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Brain evoked responses reflect information processing changes with the menstrual cycle in young female athletes

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In sport activity, information processing plays a role crucial for sport performance. Neuropsychological and psychophysiological evidence based on behavioral and psychophysical tasks has been accumulated showing that the latter changes over the course of the menstrual cycle, but the available data are rather inconsistent. On the other hand, in sport literature, not much attention has been devoted to these topics by researchers who have mainly been asked to investigate changes in mood and well-being. Therefore, a study has been undertaken to investigate the relationships between the menstrual cycle and information processing in young female athletes, some of whom took oral contraceptives. The study was based on Auditory Evoked Responses that, unlike behavioral and psychophysical techniques, were revealed to be an exceptionally reliable tool for the study of neural activity during sensory information processing. The results showed the existence of clear fluctuations over the course of the menstrual cycle in time taken to handle information and in the amount of information processing that, with differences and similarities, could be observed both in spontaneously menstruating and on-pill athletes. In addition, neuroanatomical differences were evident in the response of different neural structures of the auditory pathways. In fact, the effects of the hormonal changes accompanying the menstrual cycle appear to be more effective and influential at higher central levels of the auditory pathway.


Key words: Event-related brain potentials - Information processing - Young female athletes - Menstrual cycle.

Since the influences of the menstrual cycle upon performance have been recognised for years (Procope and Timonen, 1971; Dorlitte and Engebretsen, 1972), female athletes and coaches have ever since devoted much attention to changes in mood, physical well-being and muscular work capacity with its different phases.

For this reason, biomedical and behavioral scientists have been asked to investigate these topics in the attempt to understand the psychophysiological processes on which they depend and, as result of this understanding, to help to find a way out of these troublesome difficulties for sport performance.

At the present, several positive general results have emerged from studies dealing with these topics (Gamberale, Strindberg and Wanberg, 1975; Scheone, Robertson, and Peterson, 1981; Stephenson, Kolka, and Wilkerson, 1982).

Nevertheless, and surprisingly, no specific information is currently available on the influences of menstrual cycle phases on female athletes' brain sensory information processing mechanisms. This is especially true in the areas of sensory information processing capacity, sensory reception, and perceptual information processing expenditure in decision-making related to motor behavior.

Our poor knowledge of these mechanisms in sport can be attributed, on the one hand, to the general lack of systematic research into these topics by behavioral researchers who are mainly asked to deal
with mood, personality and premenstrual symptoms, and, on the other hand, to the
general inconsistency existing in the data of the general neuropsychological litera-
ture (Parlee, 1983; Patkai, 1985). According to the latter, in fact, it can be con-
cluded that most of women’s sensory and perceptual processes show a change with
the menstrual cycle. Not much agreement exists, however, between the different au-
thors about the shape of the curve of changing sensory performance over the
phases of the menstrual cycle. In addition, differences of shape between sensory mo-
dalities have been proposed (Parlee, 1983; Patkay, 1985).

Very probably, the inconsistency in the data is due to the use of research para-
digms based on behavioral and psychophysical tasks. Both of these methodo-
logical paradigms are tied to attention and task demands. In addition, behavioral
access to sensory channels is rather indirect and limited. In this context, the elec-
trophysiological recording has the advantage that it allows the examination of
neural sensory processing both inside and outside the focus of attention.

The Evoked Brain Potential (EP) technique represents, in fact, an unintrusive
method of probing the on-line neural activity during sensory information process-
ing. Although it must be confessed that this technique also has some limitations,
it appears to be much closer to intracerebral events underlying the actual pro-
cessing of the input, given the anatomical distribution and relatively short latency
of its components (Hillyard, Picton, and Regan, 1978; Donchin, 1979; Näätänen,

In this regard, the early latency Brainstem Auditory Evoked Responses (BAERs)
represent an exceptionally reliable measure of neural functioning in the auditory
pathway. These evoked potentials are con-
stituted by seven scalp vertex-positive waves occurring between the first and
tenth msec after the onset of auditory
signals. These waves actually reflect the
sequential neural activity at successively
higher levels of the brainstem auditory
pathway (Jewett, Romano and Willinston,
1970; Jewett and Willinston, 1971; Picton,
Stopells and Campbell, 1981; Boston and
Møller, 1985). In other terms, the wave I
through wave VII are generated by the
acoustic nerve, the cochlear nuclei, the
superior olives, the lateral lemniscus, the
inferior colliculus, the medial geniculate,
and the thalamocortical radiations to the
auditory temporal cortex, respectively
(Stockard and Rossiter, 1977). The first,
the third and fifth peaks can be unambi-
guously identified in most normal hearing
subjects and the reproducibility of the
waveform in a given subject is high. For
this reason, the BAER appears a highly
desirable psychophysiological measure be-
cause of its apparently close relationships
between the waveform and specific neural
structures.

Unlike the latter, long latency cortical
Auditory Evoked Responses (AERs) fol-
lowing sensory stimulus consist of a series
of waves—most prominently the N1-P2
components—that occur between 50 and
250 msec after a stimulus and that are
considered to be the neural processing
response of the brain’s sensory cortex to
the incoming sensory information (Picton
et al., 1974a, b; Gibson, 1980).

Thus, the application of the EP tech-
nique to the study of sport performance
provides considerable promise as a meter
for sensory and perceptual information
processing and mental workload assess-
ment.

Starting from this kind of approach,
a study was undertaken to investigate the
influences of the different phases of the
menstrual cycle on sensory information
reception and information processing by
means of a BAER and AER recording para-
digm. Since for different reasons, many
athletes take oral contraceptives, two
small groups of young athletes with spontaneous and contraceptive-controlled cycle were compared in order to investigate possible differences in information processing mode between them.

Method

Subjects

Eight young female athletes with ages ranging from 20 to 24 years, regularly and intensively training in different sports participated in the study.

All subjects had a cycle length of about 28-31 days, reported mild discomfort and minimal interference with activities from periods, and viewed their menstrual periods as a normal part of their physiology. All were nulliparous and had normal hearing and normal or corrected-to-normal vision.

Four of them were taking combined oral contraceptives during the investigation and had done so for at least several months before it began (oral contraceptive group: o.c.g.). On the contrary, four had never taken oral contraceptives and did so for the whole duration of the study (spontaneous cycle group: s.c.g.).

Procedure

Before the recording sessions, subjects were asked to keep a daily record of basal temperature (BT) and mood immediately upon awakening for two successive menstrual cycle. This permitted the assessment of regularity of the cycle period and the relative absence of premenstrual symptoms. Subjects were also asked to continue to make a record of days of cycles on which examination occurred. On the recording days, the oral temperature was also taken by means of an oral clinical thermometer before and after the electrophysiological recording. A detailed description of temperature and mood recordings will be given elsewhere (Zani, in preparation).

Each subject participated in four different recording sessions of BAERs and AERs, each in a different phase of the menstrual cycle. AER recording always followed BAER recording. Based on their cycle length and BT data, they were examined on the 2nd day (i.e., menstrual phase), the 9th day (i.e., follicular phase), between the 14th and 15th day (i.e., ovulatory phase) and the 23rd-24th day (i.e., late luteal/premenstrual phase) of the menstrual cycle. To counterbalance the order in which they were tested, subjects began participation at one of the scheduled points in their cycles. Finally, in order to avoid the well-known post-prandial dip in sensory perceptual functions and performance (Craig, Baer, and Diekman, 1981) and the confusing effects of a diurnal variation in the latter (Brown and Graeber, 1982), all measurements were performed between 10 and 12 a.m.

BAER recording. Each subject was instrumented with Beckman silver/silver chloride electrodes at vertex (Cz) and linked earlobes. A ground electrode was placed on the forehead. Electrode impedance was kept well below 2 Kohms. The subject was then comfortably seated in a sound-attenuated, electrically shielded, dimly lit chamber.

The BAER data were recorded on a Nicolet CA-1000 clinical averager. The broadband click stimuli (center frequency 2 KHz) were binaurally delivered to the subject by means of earphones at a rate of 11.1 c/sec, at 65 dB SPL, with a duration of 100 μsec. Low and high pass filters were 150 and 3000 Hz, respectively. The differential amplifier gain was 10 μVs/cm. To obtain an average waveform, whose time sweep was 10 msec, 2000 single click responses in sequence were summed. Finally, in order to investigate whether the BAER stability would hold for the different phases of the cycle, two successive runs were given, separated by a two minutes rest during which average data were
transferred from the Nicolet to an Apple IIe microcomputer for storage and off-line latency analysis.

**Long latency AER recording.** The CA-1000 averager amplifier was set up at 50 μV/cm, whereas low and high pass filters were at 1 and 100 Hz. Waveform time sweep was 250 msec and 100 click artifact-free trials were averaged. Click stimuli had the same intensity, frequency and duration as for BAERs recordings. In this case, however, the stimulus rate was 0.07 c/sec, i.e. about 1 Hz. Unlike the previous condition a “moving window” artifact rejection system checked for muscular and body movement artifacts and rejected trials which exceeded the amplification range set up. For each rejected trial an extra trial was given till the total of 100 trials was completed. Altogether, no more than 8-10% trials were rejected during recordings. Like BAERs, Ss received two successive runs stored on disk for later analysis.

**Data measurements.** The peak latency of wave I, III, and V of brainstem poten...

**Fig. 1.** Vertex Brainstem Auditory Evoked Responses (BAERs) to broadband click stimuli for a subject (A.V.) with spontaneous menstrual cycle and a subject (D.B.) taking oral contraceptives recorded in four different phases of the menstrual cycle (A = menstrual phase; B = follicular phase; C = ovulatory phase; D = late luteal-premenstrual phase). The solid line represents the first run, the dashed line the second run.

**Fig. 2.** Vertex long-latency Auditory Evoked Responses (AERs) elicited by broad band click stimuli in a subject (A.V.) with spontaneous menstrual cycle, and one (D.B.) taking pill in four phases of the menstrual cycle. Further notations as in Figure 1.

trials was measured. In contrast, long latency cortical evoked responses were analyzed by detecting a negative peak N1, followed by a second positive peak P2, followed by a second negative peak N2. Then, N1-P2 and P2-N2 components peak-to-peak amplitude and latency at the peak (N1, P2, N2) amplitude from stimulus onset were measured. Figures 1 and 2 show examples of these ERP components for two subjects belonging to the two different groups.

For each measurement, a three way analysis of variance was performed with group as between factor and menstrual phase and run as within factors.

**Results**

**Wave I.** No significant differences were found for any of the factors. It is worth noting, however, that in the last two phases of the menstrual cycle the s.c.g. seems to have longer latencies than the o.c.g., as can be seen in Figure 3A.

**Wave III.** For this peak also, no significant differences were found, but for the two groups the trend was similar to that shown by wave I. This is illustrated by Figure 3B.
Fig. 3.—Latency mean values for waves I (A), III (B), and V (C) of BAERs for the s.c.g. and o.c.g. in different phases of the menstrual cycle (A=menstrual period; B=follicular phase; C=ovulatory phase; D=late luteal-premenstrual phase). Empty and filled circles represent the first and second run, respectively, for the s.c.g.; empty and filled squares represent the first and second run, respectively, for the o.c.g.

Fig. 4.—AER N1 peak latency mean values for the four different phases of the menstrual cycle studied for the s.c.g. and o.c.g.; notations as in Figure 3. Fig. 5.—AER P2 component latency measures averaged across the subjects of the s.c.g. and o.c.g. as a function of the different phases of the menstrual cycle under study. Notations as in Figure 3. Fig. 6.—AER N2 component latency measures for the four different phases of the menstrual cycle for the s.c.g. and o.c.g.; notations as in Figure 3.

Wave V. The ANOVA gave a significant interaction (F3, 18=3.61; p<0.05) between group and phase of the cycle. Analysis for simple effects showed that the inverted-U trend going from menstrual days to the premenstrual days was statistically significant (F3, 9=4.1; p<0.05) for the s.c.g. This trend can be clearly appreciated in Figure 3C.

N1 latency. N1 mean latencies are shown in Figure 4. It appears that the two groups are significantly different from each other (F1, 6=6.16; p<0.05). In addition, irrespective of group, a significant difference between the phases of the cycle was found (F3, 18=8.77; p<0.01). Again, a significant interaction of group×phase was obtained (F3, 18=5.01; p<0.05). Intragroup compa-
Fig. 7. — AER N_1-P_1 component mean amplitude as a function of the phase of the menstrual cycle for the s.c.g. and o.c.g.; notations as in Figure 3. Fig. 8. — AER P_2-N_2 component amplitude mean values for the different phases of the menstrual cycle for the s.c.g. and o.c.g.; notations as in Figure 3.

Comparisons showed a significant difference between the phases for the o.c.g. (F3, 9 = 25.11; p < 0.01).

P_2 latency. The effect of the phase of the cycle over the latency of this component was statistically significant (F3, 18 = 3.68; p < 0.05), irrespective of the group. Although no significant differences were observed between the groups, a tendency was apparent, as illustrated by Figure 5.

N_2 latency. There was a significant difference between groups (F1, 6 = 8.99; p < 0.05), with the s.c.g. showing shorter latencies than the o.c.g. Figure 6 summarizes N_2 latency findings for the two groups.

N_1-P_1 amplitude. No differences could be found between groups. However, a significant decrease over the course of the cycle was obtained (F3, 18 = 4.12; p < 0.05) going from menses to the premenstrual days. This is depicted in Figure 7.

P_2-N_2 amplitude. Figure 8 presents the mean amplitude values for the two groups of subjects. Beyond a significant decrease in this complex amplitude over the course of the menstrual cycle (F3, 18 = 3.72; p < 0.05), with the same shape as that relative to the N_1-P_1 complex, a significant interaction of group x run was evident (F1, 6 = 13.55; p < 0.05). Post hoc comparisons revealed that whereas for the o.c.g. the small increment across runs was not significant, the small decrease across runs observed in the vertex P_2-N_2 complex for the s.c.g. was statistically significant (F1, 3 = 11.61; p < 0.05).

Discussion

In this study, broadband click stimuli were found to evoke early and long latency auditory neural responses, the nature of which depended upon the phase of the menstrual cycle, the district of the nervous system examined, and the state of the subject. Where early auditory responses are concerned, a different trend is observed depending on whether or not the subject takes oral contraceptives. Whereas, in fact, the o.c.g. shows a stable trend over the course of the menstrual cycle, the s.c.g. shows a constantly increasing delay in wave V latency going from the days of menses to midcycle (ovulatory phase) and a dramatic and sharp decrease of the latter in the premenstrual days. This finding is consonant with previous results by Zani and Mecacci (1984) of an inverted-U trend in wave V latency obtained in six healthy spontaneously menstruating young female students recruited from a University population.

One possible explanation for the different trend shown by the two groups for wave V latency, but not for wave I and III mirroring the neural responses of more peripheral neural structures of the auditory pathway, may lie with the type of neurofunctional interactions between the different level neural structures and gonadal steroid hormones.
In view of these results, in fact, it is suggested that in spontaneously menstruating women the well known interactions of steroid hormones with the nervous system are different in nature according to the district of the neural auditory pathway examined. It is also suggested, that: (1) these interactions, with their relative influences upon the brain tissue spontaneous activity revealed by the well known EEG alpha power changes over the course of the menstrual cycle (Vogel, Broverman, and Klaiber, 1971; Creutzfeldt et al., 1976), have, as a result, a cyclic fluctuation in the time required for processing or transmitting sensory information along the neural pathways; and (2) the chemical mediation involved in the information processing delay over the course of the menstrual cycle is more effective and influential at higher central levels of the auditory pathway.

The great differences between groups in cortical AER components latency seem to lend credence to these suggestions. In comparing vertex AER cortical component latency for the two groups, in fact, a similar shape of the curve is apparent as a whole over the course of the cycle. A decrease in latency occurs from menses to the preovulatory days, when blood estrogen levels are rising, followed by an increment in both the ovulatory phase, when blood estrogen is high but the blood progesterone level is rising, and the late luteal/premenstrual phase, when blood estrogen and progesterone are both elevated. In general, however, the o.c.g. shows longer latencies than the s.c.g. in all the phases of the cycle, thus suggesting a general delay in sensory information processing in the former group with respect to the second. These results can be taken as evidence for the fact that: (1) although hormonal balance over the cycle is different for the two groups, the logistics of the neural sensory processors' function is affected in a similar way by steroids in both the groups; and (2) that the delay in sensory information processing found for the o.c.g. is very probably due to the continuous exogenous administration of progesterone over the cycle since this same delay is evident for the s.c.g. during the last span of the cycle, when levels of this hormone are known to be high.

Although these results support the concept of a generally delayed information processing in the o.c.g., it has to be said, however, that this group gives the impression of greater stability over time, within the single phases of the menstrual cycle, in the time of response to sensory inputs than the s.c.g. This may well be due to the exogenous control of their internal hormonal balance. In contrast to this, the s.c.g. shows small differences across runs in time of neural response to inputs that, although not significant, can be taken as the reflection of short-term changes in the time required for information processing by cortical sensory areas. Whether this is linked to neural habituation processes, it is difficult to say as yet, since in some cases instead of longer latencies, generally found because of habituation, shorter latencies can be observed.

Findings relative to the cortical component amplitudes are consistent with the view here proposed that, in both groups, information processing time latency follows a similar trend over the course of the menstrual cycle and that the further time delay found in controlled cycle women is a consequence of the exogenously administered progesterone. Going from menses to the premenstrual phase, in fact, both groups show a relatively constant decrease in cortical component amplitude without any significant difference between them. It is possible, however, that the small increment shown by the s.c.g. for the ovulatory phase is the reflection of an increasing magnitude of the neural response mediated by the high
levels of estrogens, but contrasted by rising levels of progesterone. These data support the suggestion that differences exist in cortical responses to sensory inputs during different phases of the menstrual cycle and that the magnitude of this processing response changes remarkably in relation to steroid hormonal balance. It is tempting to postulate that, in general, neural sensory information processing is more effective in between the menses and the preovulatory time span of the menstrual cycle when, because of the exciting influences of estrogens, neural responses are greater and of shorter latency. In contrast to this, because of the depressing influences of progesterone on neural cortical responses, in the last two weeks of the cycle information processing becomes less effective, as shown by lower amplitudes and longer latencies of neural responses. Despite the anovulatory nature of the exogenously controlled cycle, these same processing changes also occur in on-pill women.

As for cortical component latency, component amplitudes showed small changes across runs that, at least for the P2-N2 component resulted in a significant decrease in amplitude from the first to the second run for the s.c.g. This supports the suggestion of a relatively less stable processing response over time in spontaneously menstruating subjects. Whether such changes might reflect neurophysiological processes associated with the decrease in attentiveness and orienting behavior to the stimuli which occur during neural habituation is difficult to say. In this regard, in fact, it is worthy of note that on-pill subjects seem to show an insignificant amplitude increment across runs.

It seems to be premature to speculate about the applications of these findings to sport performance given the general lack of knowledge about the relationships between overt performance fluctuations and these brain sensory response changes over the course of the menstrual cycle, as seen by means of Event Related Brain Potentials.

However, it is indeed tempting to postulate that although both groups should show significant fluctuations of performance over the course of the menstrual cycle, the s.c.g. should show better results than the o.c.g. in tasks based on response time pressure or requiring fast reaction times even though the fluctuations shown by this group may negatively affect their performance stability over time. In contrast, because of its general delay in sensory information processing, which however appears to be rather stable over time, the o.c.g. should score better in tasks based on response accuracy.

At the present stage of research, due also to the inconsistencies in the neuropsychological literature, these suggestions remain only hypotheses to be investigated further.

To sum up, it may be concluded that altogether these findings can be taken as evidence for the existence of changes over the course of the menstrual cycle in the time taken by sensory information to be handled by neural pathways and, as a consequence of this, of changes in the quantity of information handled per time unit. Together with these temporal fluctuations, quantitative changes in sensory processing the relation of which to overt performance is not yet known also occur. As proved by obtained results, these changes occur with some differences and similarities in both the groups, and it is worth noting that the magnitude of these changes is large enough to turn a “loser” into a “winner” and vice versa.

References


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