP parameters submitted for the analysis were amplitudes and latencies of the peaks of the consecutive components: P1, N1, P2, N2, early frontal P3 (P3e) and parietal

P300 (P3b), as reflecting consecutive stages of processing. These components were compared between each two of the four phases of the cycle with the Wilcoxon test for related samples. The differences were referred to the results of the CAT. Additionally, the maps of the surface (scalp) potential corresponding to the peak of each component were compared, lead by lead, with the paired t-test. The results of such comparisons were presented as maps of the t.

Results

During the menstrual phase, in non-target and target condition, the amplitude of the N1 (N160) component at occipital and posterotemporal leads was lower and the amplitude of the posterior P2 (P220) was higher than in the other phases (table 1). These differences reached significance for N1 at right occipital (O2) lead in non-target

Table 1
Changes in ERP parameters, differentiating the menstrual (A) phase from the other phases

| Component | Condition | Location | Phases | Amplitudes (μV) | Significance (p) |
|-----------|------------|----------|-------------------------------------|---------------------------------------|------------------|
| N1 | non-target | O2 | A vs. D | -7.49 ± 6.76 vs. -9.15 ± 6.78 | 0.008 |
| N1 | target | O1 | A vs. B | -7.74 ± 3.25 vs. -4.95 ± 2.95 | 0.026 |
| | | | A vs. C | -7.69 ± 3.25 vs. -4.95 ± 2.90 | 0.005 |
| | | | A vs. D | -8.07 ± 5.15 vs. -4.95 ± 2.95 | 0.007 |
| | | O2 | A vs. C | -7.13 ± 5.37 vs. -8.89 ± 5.96 | 0.003 |
| | | | A vs. D | -7.13 ± 5.37 vs. -9.45 ± 5.79 | 0.008 |
| | | | A vs. B | -3.42 ± 2.22 vs. -5.40 ± 2.37 | 0.012 |
| | | T5 | A vs. C | -3.42 ± 2.22 vs. -4.44 ± 2.14 | 0.050 |
| | | | A vs. D | -3.42 ± 2.22 vs. -6.45 ± 3.67 | 0.049 |
| | | | A vs. B | -3.42 ± 2.22 vs. -5.40 ± 2.37 | 0.012 |
| P2 | non-target | O1 | A vs. C | 2.47 ± 4.86 vs. 1.28 ± 4.52 | 0.034 |
| | | | A vs. D | 2.47 ± 4.86 vs. 1.39 ± 5.39 | 0.050 |
| | | T5 | A vs. D | 2.48 ± 2.03 vs. 0.87 ± 3.07 | 0.041 |
| | target | O1 | A vs. C | 3.82 ± 4.62 vs. 1.38 ± 4.65 | 0.008 |
| | | | A vs. D | 3.82 ± 4.62 vs. 1.23 ± 3.84 | 0.019 |
| | | O2 | A vs. C | 2.75 ± 4.05 vs. 1.24 ± 4.38 | 0.049 |
| | | | A vs. D | 2.75 ± 4.05 vs. 0.80 ± 3.58 | 0.019 |
| | | A vs. B | 2.75 ± 4.05 vs. 1.24 ± 4.38 | 0.049 | |

condition, for N1 at both left (O1) and right (O2) occipital leads and at left posterotemporal (T5) location in target condition, as well as for P2 at the left-side posterior locations (O1 and T5) in non-target condition, and for P2 at bilateral occipital (O1 and O2) leads. These differences (regarding lower N1 and higher P2 in the menstrual phase) were accompanied by numerous similar trends in the other posterior derivations, but only in both attended conditions. There were no such differences in N1 nor P2 elicited by the ignored stimuli.

The other group of significant results concerned the pre-menstrual phase. In contrast

to the other phases, an increase in the N1/P2 amplitude (i.e., P2 measured against the peak of preceding N1 component) following ignored digits occurred. Furthermore, heightened amplitude of the early frontal P3 component (P3e, abbreviation of the authors) in the non-target condition was also observed, when measured against the peak of the preceding N2 component (ref. table 2).

In that phase, in addition, spatial analysis of the N1 component following non-target stimuli revealed an associated increase in a contemporary frontal positive potential

Alterations in ERP amplitudes – the premenstrual phase

| Component | Condition | Location | Phases | Amplitudes (µV) | Significance (p) |
|--------------------|------------|----------|---------|-----------------------------|------------------|
| P2 (ref to N1) | ignored | C2 | D vs. A | 1406 ± 4.66 vs. 1186 ± 3.79 | 0.038 |
| | | | D vs. B | 1406 ± 4.66 vs. 1145 ± 3.57 | 0.034 |
| | | | D vs. C | 1406 ± 4.66 vs. 1105 ± 6.72 | 0.021 |
| P3e (ref to N2) | non-target | Fz | D vs. A | 9.98 ± 3.73 vs. 8.22 ± 3.38 | 0.028 |
| | | | D vs. B | 9.98 ± 3.73 vs. 8.46 ± 3.33 | 0.013 |
| | | | D vs. C | 9.98 ± 3.73 vs. 6.79 ± 2.93 | 0.006 |

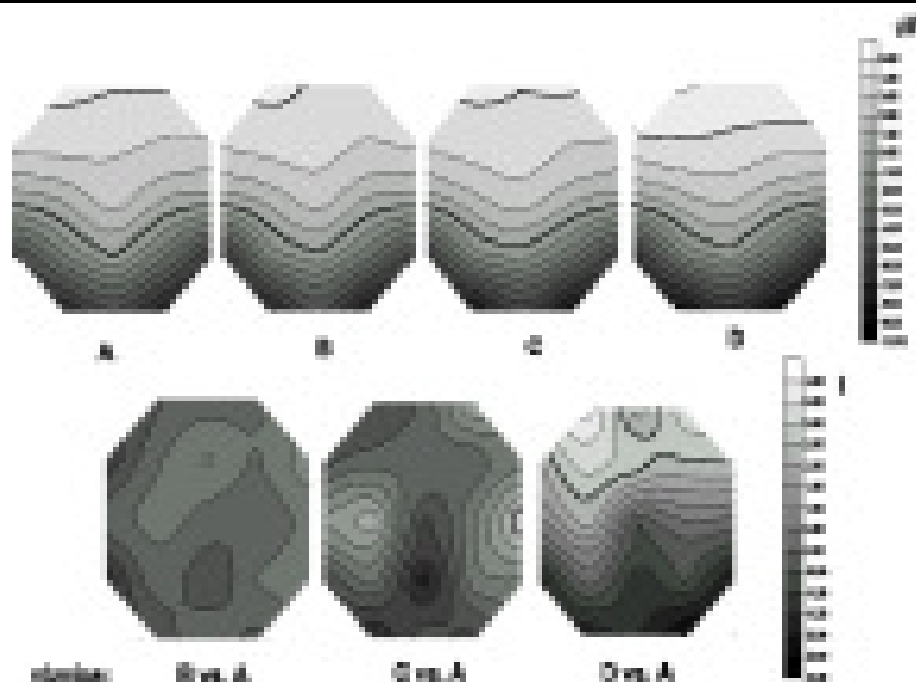


Fig.1 The increase in frontal positive potential during the peak of the N1 component in response to the non-target stimuli in the pre-menstual (D) phase. Upper row: the maps of the scalp potential during the peak of N1 component, for four (A-D) phases of the cycle. For better illustration of the differences, the lines 0 mV and 4 mV are thickened. Lower row: the maps of differences (values of the t in the paired t-test) in scalp potentials for the phases B, C, and D as compared with that for the phase A as a baseline. Thickened lines mark the threshold for significance of differences (p=0.05).

(fig. 1), with the most pronounced excess at the left prefrontal lead.

The latencies of the components, especially those of the parietal P2 (measured at the midline parietal Pz location) in non-target condition or the right-occipital N1 in target condition, were the shortest in the pre-menstrual phase and the longest in the pre-ovulatory one (latencies of the P2 in phases D vs. A, B, C were: 193 ± 16 ms vs.: 199 ± 21 ms, 206 ± 21 ms, 201 ± 15 ms, respectively, at $p=0.016$, $p=0.041$, $p=0.009$, respectively; and for the N1 in phases B vs. A, C, D were: 152 ± 13 ms vs. 147 ± 16 ms, 146 ± 15 ms, 144 ± 16 ms, respectively, at $p=0.028$, $p=0.021$, $p=0.023$).

There were no phase-related changes in CAT errors (the participants performed the test very well and errors were too rare to assess any phase-related variations).

Mean reaction time was the shortest in the pre-menstrual phase, and the longest in the pre-ovulatory phase (reaction time in phase D vs B was 460 ± 83 ms vs. 484 ± 72 ms at $p=0.019$).

Discussion

The alterations within the N1 and P2 ERP components, observed in the menstrual phase, followed only attended stimuli. As the lower (less pronounced) amplitude of the negative N1 and the higher amplitude of the positive P2, they might reflect an attention-related shift of the potential towards more positive values. Since the processing negativity superimposes both the N1 and P2 components, we may hypothesise, that in the observed data, the positive shift in potential in N1 and P2 latency range, following attended stimuli, could be a result of lowered (less negative) peak of overlapping processing negativity (here: oriented to geometrical patterns). Such hypothesis implies weakened selective attention in the menstrual phase.

In contrast, the ERP variations observed in the pre-menstrual phase (heightened N1/P2 amplitude following ignored stimuli as well as heightened P3e amplitude in response to non-target patterns), reflect increased excitability following stimuli less important in the CAT. These results, as well as increased frontal and prefrontal positive potential accompanying the N1 component in non-target condition, may suggest an increased activation of non-specific (non-selective) attentional resources during the pre-menstrual phase. Such findings could provide explanations for some late-luteal symptoms (i.e., irritability, hypersensitivity) as resulted from an increased distractibility and relative sensory overload. The idea of non-specific sensory hyperexcitability may be also confirmed by the data revealing the highest speed of processing (the shortest latencies of the P2 ERP component, with the most significant results for the non-target condition).

However, verification of the proposed hypotheses, related both to suppressed selective attention in the menstrual phase and increased non-selective attention with accompanied by fastening in processing in the pre-menstrual phase, could be provided only by clinical observations of any behavioural counterparts of presented ERP results.

The highest speed of processing in the pre-menstrual phase, as well as the lowest speed in the pre-ovulatory one, find confirmation in the respective cycle-dependent variations in the reaction time. The results confirm the finding of the lowest speed of

processing in the pre-ovulatory phase, evidenced before [11].

On the other hand, the ERP-based hypotheses concerning the variations in attention were not reflected in the CAT scores. This resulted from the very good performance of the CAT by the examined women. Rarely occurring errors did not differentiate the subjects nor the phases, and the minimal dispersion of the CAT scores disabled any assessment of their correlations with the ERP data. Following former analysis of ERP results, more omissions in the menstrual phase (i.e. lowered number of target detections, as a measure of weakened selective attention) as well as an increased number of commissions in the pre-menstrual phase (as a result of increased reactivity to non-target or ignored stimuli) might be expected. However, in order to check that, a more complex paradigm should be introduced to the further studies.

For the present, lack of cycle-dependent changes in the CAT performance, confronted with significant variations in electrophysiological measures, gives rise to the postulate that event-related potentials may be very precise (more sensitive than related behavioural tests) indicators of phase-related alterations in visual processing and attention.

Conclusions

1. The alterations in ERPs revealed significant cycle-dependent changes in visual signal processing involving attention.
2. Changes in N1 and P2 following attended stimuli in the menstrual phase might result from a decrease in the overlapping processing negativity and might imply weakened selective attention. However, these did not find their behavioural counterparts and seemed to exert no influence on the performance of the CAT.
3. The highest speed of processing as well as over-activation of non-specific attentional resources may be related to some pre-menstrual symptoms.
4. The ERP measures may be sensitive indicators of phase-related alterations in visual processing and attention.
5. In the further studies CAT should be replaced by more complex behavioural test.

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