Hormones and Behavior 55 (2009) 203–209

Contents lists available at ScienceDirect

Hormones and Behavior

journal homepage: www.elsevier.com/locate/yhbeh

Female menstrual phases modulate human prefrontal asymmetry: A magnetoencephalographic study ☆

Ren-Jen Hwang [a,b,c], Chi-Hsun Wu [b,f], Li-Fen Chen [b,d,e], Tzu-Chen Yeh [b,d,e], Jen-Chuen Hsieh [a,b,d,e,*]

[a] Institute of Neuroscience, School of Life Science, National Yang-Ming University, Taipei, Taiwan
[b] Laboratory of Integrated Brain Research, Department of Medical Research and Education, Taipei Veterans General Hospital, Taipei, Taiwan
[c] Chang Gung Institute of Technology, Tao-Yuan, Taiwan
[d] Brain Research Center, National Yang-Ming University, Taipei, Taiwan
[e] Institute of Brain Science, School of Medicine, National Yang-Ming University, Taipei, Taiwan
[f] Department of Electrical Engineering, National Central University, Jhongli, Taiwan

ARTICLE INFO

Article history:
Received 1 September 2008
Revised 9 October 2008
Accepted 9 October 2008
Available online 1 November 2008

Keywords:
Emotion
Fear
Menstrual cycle
Frontal asymmetry
Brain
Magnetoencephalography

ABSTRACT

We previously reported that the trait/baseline prefrontal cortex (PFC) activity expresses a dynamic plasticity during female menstrual cycle. The shift of asymmetric lateralization of PFC baseline activity pinpoints a possible emotional regulation of negative affection. The current emotional Go/NoGo study aimed to investigate the state PFC responses of different menstrual phases during fear facial stimulation in fourteen healthy women. Our data disclosed that the menstrual cycle was coupled with a shift of asymmetric lateralization of frontal activation across different menstrual phases. Evoked magnetic field activity in the time window 200–300 ms (M1) and 300–450 ms (M2) after stimulus onset demonstrated significant interactions between hemispheric side and menstrual phase. The right hemispheric dominance in periovulatory phase (OV) changed to left hemispheric dominance in menstrual (MC) phase. Significant association between the anxiety score and the left PFC activation was particularly observed in MC phase. Our study revealed a plastic resilience of functional organization of human brain and a dynamic automaticity of inter-hemispheric synergism for possible adaptive regulation under the aversive confrontation in accordance with hormonal fluctuation during the menstrual cycle.

© 2008 Elsevier Inc. All rights reserved.

Introduction

Female's capability to regulate the negative emotion, an ability which is associated with women health or hedonic well-being with adaptation to the changing environments, has been considered one of the central functions of the prefrontal cortex (PFC) (Davidson et al., 2000; Keenan et al., 2001). It has been postulated that the left and right anterior regions of the brain are parts of two separate neural systems underlying approach and withdrawal (promotion vs. prevention) motivation, respectively (Amodio 2004; Davidson et al., 2000; Eddington et al., 2007; Higgins, 1997). Gonadal steroid hormones vary systematically during the menstrual cycle and can influence neuronal activity, which in turn may be responsible for cyclic modulation of mood or affective processing (Dreher et al., 2007; Protopopescu et al., 2005). However, the exact relationship between different menstrual phases and the PFC lateralization for negative emotional processing remains undocumented.

Kline et al. (2007) proposed that a greater left frontal baseline activity may reflect a protective factor against maladaptive responses to stress. Subjects with higher left frontal baseline activity may show a significant increase in the left anterior activation from aversive to recovery condition and are better in stress adjustment and emotional regulation, resulting in a reduced occurrence of psychological and/or physiological dysfunction (Davidson, 2003; Jackson et al., 2003). It has also been reported that greater left PFC activity can be associated with lower metabolic activity in the amygdale (Davidson et al., 2000) and can manifest a top-down coping or inhibition of negative reactivity (Jackson et al., 2003). However, our recent study reported that female hormone cycle may influence the resting PFC activity; relative higher left frontal activation during menstruation phase (MC) as compared with the periovulatory phase (OV) (Hwang et al., 2008). The shift of asymmetric lateralization of PFC baseline activity pinpoints a possible emotional regulation of negative affection to meet with different demand across menstrual cycle.

The emotional Go/NoGo task can serve as an effective probe for frontal lobe functions (Swainson et al., 2003; Watanabe et al., 2002). Fear facial expression may invoke biological stress responses (Lerner et al., 2007). The fear facial NoGo task has been used to elicit negative emotion as compared with passively viewing simple unpleasant pictures for the NoGo condition (Boecker et al., 2007; Phan et al.,

☆ MEG study of prefrontal activity across menstrual cycle.

* Corresponding author. Brain Research Center and Institute of Brain Science, School of Medicine, National Yang-Ming University, No. 155, Sect. 2, Linong Street, Taipei 112, Taiwan. Fax: +886 2 28757480.

E-mail addresses: rjhwang2@vghtpe.gov.tw (R.-J. Hwang), jchsieh@ym.edu.tw (J.-C. Hsieh).

0018-506X/$ – see front matter © 2008 Elsevier Inc. All rights reserved.
doi:10.1016/j.yhbeh.2008.10.008

2004). The task efficiently commands attention to evocative stimuli and potentially invokes stress during the NoGo processing. The time windows for the NoGo-trial evoked PFC activation often occur around 200–400 (N2) ms or 300–500 (P3) ms (Bruin and Wijers, 2002; Falkenstein et al., 1999). The frontal N2 and P3 had both been suggested to tap inhibitory control in response to negative emotional state (Lewis et al., 2006). The cerebral engagement may connote self-regulation, conflict monitoring, inhibition of prepotent or impulsive responses, and/or cognitive control for emotional regulation depending on experimental manipulations (Botvinick et al., 2001; Lewis et al., 2006; Nieuwenhuis et al., 2003).

The current fear facial Go/NoGo study aimed to investigate the state PFC responses of different menstrual phases during fear facial stimulation in healthy women. We speculated that female may exhibit divergent hemispheric contribution during menstrual cycle under a negative emotion-laden cognitive challenge albeit the documented right hemispheric dominance for negative emotion processing. (Cunningham et al., 2005a; Davidson, 2003; Demaree et al., 2005).

Material and methods

Participants

Fourteen, right-handed, healthy young women participated in this study. Inclusion criteria were (1) consistent menstrual cycles of 26–35 days, (2) 18–35 y/o, (3) no pregnancy or oral/hormonal contraceptive use. Exclusion criteria included history of neurological or psychiatric disorders, chronic illnesses (with the exception of allergies), and premenstrual syndrome. The subjects were instructed to avoid alcohol for at least 48 h and caffeine/tobacco for 12 h before study. The study was approved by the institutional ethic committee of Taipei Veterans General Hospital and written informed consent was obtained from each subject prior to study.

Procedure

We used magnetoencephalography (MEG) to measure the brain neuromagnetic activity across the menstrual cycle. In this study, each subject underwent two MEG measurements, one scan was performed on the 2nd–4th day of the subject's menstrual cycle (MC condition) while the other scan on the 12th–16th day of the subject's periovulatory (OV) phase. The urinary luteinizing hormone (LH) test kit (Biotron, IND Diagnostic Inc., Canada) was used to verify the OV phase. The urinary LH test yields good correlation with blood hormonal level (Corson, 1986; Miller and Soules, 1996) and has been extensively exploited for clinical research (Krug et al., 2000) and self-prediction of ovulation (Corson, 1986). The LH urine kit used in the current study affirms LH surge by means of color indicator with a sensitivity of 20 mIU/mL. One purple band (null control) indicates no LH increase. The presence of two purple bands with similar hue indicates a LH surge above the cut-off value. All participants had regular menstrual cycles of 26–32 days. They were meticulously instructed with the proper way of using the test kit during the middle period of menstrual cycle, i.e., between day 10 and 16 for every day. The MEG study was conducted within 36 h after the LH surge was detected. The measurements for each subject were completed within two month cycles since some subjects missed the available MEG scanning time. To avoid order effects, counterbalanced repeated-measure design was used, with half of the sample completing either the MC or OV phase measurement first. The within-subject comparison design would ameliorate intersubject variations and thus yield a higher statistical power than that of between-subject comparison experiment (Compton et al., 2004).

Stimuli

Subjects were required to complete a fear facial Go/NoGo task. Participants either responded to a particular emotional facial expression (neutral, sad, and happy; Go trials) or prohibit the response to fearful expression (NoGo trials). The stimulation set consisted of digitized black and white faces taken from the Ekman collection of faces. Subjects received a 500-ms fix-cross picture as a warning signal followed 1000 ms later by a 400-ms facial expression picture. To discern possible confound contribution from other cognitive component, e.g., executive control, as commonly involved in a Go/NoGo task, subjects also performed an emotionally neutral Go/NoGo task in a different experimental session on the same day. The participant should respond to a symbol set (square, star and triangle; Go trials) but prohibit the response to a circle symbol (NoGo trials). We used the symbol Go/NoGo task as the neutral control instead of using neutral face as the NoGo event since the neutral face could be recognized as of negative valence and may further complicate the experimental situation (Casey et al., 1997; Chiu, 2007). Pictures (or symbols) were presented sequentially in the middle of a screen in front of the subject with white background. At least 30 successful NoGo trials were acquired for each task (fear and neutral). Subjects used the right index finger for the Go response. The frequency ratio of the Go/NoGo trials was 80% over 20%.

MEG recording

Participants sat in a magnetically shielded room. Brain signals were recorded with a whole-head 306-channel neuromagnetometer (Vectoview, Elekta Neuromag, Helsinki, Finland) digitized at 1024 Hz using a 0.03–330 Hz band pass filter. Vertical and horizontal electrooculograms were monitored to reject epochs coinciding with blinks and excessive eye movements with an amplitude cutoff of 600 mV. Four head-position-indicator (HPI) coils were attached onto the subjects' head and were used to ensure no large head movement throughout the measurement period by comparing the positions of these HPI coils before and after the recordings. In order to ensure the same cortical regions were covered for each subject at different measurements, three predefined anatomical landmarks (the nasion and bilateral preauricular points) were used to verify that head positions were similar relative to the sensor array across sessions (Hwang et al., 2008).

Behavioral assessment

Each participant was asked to complete a State-Trait Anxiety Inventory (STAI) after each MEG measurement for examination of state and trait aspects of anxiety as an index of negative mood, with state anxiety (SAI) reflecting a “transitory emotional state or condition of the human organism” (Spielberger, 1983). SAI scores were assessed for all subjects in the OV and MC phases, respectively. Each of the 20 SAI items was given a weighted score of 1–4, with the rating of 4 indicated the highest level of anxiety. Total score range was from 20 to 80.

Analysis

Magnetic field strength (fT, femtoTesla) was analyzed for successful NoGo trials according to the root mean square (RMS) that calculated from eight planar gradiometers of selected sensors for each subject and for each condition (Fig. 1). The RMS analysis employed eight sensors over four sites of each hemisphere thus providing a better assessment of peak amplitude and latency in the context of field potential than those by a single sensor (Chait et al., 2005; Kato et al., 2007; Shahin et al., 2007). Based on the aforementioned time windows of evoked responses (see Introduction), the difference of mean peak amplitude (MPA) of every 50 ms during 150–450 ms after stimulus onset for each hemisphere was carefully calculated and compared respectively (Left vs. Right, i.e. LMPA vs. RMPA) by paired-*T* test in order to detect the interhemispheric difference for each time

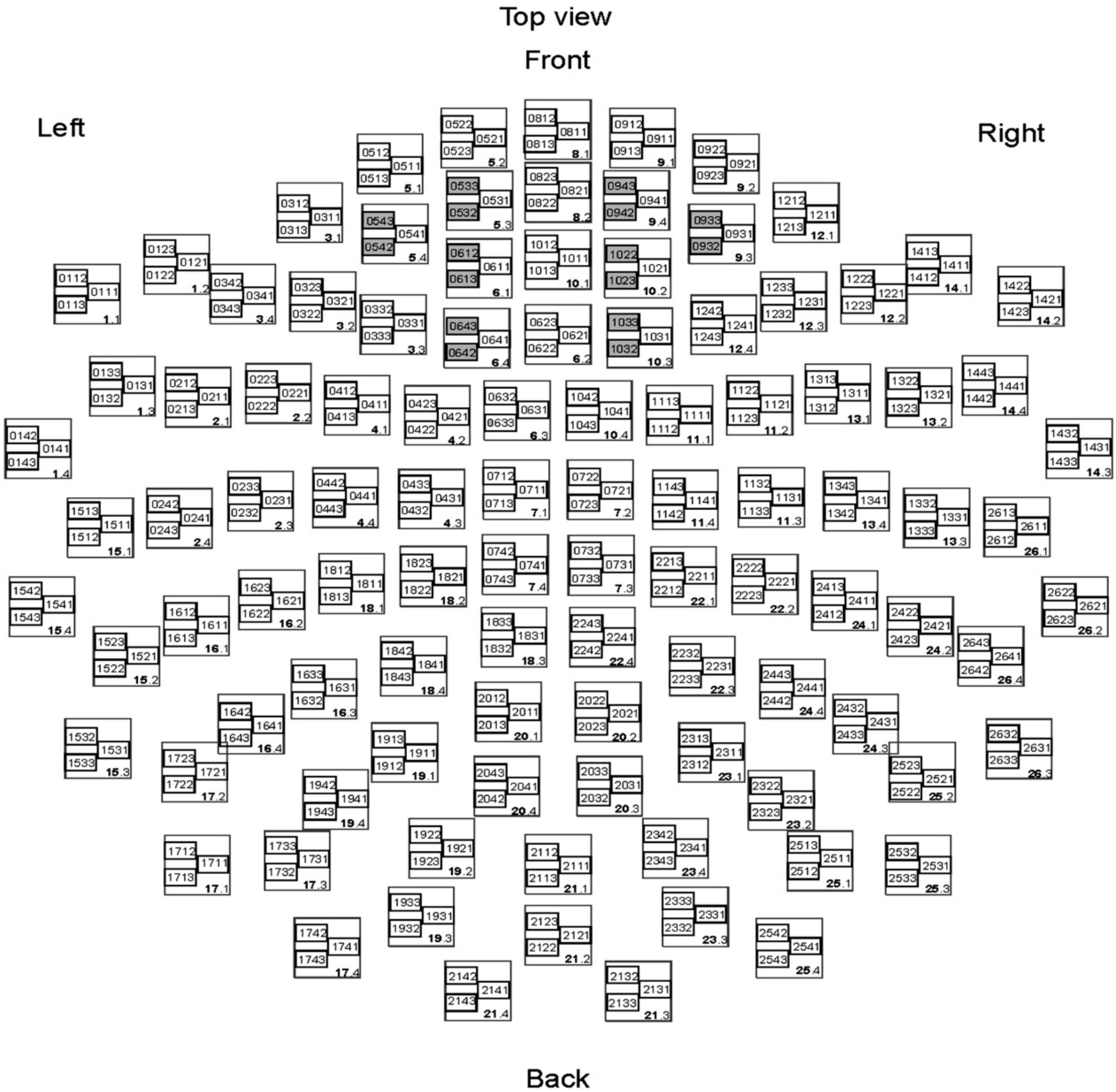

Fig. 1. Frontal regions selected for RMS analysis. The MEG channels (paired gradiometers) selected are blacken. MEG, magnetoencephalography.

segment. Significant level was threshold at $p=0.05$. Then, the mean values within the time window 200–300 ms (M1) and 300–450 ms (M2) of the two hemispheres were respectively taken for subsequent lateralization/interaction and behavior correlation analysis with SAI scores. A 2×2 repeated-measure analysis of variance (ANOVA) was conducted for the main effects of hemisphere (LMPA and RMPA) and menstruation phase (MC vs. OV) as well as the interaction (SPSS-12, SPSS Inc, USA). Significant level was threshold at $p=0.05$. Pearson approach was used to evaluate whether correlation existed between the hemispheric MAP and anxiety rating (SAI scale) during respective phase across hormonal cycle. Each test session (two per subject across menstrual cycle) was used as one individual data point for the overall correlation analysis.

Results

Magnetic responses

Fear facial NoGo response

The means of the magnetic field amplitude for each 50 ms interval in bilateral PFCs were shown in Fig. 2. The LMPA (fT) of 200–250 ms was significantly greater in MC phase as compared with that in OV phase ($t(13)=2.9$, $p=0.012$). Significantly greater LMPA (fT) as compared with RMPA was observed in the interval 200–250 and 250–300 ms during MC phase ($t(13)=2.31$, $p=0.038$ $t(13)=2.67$, $p=0.019$). The 300–350 ms RMPA was significantly greater than 300–350 ms LMAP during OV phase ($t(13)=-2.25$, $p=0.043$). Significant interaction between phase and hemisphere was noted in M1 and M2 [$F(1, 13)=7.62$, $p=0.016$ $F(1,13)=4.902$, $p=0.045$] (Geiser–Greenhouse corrected), demonstrating an interhemispheric asymmetry across menstrual cycle. The data disclosed a relative left PFC preponderance in the MC phase and right PFC preponderance in the OV phase for fear facial processing.

Neutral NoGo response

The means of magnetic field amplitude for each 50 ms interval in bilateral PFCs were shown in Fig. 2. No significant difference between the two phases (MC vs. OV) was found either in RMPA or LMPA ($p>0.05$) for each 50 ms segment. No significant interaction between phase and hemisphere was noted for the time segment M1 and M2 ($p>0.05$) (Geiser–Greenhouse corrected). The amplitude difference of interval 150–200 ms between bilateral hemisphere was not significant neither ($t=2.03$ $p=0.064$) during MC phase.

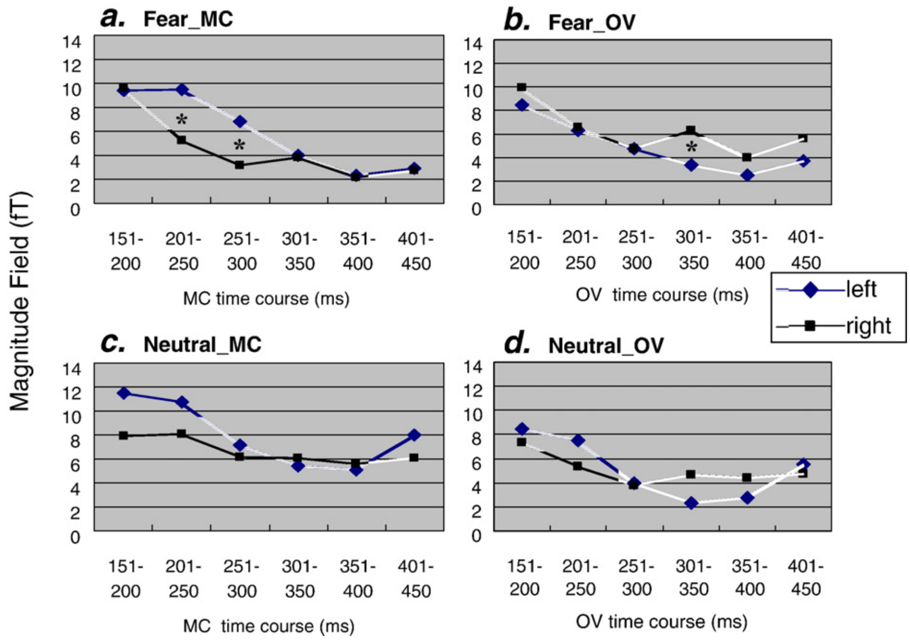

Fig. 2. Group-RMS comparisons between the left and right hemisphere for each 50 ms interval within 150–450 ms post stimulation, Upper panel, during fear facial condition. Lower panel, during neutral control condition. fT, femtotesla. * Significant difference by paired-*T* test as thresholded at $p=0.05$.

Behavioral data

There was no difference of the anxiety score (SAI) across the menstrual phases. The SAI mean score±standard deviation (SD) was 35.8±8.4 and 34.2±5.7 during the MC and OV phase, respectively. There was no difference in the error rate between fear facial NoGo trail (17% for MC vs. 18% for OV) and neutral symbol NoGo trial (3% for MC vs. 4% for OV) across the menstrual cycle.

Correlation of component M1 and M2 and behavioral measurement

The correlation analysis was conducted between MPAs (M1 and M2 respectively) of each hemisphere and SAI score. Table 1 shows a significantly positive correlation between the LMPA (M1, M2) and SAI score ($r=0.432$, $p=0.022$; $r=0.5$, $p=0.007$ respectively, $n=28$ data point) during the fear facial NoGo confrontation. The LMPA of the respective M1 and M2 was in particular positively correlated with the SAI score during MC phase (M1: $r=0.541$, $p=0.046$; M2: $r=0.543$, $p=0.045$; $n=14$) but not during the OV phase. No significant correlation was observed between LMPA/RMPA with SAI scores in the neutral NoGo trails ($p>0.05$) (Table 2).

Discussion

We set out to investigate the interrelationship between bilateral PFC activation conformed to hormonal modulation under the negative-emotion inhibitory challenge. A clear dominance shift was observed on the fear facial NoGo task where the right hemispheric engagement during OV phase was changed to the left hemispheric prominence during MC stage. Our findings demonstrated that hormone cycle could modulate the pattern of frontal activation. Significant association of the anxiety score and the left PFC activation was particularly observed in the MC phase during the fear facial NoGo task. Interhemispheric synergism of these neurobehavioral motivational systems are assumed to prime a repertoire of motivation-related behaviors as well towards different regulatory focus orientation, e.g., promotion versus prevention (Amodio 2004; Cunningham et al., 2005b; Davidson et al., 2000; Eddington et al., 2007; Higgins, 1997).

Menstrual cycle and affective motivation system

Our data disclosed that young females could display a clear reversal of hemispheric dominance for the challenged negative emotional processing across the menstrual cycle (Fig. 2). The findings should pertain to the emotional context disposed since the pattern shift was not observed in the neutral control condition. Two social–cognitive motivational systems, the promotion and prevention systems, have been proposed for self-regulation of goal pursuit orientation; promotion (e.g., well-being) and prevention (e.g., cognitive dissonance) (Amodio 2004; Eddington et al., 2007; Higgins, 1997). The disparity between these two goal-directed pursuit behaviors can be associated with different hemispheres, i.e., the left PFC for the promotion while the right PFC for the prevention which in synergism is critical for seeking advancement/accomplishments (promotion focus) and safety/responsibility respectively (prevention focus) (James Shah, 1998). The relative stronger expression of right

Table 1
Correlations between LMAP, RMAP and SAI score in *fear facial NoGo events*

	M1 (201–300 ms)				M2 (301–450 ms)			
	LMAP		RMAP		LMAP		RMAP	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Anxiety mean (*n*=28)	0.432	***0.022***	0.339	0.077	0.5	***0.007***	0.36	0.060
MC anxiety mean (*n*=14)	0.541	***0.046***	0.534	***0.049***	0.543	***0.045***	0.466	0.093
OV anxiety mean (*n*=14)	0.294	0.308	0.100	0.733	0.428	0.127	0.197	0.500

Table 2
Correlations between LMAP, RMAP and SAI score in *neutral control NoGo events*

	M1 (201–300 ms)				M2 (301–450 ms)			
	LMAP		RMAP		LMAP		RMAP	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Anxiety mean (*n*=28)	0.329	0.094	0.314	0.111	0.223	0.264	0.107	0.596
MC anxiety mean (*n*=14)	0.306	0.287	0.358	0.209	0.249	0.390	0.182	0.530
OV anxiety mean (*n*=14)	0.373	0.209	0.214	0.483	0.129	0.674	0.088	0.776

hemisphere during OV might implicate an advantage in sustaining vigilance. The right hemisphere is involved in vigilance and autonomic arousal for detecting salient stimuli that are behaviorally relevant (Corbetta and Shulman, 2002). The right hemispheric vigilance system can be enhanced by hormone replacement therapy (HRT) as shown in an EEG study (Saletu et al., 2005). It has also been shown that estrogen can augment fear facial recognition in human (Pearson and Lewis, 2005) and increase freeze action to danger cues in ovariectomized mice (Morgan et al., 2004). Such reactions might bear evolutional advantages for reproduction during periovulatory period.

A stronger left hemisphere engagement during MC phase may suggest the proposed promotion function that could subsequently modulate the amygdale with a faster recovery from negative and stressful events (Davidson, 2004; Kline et al., 2007) followed by an experience of well-being or better emotional revision (Urry et al., 2004). Our findings were in resonance with the previous proposition that a higher baseline left PFC activity during MC phase as compared with OV phase (Hwang et al., 2008) may lead to an activation of higher magnitude in response to aversive stimulation (state reactions as in the current study) (Kline et al., 2007). The temporal scenario may prime a repertoire of motivation-related behavioral modulation. Such differential and resilient patterns may assume different neural bases for different regulatory needs across menstrual cycle.

The left frontal activity correlates with anxiety

We reported a positive correlation between the evoked LMPA (M1 and M2) and self-reported anxiety rating ($p<0.01$, $n=28$) upon negative emotion challenge as opposed to neutral condition. This was in congruence with a recent fMRI study that the anxious apprehension group demonstrated a greater activation in the left inferior frontal gyrus (IFG) for negative than neutral words (Engels et al., 2007). Anxiety has specific effects on cognition and emotion. In particular, it has been associated with an attention bias and faster response toward threatening stimuli (Bishop et al., 2004). The aversive states may booster left PFC accounting for a better automatic emotional regulation toward homeostatic equilibrium (a motivational goal) (Seymour et al., 2005).

The left frontal activity imparts the inhibition to the amygdala in an inverse manner (Davidson et al., 2000) and tunes the function of the amygdale for the valence appraisal and responsiveness to the stimulus (Jackson et al., 2000; Jackson et al., 2003). A reciprocal tonic inhibition of the amygdala may be reflected in studies in which subjects with higher left PFC activation report more trait positive affect and less trait negative affect, and display greater reactivity to positive stimuli (Davidson et al., 2000) than individuals with lower levels of left PFC activity. It is noteworthy that in the separate sub-cycle analysis the correlation between the left PFC and anxiety (contains M1, M2) was noted only during the MC phase (Table 1). It may connote a top-down modulation during the menstrual phase for biologically salient stimuli. This is indispensable for coping negative stimuli against mood and anxiety disorders (Jackson et al., 2003), and may pinpoint a possible compensatory mechanism in the healthy young female for automatic emotional regulation, accounting in part for the lack of difference of behavioral measurements on the group level between menstrual phases in our study. This view might gain indirect support from the studies showing that anxiety does not change significantly across menstrual cycle in healthy young women (Amin et al., 2006; Goldstein et al., 2005).

Possible mechanisms underlying the shift of frontal asymmetry during menstrual cycle

The prefrontal cortex is known to play a significant role not only in the regulation of emotion, but also in the integration of affective states by means of appropriate modulation of autonomic and neuroendocrine stress regulatory systems (Dreher and Burnod, 2002; Sullivan and Gratton, 2002; Tanida et al., 2008). It has been reported that an augmented stress or an increase of arousal intensity will invoke a brain expression toward a left-sided asymmetry (Canli et al., 1998; Davidson et al., 1992; Dolcos et al., 2004; Kalin et al., 1998; Papousek and Schulter, 2001).

We had observed right hemisphere dominance during OV phase (M2). The right PFC has been associated with control of withdrawal (avoidance) from harmful stimulus (Demaree et al., 2005). Anxiety, tension, and depression were found to decrease when frontopolar activation asymmetry shifted to the right (Papousek and Schulter, 2002). However, the relative left PFC preponderance was more expressed during MC phase (M1) (Fig. 2). To our knowledge, there is no report on the shift of state-related frontal asymmetry under the appreciation of negative confrontation across the menstrual cycle. Affective facial displays have the potential to interact with an individual's current emotional state (Maxwell et al., 2005). It is conceivable to speculate that the dynamic change of left–right hemispheric preponderance may mediate automatic modulation and the emotional regulation across the menstrual cycle.

The estrogen can modulate the arousal effect via cortical–subcortical control within the Hypothalamus–Pituitary–Adrenal axis (HPA) circuitry. It has been suggested that estrogen might attenuate arousal in women via cortical–subcortical control within HPA circuitry (Goldstein, 2006; Serova et al., 2005; Sullivan and Dufresne, 2006) that women actually exhibit higher arousal status to negative stimulus during relative lower estrogen condition, i.e., in the MC phase, as compared with OV phase (Goldstein et al., 2005). Thus, a decrease of estrogen also enhances the engagement of central regions for stress response. The dysfunction and hypoactivation of the left PFC have been coupled with a variety of psychopathology (Fallgatter and Strik, 2000; Gruzelier, 1999; Henriques and Davidson, 1991; Henriques et al., 1994; Johnstone et al., 2007; Minnix et al., 2004; Papousek and Schulter, 2001). The leftward expression of M1 (with sub-significantly faster reaction in terms of a shorter latency) during MC phase in the current study might underlie a relatively high arousal during MC phase as indexed to the OV phase, and targeted the left PFC for an effective adaptive mechanisms for a better homeostatic equilibrium.

We had in the current study implemented an emotionally neutral NoGo task to serve as a control to discern common cognitive components, e.g., executive function, attention, working memory, motor act, and inhibitory control. Neither had we observed any functional hemispheric asymmetry nor shift of asymmetric response across the menstrual cycle. We also observed an interaction between hemisphere × phase for the fear facial NoGo (M1, $p=0.016$; M2, $p=0.045$) but not in the neutral NoGo (M1, $p=0.851$; M2, $p=0.425$). Thus it was affirmed that the shift of PFC activity across the menstrual cycle should be attributed to emotional context instead of cognitive components of the fear facial Go/NoGo task. Thus the asymmetry of hemispheric expression in the fear facial NoGo event during the menstrual cycle should be related to the contextual information and thus emotion-specific.

Conclusions

Our study revealed a plastic resilience of functional organization of human brain and the dynamic automaticity of inter-hemispheric synergism for emotional regulation under the aversive confrontation in accordance with hormonal fluctuation during the menstrual cycle. The observations that functional hemisphere asymmetries varied across the menstrual cycle is compatible with the proposition that relative differences in the functional competence of one hemisphere are not fixed but may be subject to dynamic processes (Papousek and Schulter, 2001). Future work with fine manipulation of valence and arousal is required to further probe the profound functional significance of these central signatures.

Acknowledgments

We thank Mr. Chih-Che Chou and Chou-Ming Tseng for the MEG technical support. The study was sponsored by the National Science Council (962752B010006; 962628B075028, 972314B010005MY3).

References

Amin, Z., Epperson, C.N., Constable, R.T., Canli, T., 2006. Effects of estrogen variation on neural correlates of emotional response inhibition. Neuroimage 32 (1), 457–464.
Amodio, J.Y.S., Sigelman, J., Brazy, P.C., Harmon-Jones, E., 2004. Implicit regulatory focus associated with asymmetrical frontal cortical activity. J. Exp. Soc. Psychol. 40, 225–232.
Bishop, S., Duncan, J., Brett, M., Lawrence, A.D., 2004. Prefrontal cortical function and anxiety: controlling attention to threat-related stimuli. Nat. Neurosci. 7 (2), 184–188.
Boecker, M., Buecheler, M.M., Schroeter, M.L., Gauggel, S., 2007. Prefrontal brain activation during stop-signal response inhibition: an event-related functional near-infrared spectroscopy study. Behav. Brain Res. 176 (2), 259–266.
Botvinick, M.M., Braver, T.S., Barch, D.M., Carter, C.S., Cohen, J.D., 2001. Conflict monitoring and cognitive control. Psychol. Rev. 108 (3), 624–652.
Bruin, K.J., Wijers, A.A., 2002. Inhibition, response mode, and stimulus probability: a comparative event-related potential study. Clin. Neurophysiol. 113 (7), 1172–1182.
Canli, T., Desmond, J.E., Zhao, Z., Glover, G., Gabrieli, J.D., 1998. Hemispheric asymmetry for emotional stimuli detected with fMRI. Neuroreport 9 (14), 3233–3239.
Casey, B.J., Castellanos, F.X., Giedd, J.N., Marsh, W.L., Hamburger, S.D., Schubert, A.B., Vauss, Y.C., Vaituzis, A.C., Dickstein, D.P., Sarfatti, S.E., Rapoport, J.L., 1997. Implication of right frontostriatal circuitry in response inhibition and attention-deficit/hyperactivity disorder. J. Am. Acad. Child Adolesc. Psychiatry 36 (3), 374–383.
Chait, M., Poeppel, D., de Cheveigne, A., Simon, J.Z., 2005. Human auditory cortical processing of changes in interaural correlation. J. Neurosci. 25 (37), 8518–8527.
Chiu, Y.-C., Lin, C.-H., Lin, J.-H., 2007. The neurtral face is not really expressionless and emotionless. Taiwanese Psychology Association. 46th Annual Conference, p. 35.
Compton, R.J., Costello, C., Diepold, J., 2004. Interhemispheric integration during the menstrual cycle: failure to confirm progesterone-mediated interhemispheric decoupling. Neuropsychologia 42 (11), 1496–1503.
Corbetta, M., Shulman, G.L., 2002. Control of goal-directed and stimulus-driven attention in the brain. Nat. Rev. Neurosci. 3 (3), 201–215.
Corson, S.L., 1986. Self-prediction of ovulation using a urinary luteinizing hormone test. J. Reprod. Med. 31 (Suppl. 8), 760–763.
Cunningham, W.A., Espinet, S.D., DeYoung, C.G., Zelazo, P.D., 2005a. Attitudes to the right- and left: frontal ERP asymmetries associated with stimulus valence and processing goals. Neuroimage 28 (4), 827–834.
Cunningham, W.A., Raye, C.L., Johnson, M.K., 2005b. Neural correlates of evaluation associated with promotion and prevention regulatory focus. Cogn. Affect. Behav. Neurosci. 5 (2), 202–211.
Davidson, R.A., Fedio, P., Smith, B.D., Aureille, E., Martin, A., 1992. Lateralized mediation of arousal and habituation: differential bilateral electrodermal activity in unilateral temporal lobectomy patients. Neuropsychologia 30 (12), 1053–1063.
Davidson, R.J., 2003. Affective neuroscience and psychophysiology: toward a synthesis. Psychophysiology 40 (5), 655–665.
Davidson, R.J., 2004. What does the prefrontal cortex "do" in affect: perspectives on frontal EEG asymmetry research. Biol. Psychol. 67 (1–2), 219–233.
Davidson, R.J., Jackson, D.C., Kalin, N.H., 2000. Emotion, plasticity, context, and regulation: perspectives from affective neuroscience. Psychol. Bull. 126 (6), 890–909.
Demaree, H.A., Everhart, D.E., Youngstrom, E.A., Harrison, D.W., 2005. Brain lateralization of emotional processing: historical roots and a future incorporating "dominance". Behav. Cogn. Neurosci. Rev. 4 (1), 3–20.
Dolcos, F., LaBar, K.S., Cabeza, R., 2004. Dissociable effects of arousal and valence on prefrontal activity indexing emotional evaluation and subsequent memory: an event-related fMRI study. Neuroimage 23 (1), 64–74.
Dreher, J.C., Burnod, Y., 2002. An integrative theory of the phasic and tonic modes of dopamine modulation in the prefrontal cortex. Neural Netw. 15 (4–6), 583–602.
Dreher, J.C., Schmidt, P.J., Kohn, P., Furman, D., Rubinow, D., Berman, K.F., 2007. Menstrual cycle phase modulates reward-related neural function in women. Proc. Natl. Acad. Sci. U. S. A. 104 (7), 2465–2470.
Eddington, K.M., Dolcos, F., Cabeza, R., Krishnan, R., Ranga, K., Strauman, T.J., 2007. Neural correlates of promotion and prevention goal activation: an fMRI study using an idiographic approach. J. Cogn. Neurosci. 19 (7), 1152–1162.
Engels, A.S., Heller, W., Mohanty, A., Herrington, J.D., Banich, M.T., Webb, A.G., Miller, G.A., 2007. Specificity of regional brain activity in anxiety types during emotion processing. Psychophysiology 44 (3), 352–363.
Falkenstein, M., Hoormann, J., Hohnsbein, J., 1999. ERP components in Go/Nogo tasks and their relation to inhibition. Acta Psychol. (Amst) 101 (2–3), 267–291.
Fallgatter, A.J., Strik, W.K., 2000. Reduced frontal functional asymmetry in schizophrenia during a cued continuous performance test assessed with near-infrared spectroscopy. Schizophr. Bull. 26 (4), 913–919.
Goldstein, J.M., 2006. Sex, hormones and affective arousal circuitry dysfunction in schizophrenia. Horm. Behav. 50 (4), 612–622.
Goldstein, J.M., Jerram, M., Poldrack, R., Ahern, T., Kennedy, D.N., Seidman, L.J., Makris, N., 2005. Hormonal cycle modulates arousal circuitry in women using functional magnetic resonance imaging. J. Neurosci. 25 (40), 9309–9316.
Gruzelier, J.H., 1999. Functional neuropsychophysiological asymmetry in schizophrenia: a review and reorientation. Schizophr. Bull. 25 (1), 91–120.
Henriques, J.B., Davidson, R.J., 1991. Left frontal hypoactivation in depression. J. Abnorm. Psychol. 100 (4), 535–545.
Henriques, J.B., Glowacki, J.M., Davidson, R.J., 1994. Reward fails to alter response bias in depression. J. Abnorm. Psychol. 103 (3), 460–466.
Higgins, E.T., 1997. Beyond pleasure and pain. Am. Psychol. 52 (12), 1280–1300.
Hwang, R.J., Chen, L.F., Yeh, T.C., Tu, P.C., Tu, C.H., Hsieh, J.C., 2008. The resting frontal alpha asymmetry across the menstrual cycle: a magnetoencephalographic study. Horm. Behav. 54 (1), 28–33.
Jackson, D.C., Malmstadt, J.R., Larson, C.L., Davidson, R.J., 2000. Suppression and enhancement of emotional responses to unpleasant pictures. Psychophysiology 37 (4), 515–522.
Jackson, D.C., Mueller, C.J., Dolski, I., Dalton, K.M., Nitschke, J.B., Urry, H.L., Rosenkranz, M.A., Ryff, C.D., Singer, B.H., Davidson, R.J., 2003. Now you feel it, now you don't: frontal brain electrical asymmetry and individual differences in emotion regulation. Psychol. Sci. 14 (6), 612–617.
Shah, J., Tory Higgins, E., Friedman, R.S., 1998. Performance incentives and means: how regulatory focus influences goal attainment. J. Pers. Soc. Psychol. 74 (2), 285–293.
Johnstone, T., van Reekum, C.M., Urry, H.L., Kalin, N.H., Davidson, R.J., 2007. Failure to regulate: counterproductive recruitment of top-down prefrontal-subcortical circuitry in major depression. J. Neurosci. 27 (33), 8877–8884.
Kalin, N.H., Larson, C., Shelton, S.E., Davidson, R.J., 1998. Asymmetric frontal brain activity, cortisol, and behavior associated with fearful temperament in rhesus monkeys. Behav. Neurosci. 112 (2), 286–292.
Kato, Y., Muramatsu, T., Kato, M., Shintani, M., Kashima, H., 2007. Activation of right insular cortex during imaginary speech articulation. Neuroreport 18 (5), 505–509.
Keenan, P.A., Ezzat, W.H., Ginsburg, K., Moore, G.J., 2001. Prefrontal cortex as the site of estrogen's effect on cognition. Psychoneuroendocrinology 26 (6), 577–590.
Kline, J.P., Blackhart, G.C., Williams, W.C., 2007. Anterior EEG asymmetries and opponent process theory. Int. J. Psychophysiol. 63 (3), 302–307.
Krug, R., Plihal, W., Fehm, H.L., Born, J., 2000. Selective influence of the menstrual cycle on perception of stimuli with reproductive significance: an event-related potential study. Psychophysiology 37 (1), 111–122.
Lerner, J.S., Dahl, R.E., Hariri, A.R., Taylor, S.E., 2007. Facial expressions of emotion reveal neuroendocrine and cardiovascular stress responses. Biol. Psychiatry 61 (2), 253–260.
Lewis, M.D., Lamm, C., Segalowitz, S.J., Stieben, J., Zelazo, P.D., 2006. Neurophysiological correlates of emotion regulation in children and adolescents. J. Cogn. Neurosci. 18 (3), 430–443.
Maxwell, J.S., Shackman, A.J., Davidson, R.J., 2005. Unattended facial expressions asymmetrically bias the concurrent processing of nonemotional information. J. Cogn. Neurosci. 17 (9), 1386–1395.
Miller, P.B., Soules, M.R., 1996. The usefulness of a urinary LH kit for ovulation prediction during menstrual cycles of normal women. Obstet. Gynecol. 87 (1), 13–17.
Minnix, J.A., Kline, J.P., Blackhart, G.C., Pettit, J.W., Perez, M., Joiner, T.E., 2004. Relative left-frontal activity is associated with increased depression in high reassurance-seekers. Biol. Psychol. 67 (1–2), 145–155.
Morgan, M.A., Schulkin, J., Pfaff, D.W., 2004. Estrogens and non-reproductive behaviors related to activity and fear. Neurosci. Biobehav. Rev. 28 (1), 55–63.
Nieuwenhuis, S., Yeung, N., van den Wildenberg, W., Ridderinkhof, K.R., 2003. Electrophysiological correlates of anterior cingulate function in a go/no-go task: effects of response conflict and trial type frequency. Cogn. Affect. Behav. Neurosci. 3 (1), 17–26.
Papousek, I., Schulter, G., 2001. Associations between EEG asymmetries and electrodermal lability in low vs. high depressive and anxious normal individuals. Int. J. Psychophysiol. 41 (2), 105–117.
Papousek, I., Schulter, G., 2002. Covariations of EEG asymmetries and emotional states indicate that activity at frontopolar locations is particularly affected by state factors. Psychophysiology 39 (3), 350–360.
Pearson, R., Lewis, M.B., 2005. Fear recognition across the menstrual cycle. Horm. Behav. 47 (3), 267–271.
Phan, K.L., Wager, T.D., Taylor, S.F., Liberzon, I., 2004. Functional neuroimaging studies of human emotions. CNS Spectr. 9 (4), 258–266.
Protopopescu, X., Pan, H., Altemus, M., Tuescher, O., Polanecsky, M., McEwen, B., Silbersweig, D., Stern, E., 2005. Orbitofrontal cortex activity related to emotional processing changes across the menstrual cycle. Proc. Natl. Acad. Sci. U. S. A. 102 (44), 16060–16065.
Saletu, B., Anderer, P., Saletu-Zyhlarz, G.M., Gruber, D., Metka, M., Huber, J., 2005. Identifying target regions for vigilance improvement under hormone replacement therapy in postmenopausal syndrome patients by means of electroencephalographic tomography (LORETA). Psychopharmacology (Berl) 178 (4), 389–399.
Serova, L.I., Maharjan, S., Sabban, E.L., 2005. Estrogen modifies stress response of catecholamine biosynthetic enzyme genes and cardiovascular system in ovariectomized female rats. Neuroscience 132 (2), 249–259.
Seymour, B., O'Doherty, J.P., Koltzenburg, M., Wiech, K., Frackowiak, R., Friston, K., Dolan, R., 2005. Opponent appetitive–aversive neural processes underlie predictive learning of pain relief. Nat. Neurosci. 8 (9), 1234–1240.
Shahin, A.J., Roberts, L.E., Miller, L.M., McDonald, K.L., Alain, C., 2007. Sensitivity of EEG and MEG to the N1 and P2 auditory evoked responses modulated by spectral complexity of sounds. Brain Topogr. 20 (2), 55–61.
Spielberger, C.D., Gorusch, Richard, L., Lushene, Robert E., 1983. Manual for the State-Trait Anxiety Inventory (Form Y). Consulting Psychologist Press, Palo Alto.
Sullivan, R.M., Dufresne, M.M., 2006. Mesocortical dopamine and HPA axis regulation: role of laterality and early environment. Brain Res. 1076 (1), 49–59.
Sullivan, R.M., Gratton, A., 2002. Prefrontal cortical regulation of hypothalamic–pituitary–adrenal function in the rat and implications for psychopathology: side matters. Psychoneuroendocrinology 27 (1–2), 99–114.

Swainson, R., Cunnington, R., Jackson, G.M., Rorden, C., Peters, A.M., Morris, P.G., Jackson, S.R., 2003. Cognitive control mechanisms revealed by ERP and fMRI: evidence from repeated task-switching. J. Cogn. Neurosci. 15 (6), 785–799.
Tanida, M., Katsuyama, M., Sakatani, K., 2008. Effects of fragrance administration on stress-induced prefrontal cortex activity and sebum secretion in the facial skin. Neurosci. Lett. 432 (2), 157–161.
Urry, H.L., Nitschke, J.B., Dolski, I., Jackson, D.C., Dalton, K.M., Mueller, C.J., Rosenkranz, M.A., Ryff, C.D., Singer, B.H., Davidson, R.J., 2004. Making a life worth living: neural correlates of well-being. Psychol. Sci. 15 (6), 367–372.
Watanabe, J., Sugiura, M., Sato, K., Sato, Y., Maeda, Y., Matsue, Y., Fukuda, H., Kawashima, R., 2002. The human prefrontal and parietal association cortices are involved in NO-GO performances: an event-related fMRI study. Neuroimage 17 (3), 1207–1216.