Chinese Journal of Physiology 58(2): 114-123, 2015
DOI: 10.4077/CJP.2015.BAD287

Comparison of Cardiac Autonomic Nervous System Disturbed by Sleep Deprivation in Sex and Menstrual Phase

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Abstract

Sleep deprivation (SD) leads to cardiovascular risk by disturbing autonomic nervous system (ANS). Whether sex or menstrual cycle influences cardiac ANS interfered by SD remained unclear. This investigation was to further clarify the effects of different menstrual phases on cardiac autonomic nervous activity disturbed by SD. Methodologically, cardiac autonomic modulation before and after 30 h of total SD was determined by spectral analysis of heart rate variability in 10 healthy females during the mid-follicular (FF) and mid-luteal (FL) phases and 10 healthy males. The result showed that before SD, the FF subjects, but not FL, had higher normalized high frequency (nHF) (vagal activity) or lower ratio of low frequency (LF) to high frequency (HF) power (sympathetic activity) while performing deep breathing or Valsalva maneuver (40 mmHg) than the male subjects did. However, the SD for 30 h in the FF group significantly increased the LF/HF ratio and decreased nHF level at rest and in responses to deep breathing and Valsalva maneuver, despite no significant change of HRV in either male or FL group. Simultaneously, the SD substantially lowered venous PCO_2 in the FF group, and the decreased PCO_2 level was associated with the increased LF/HF ratio following SD. We concluded that 30-h acute SD promotes sympathetic and depress parasympathetic activities in female during the follicular phase rather than the luteal phase. Compared to FF, SD-triggered cardiac sympathetic activation is blunted in FL. The study provides further insight into the physiology of acute SD in different sex and menstrual phases.

Key Words: follicular phase, heart rate variability, luteal phase, sex

Introduction

Sleep deprivation (SD) jeopardizes quality of life (6) and is also a risk factor of cardiovascular disease (29). Moreover, female bear a more negative cardiovascular influence than male to have lack of sleep. Among women, short duration of sleep (≤5 h per night) was associated with a significantly higher risk of hypertension and other cardiovascular disease compared with the group sleeping 7 h with an odds ratio of 2.01. No such association was detected in men (3). Additionally, a large-scaled prospective survey found modest but significant association between short sleep duration and incidence of myocardial infarction in middle-aged

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Received: April 16, 2014; Revised: June 11, 2014; Accepted: June 25, 2014.

women, but not men (19). Meanwhile, the prevalence of sleep loss is higher in female than male population (31).

One of the pathomechanism how sleep loss leads to cardiovascular illness is through the disturbance of autonomic system (9). On the day following insufficient sleep, increased sympathetic and decreased parasympathetic cardiac modulation as well as elevated urinary excretion of norepinephrine was observed, resulting in tachycardia, higher blood pressure in male subjects (25). The heart rate variability (HRV) study disclosed that 30-h SD was associated with increased sympathetic and decreased parasympathetic cardiovascular modulation and decreased baroreceptor sensitivity in 18 normal subjects, including 16 males and 2 females (32). These could elicit the subsequent cardiovascular dysfunction. The above-mentioned and most related studies neglected sex and menstrual cycle-related differences. As to the influence of menstrual cycle on autonomic nervous system (ANS), a few studies confirmed a predominance of sympathetic tone and greater baroreflex sensitivity during luteal phase than follicular phase (14, 20, 22, 23). However, the combined influence of sex and menstrual cycle following SD was scarcely explored (4).

This investigation was to further clarify whether there was a sex difference in ANS function after SD based on menstrual cycle. We hypothesized that SD exerts different effects on cardiac autonomic activity in different phases of the menstrual cycle and sex.

Materials and Methods

Heart rate variability under four daily activities (sitting rest, deep breathing, Valsalva maneuver, standing up) were measured before and after 30-h acute SD in male (M), female during mid-follicular (FF) and mid-luteal (FL) phase by a within-subjects design. Venous blood was sampled for progesterone level and acid-base analysis.

Subjects

Twenty Mongoloid volunteers (ten males and ten females) aged 20.9 ± 1.2 years were recruited. None of the volunteers had a history of metabolic, cardiovascular, pulmonary or sleep disorders, and none were taking any regular medication. Those who had poor sleep quality (Pittsburgh Sleep Quality Index > 5 points) were excluded and the male and female participants had a score of 2.7 ± 1.2 and 3.2 ± 0.9. All subjects kept regular bed time six days prior to sleep deprivation (SD) and ensured sleep length between 6~9 h each day. All female subjects had regular menstrual cycle three months before the study. Participants who had month-to-month cycle differences longer than seven days were excluded. Female subjects started to monitor their ovulatory status by checking body temperature since three months before SD. Plasma progesterone levels were measured to confirm the subjects' actual menstrual phases (Table 1). They never took oral contraceptives and abstained from any medication for at least 2 weeks before SD (27). The 10 females underwent SD twice in the mid-follicular (FF) and mid-luteal (FL) phases in a random order and therefore, the two SD were performed either in the same menstrual period or two adjacent periods. The 10 males were exposed to SD once. The study was approved by the institutional review board in Chan Gung Memorial Hospital.

Experimental Protocol

Every participant was well explained about the purpose and procedure of the experiment. A written informed-consent was obtained before the intervention. A self-rated Pittsburgh Sleep Quality Index questionnaire and menstrual period record were obtained to select eligible subjects to perform SD. During the 30-h SD, all participants were requested to send messages to an assigned account in Windows Live Messenger or to call an assigned phone number every 15 min. The wakefulness of subjects was assured and documented by messages and the call history. The participants visited the laboratory at 9am before SD and 3PM on the next day after SD. After 10-min supine rest, the cardiovascular autonomic tests were started. Venous blood was sampled before and after SD.

HRV

Dantest- Health Assessment System DT-HW5 was utilized to assess HRV. A 4-minute continuous ECG was acquired and the beat-to-beat R-R interval was recorded and analyzed simultaneously by the analyzing system to obtain parameters in time domain analysis including total power (TP) and standard deviation of normal-to-normal R-R intervals (SDNN), and in frequency domain analysis including high frequency power (HFP) and low frequency/high frequency power (LF/HF). The HF component is generally defined as a marker of vagal modulation while the LF/HF ratio reflects the global sympathovagal balance (15, 16, 24). The cardiac autonomic activity was measured under four conditions to simulate physical stimulation in our everyday activities. A. Sitting rest: Every subject puts on an eye mask and sits on a chair, flexing their hip, knee and ankle joints to 90 degrees. They easily maintain the position for 4 min and breathe naturally. The cardiac autonomic activity is considered as the baseline value

Table 1. Plasma progesterone concentrations and blood acid-base equilibrium in males and in females during mid-follicular and mid-luteal phases

		Male	Female	
			Mid-Follicular	Mid-Luteal
Progesterone	ng/mL	ND	3.2 ± 0.3	32.6 ± 3.1
pH	unit	7.356 ± 0.010	7.361 ± 0.008	7.380 ± 0.011*, +
PCO_2	mmHg	48 ± 2	45 ± 2	41 ± 2*+
HCO_3^-	mM	27.4 ± 0.8	25.1 ± 0.3	23.2 ± 0.4*
Lactate	mM	0.91 ± 0.03	1.02 ± 0.4	0.90 ± 0.03

ND, no determination; *$P < 0.05$, Male *vs.* Female during mid-follicular or mid-luteal phase.
+$P < 0.05$, Female during mid-follicular phase *vs.* Female during mid-luteal phase.

in every individual. B. Deep breathing (DB): The subjects sit quietly and then breathe deeply and evenly with inspiration for 3 seconds, and then expiration for another 6 seconds. HR_{inhale}/HR_{exhale} is measured for baroreceptor responsiveness. A timer with voice reminder instructs subjects to repeat the inspiration-expiration cycle for one minute. The ratio of maximal HR during inspiration to the minimal HR during each breath is also calculated and averaged. C. Valsalva maneuver (VM): The participant's nostril's were clamped, taking a deep inspiration and made a forceful blow to a dead end where a pressure sensor was connected for 15 seconds. The pressure should be kept at the maximal pressure the subject can blow multiplies 0.7 ± 3 mmHg (usually 35~45 mmHg). The ratio of HR_{max} to HR_{min} was also calculated for reflex bradycardia (15, 16) D. Standing up: The subjects sit quietly and then stand up unaided and maintain an up-right position for 2 min. $HR_{standing}/HR_{sitting}$ is measured for cardiac sympathetic activation. There were 5-min sitting rest intervals between HRV tests B, C and D.

Acid-Base Analysis

pH, PCO_2, HCO_3^-, lactate concentration of venous blood was checked to investigate the disturbance of acid-base balance before and after SD.

Data Analysis

Data were expressed as mean ± standard deviation, and were analyzed using the statistical software package StatView. Experimental results were analyzed by 3 (groups) × 2 (time sample points; i.e., pre- and post-interventions) repeated measures ANOVA with Bonferroni's post hoc test to compare the variables of cardiac autonomic nervous activity and venous blood acid-base equilibrium before and after 30 h of total SD in various groups. Significance is defined as $P < 0.05$. Correlation analysis was employed in %LF/HF versus $\%PCO_2$.

Results

HRV

Before SD. LF/HF in mid-luteal phase (FL) and male (M) increased during deep breathing (DB) and Valsalva maneuver (VM) compared to that in mid-follicular phase (FF). nHF in FF increased during DB, but decreased during standing compared with that in M. In addition, during the four testing conditions, heart rate, SDNN and total power of heart rate variability revealed no difference among M, FF or FL (Table 2).

After SD. Three groups showed different autonomic response to SD. During rest, LF/HF increased in FF but unchanged in FL (Fig. 1). During DB and VM, FL showed decreased nLF and LF/HF while elevated nHF with diminished SDNN compared to FF (Figs. 2 and 3). Accordingly, in FL, the sympathetic response to SD was attenuated while the parasympathetic response was enhanced compared to FF. In M during resting, DB and VM condition, LF/HF and nLF decreased while nHF increased compared to FF. During standing-up, HRV parameter including time and frequency domain remained unchanged (Fig. 4). The findings suggested that cardiac autonomic balance shifted toward parasympathetic tone after SD in M and FL. On the contrary, in FF, autonomic modulation shifted to sympathetic dominance.

Additionally, parameters regarding time domain (%SDNN, %total power) collectively did not show difference *after SD* in FL but tended to increase in FF during DB and in M during rest (Figs. 1-4). HR_{max}/HR_{min} during VM, HR_{inhale}/HR_{exhale} during DB and $HR_{standing}/HR_{sitting}$, all indicating baroreflex responsiveness, showed no difference *before and after SD* or among the three groups (15, 16) (Table 2, Figs. 2 and 3).

Acid-Base Balance

Before SD, venous blood analysis showed that FL has higher pH and lower PCO_2 than M and FF,

Table 2. Cardiac autonomic nerve activity in males and in females during mid-follicular and mid-luteal phases

	Male	Female	
		Mid-Follicular	Mid-Luteal
Resting			
Heart rate (bpm)	72 ± 2	74 ± 3	75 ± 3
Heart rate variability			
Total power	552 ± 32	602 ± 58	597 ± 49
SDNN	47 ± 3	51 ± 5	50 ± 4
nHF	2.32 ± 0.41	2.52 ± 0.43	2.72 ± 0.51
nLF	1.73 ± 0.31	1.78 ± 0.32	1.64 ± 0.34
LF/HF	0.75 ± 0.10	0.71 ± 0.09	0.62 ± 0.4
Deep breathing			
Ratio of HR_{inhale} to HR_{exhale}	1.34 ± 0.04	1.37 ± 0.04	1.41 ± 0.03
Heart rate variability			
Total power	432 ± 34	442 ± 38	462 ± 31
SDNN	90 ± 12	91 ± 14	94 ± 15
nHF	11.21 ± 1.82	16.23 ± 2.12*	12.81 ± 3.20
nLF	5.35 ± 0.69	4.23 ± 0.92	4.82 ± 1.0
LF/HF	0.48 ± 0.08	0.26 ± 0.03*, +	0.56 ± 0.08+
Valsalva Maneuver			
Ratio of HR_{max} to HR_{min}	1.48 ± 0.09	1.68 ± 0.08	1.58 ± 0.07
Heart rate variability			
Total power	632 ± 54	644 ± 62	651 ± 58
SDNN	108 ± 9	112 ± 10	99 ± 11
nHF	7.21 ± 0.9	8.92 ± 0.08	7.31 ± 0.09
nLF	11.62 ± 1.98	10.21 ± 2.01	11.72 ± 2.20
LF/HF	1.62 ± 0.25	1.25 ± 0.31*, +	1.61 ± 0.28+
Standing			
Ratio of HR_{sit} to $HR_{standing}$	1.25 ± 0.21	1.40 ± 0.18	1.35 ± 0.15
Heart rate variability			
Total power	421 ± 44	398 ± 61	411 ± 55
SDNN	58 ± 3	52 ± 34	54 ± 5
nHF	3.72 ± 0.41	2.51 ± 0.52*	2.87 ± 0.57
nLF	3.85 ± 0.35	3.95 ± 0.36	3.73 ± 0.22
LF/HF	1.05 ± 0.25	1.55 ± 0.31	1.31 ± 0.21

*$P < 0.05$, Male *vs.* Female during mid-follicular or mid-luteal phase.
+$P < 0.05$, Female during mid-follicular phase *vs.* Female during mid-luteal.
SDNN, Standard Deviation of Normal to Normal R Wave; nHF, normalized high frequency power; nLF, normalized low frequency power; LF/HF, the ratio of low frequency power to high frequency power.

possibly suggesting hyperventilation in FL (Table 2). After SD, PCO_2 was lowered in FF while increased in FL (Fig. 5). pH, concentration of lactate and bicarbonate were unaltered among the three groups. The result indicated that SD-induced hyperventilation response was observed in FF. On the other hand, this response was blunted in FL, which is probably related to the basal hyperventilation state (or higher sympathetic tone) before SD. It is noteworthy that the degree of PCO_2 change (%) was significantly moderately negatively correlated with LF/HF change (%) during rest and DB (Fig. 6).

Discussion

The main experimental findings are summarized as follows. (I) Before SD, FL has higher sympathetic tone during DB and VM than FF. After SD, the response of cardiac sympathetic modulation of FL is blunted under the four testing circumstances compared to FF. (II) The degree of PCO_2 change (%) is negatively correlated with LF/HF change (%) during rest and DB, suggesting that hyperventilation response to SD intervention is associated with cardiac sympathetic activation. Compared to FF, SD-induced cardiac

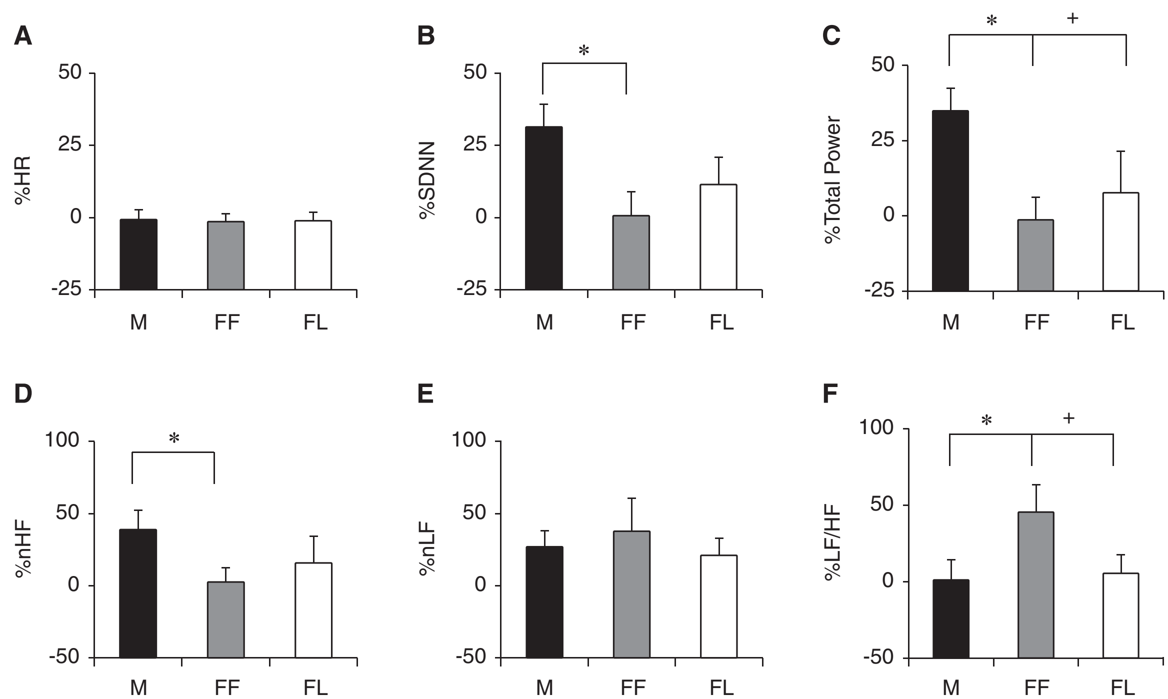

Fig. 1. The effects of sex and menstrual cycle on cardiac autonomic nervous activity at sitting rest following sleep deprivation are expressed in change percentage (%). *$P < 0.05$, Male *vs.* Female during mid-follicular or mid-luteal phase; $^+P < 0.05$, Female during mid-follicular phase *vs.* Female during mid-luteal phase. SDNN, Standard Deviation of Normal to Normal R Wave; nHF, normalized high frequency power; nLF, normalized low frequency power; LF/HF, ratio of low frequency power to high frequency power.

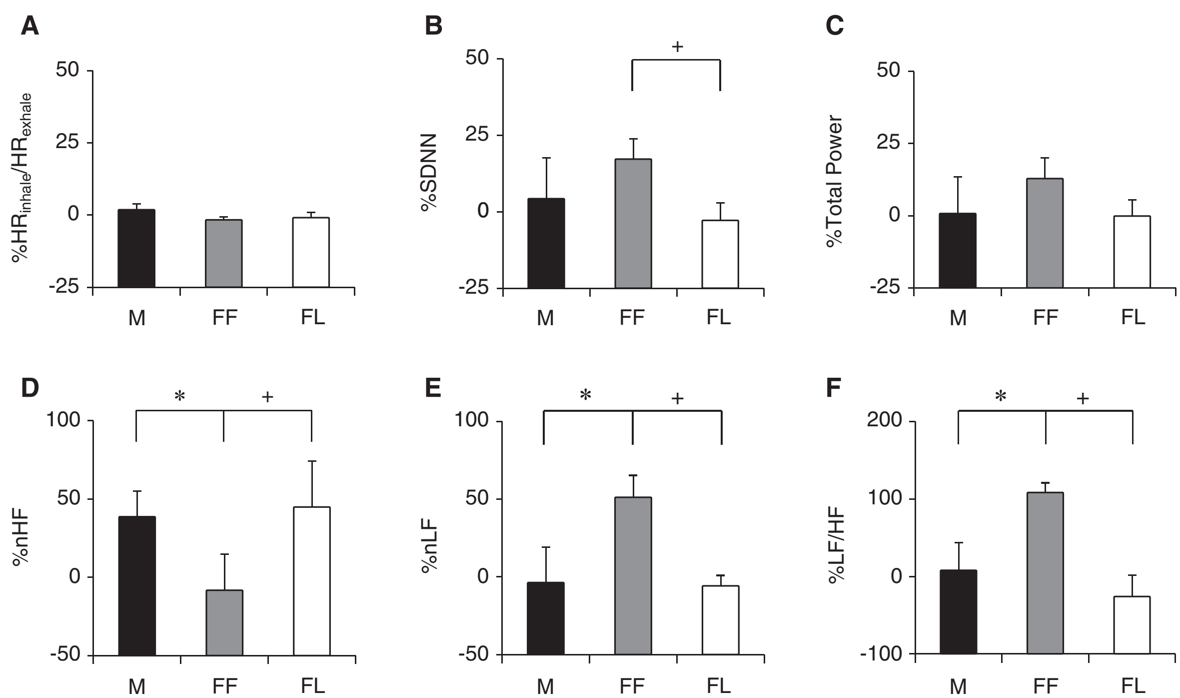

Fig. 2. The effects of sex and menstrual cycle on cardiac autonomic nervous activity in response to deep breathing following sleep deprivation are expressed in change percentage (%). *$P < 0.05$, Male *vs.* Female during mid-follicular or mid-luteal phase; $^+P < 0.05$, Female during mid-follicular phase *vs.* Female during mid-luteal phase. SDNN, Standard Deviation of Normal to Normal R Wave; nHF, normalized high frequency power; nLF, normalized low frequency power; LF/HF, ratio of low frequency power to high frequency power.

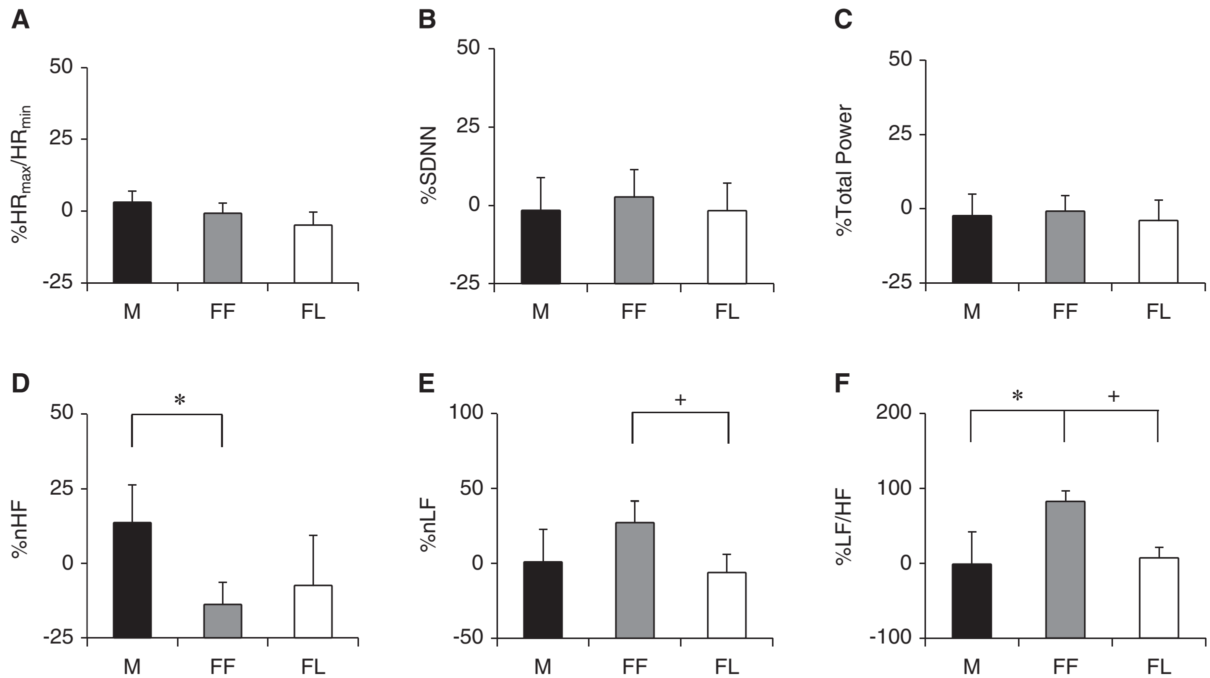

Fig. 3. The effects of sex and menstrual cycle on cardiac autonomic nervous activity in response to Valsalva maneuver following sleep deprivation are expressed in change percentage (%). $^*P < 0.05$, Male *vs.* Female during mid-follicular or mid-luteal phase; $^+P < 0.05$, Female during mid-follicular phase *vs.* Female during mid-luteal phase. SDNN, Standard Deviation of Normal to Normal R Wave; nHF, normalized high frequency power; nLF, normalized low frequency power; LF/HF, ratio of low frequency power to high frequency power.

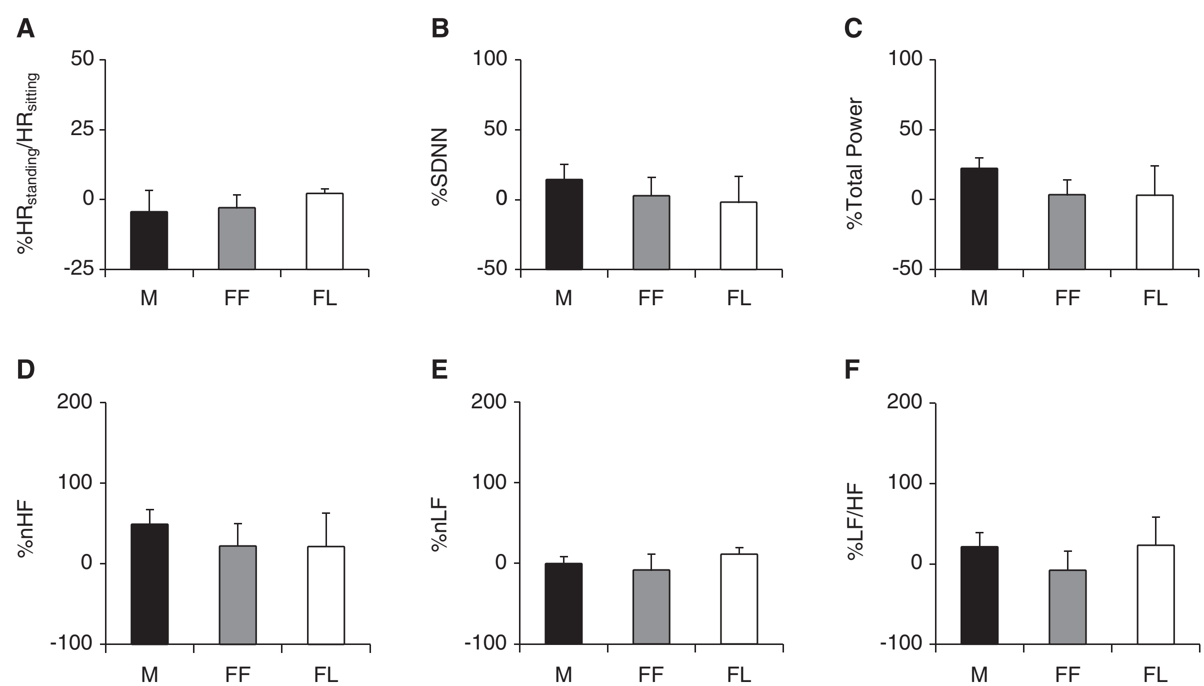

Fig. 4. The effects of sex and menstrual cycle on cardiac autonomic nervous activity in response to standing following sleep deprivation are expressed in change percentage (%). $^*P < 0.05$, Male *vs.* Female during mid-follicular or mid-luteal phase; $^+P < 0.05$, Female during mid-follicular phase *vs.* Female during mid-luteal phase. SDNN, Standard Deviation of Normal to Normal R Wave; nHF, normalized high frequency power; nLF, normalized low frequency power; LF/HF, ratio of low frequency power to high frequency power.

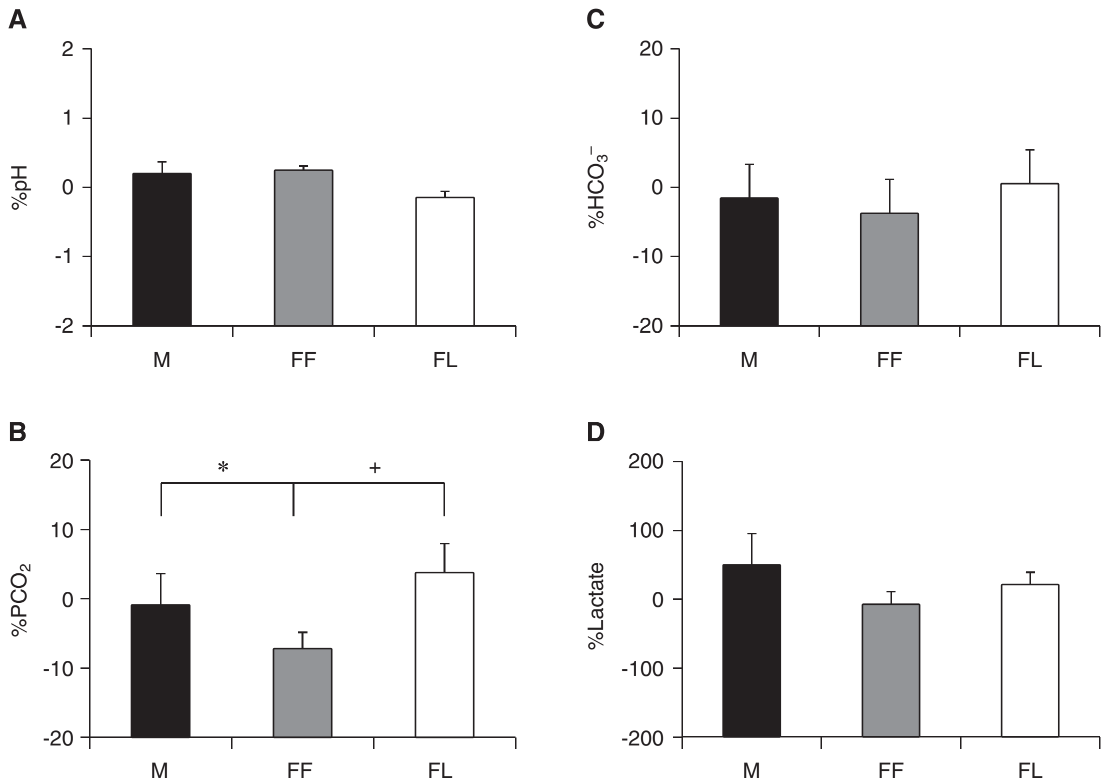

Fig. 5. The effects of sex and menstrual cycle on venous blood acid-base equilibrium following sleep deprivation are expressed in change percentage (%). *$P < 0.05$, Male *vs.* Female during mid-follicular or mid-luteal phase; $^{+}P < 0.05$, Female during mid-follicular phase *vs.* Female during mid-luteal phase.

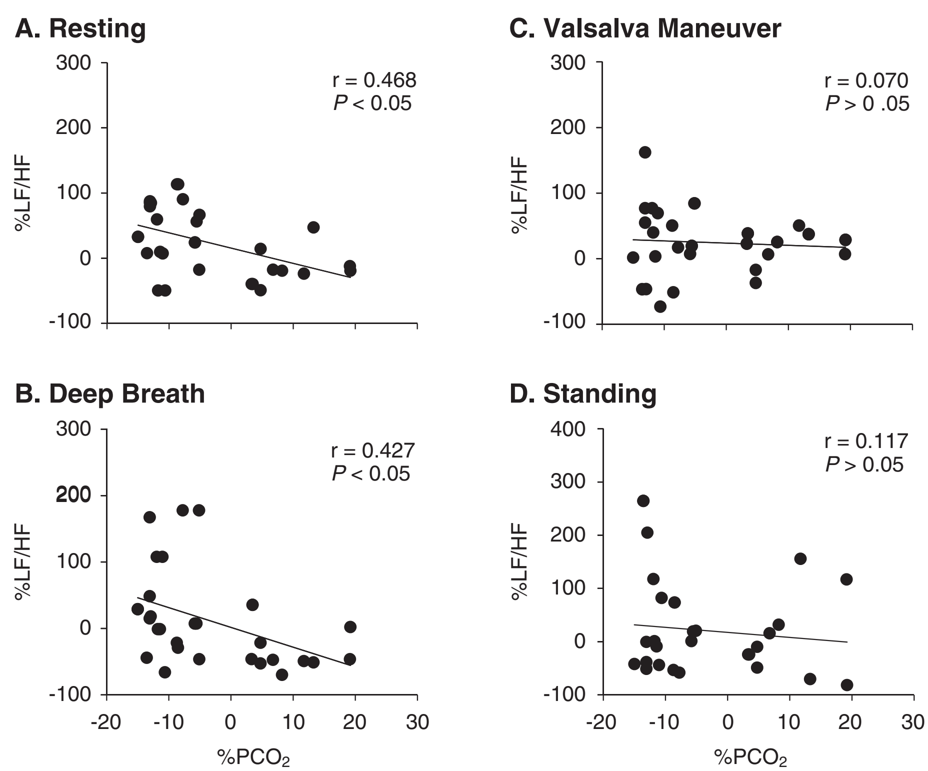

Fig. 6. Relationships between changes of PCO_2 and the LF/HF ratio at rest (A), during deep breath (B), Valsalva maneuver (C), and standing-up (D).

sympathetic activation and hyperventilation are attenuated in FL. (III) Autonomic balance after SD tends to augment vagal activity in FL and M, while shifts to sympathetic modulation in FF.

Before SD, our experimental findings regarding HRV response during normal menstrual cycle is similarly to the previous studies, in which an increased cardiac sympathetic activity associated with high progesterone levels during luteal phase was reported (14, 22, 23). Similarly, in healthy eumenorrheic females, muscle sympathetic activity and plasma norepinephrine were higher during mid-luteal time compared with the early follicular time (13, 20). The follicular phase is the period when plasma estrogen but not progesterone is gradually increasing. It seems that the sympathetic activity is negatively influenced by estrogen. It was reported that administration of high-dose estradiol resulted in systemic arterial dilation in premenopausal monkeys (28). After ovulation, the plasma concentration of progesterone rapidly goes up while estrogen slowly declined (2). In addition, the current investigation also recruited young males as a reference, in whom the autonomic balance is more similar to FL than FF. Urban *et al.* demonstrated that testosterone increases neuropeptide Y gene expression and peptide concentrations in the arcuate nucleus in the male rats, activating sympathetic system (26). Accordingly, it appears that the parasympathetic activity is primarily influenced by estrogen, while the sympathetic activity is modulated by progesterone. Testosterone is prone to activate sympathetic activity.

After SD, the current results showed that the FL is associated with a blunted response of cardiac sympathetic activation (%nLF, %LF/HF) under sitting rest, deep breathing and Valsalva maneuver and hyperventilation compared with FF. On the other hand, SD is prone to activate cardiac vagal response (%nHF) in FL under deep breathing. It is noteworthy that in FF, SD-triggered sympathetic activation is associated with hyperventilation to keep acid-base balance. Ito *et al.* found that the mean values of HRV variables over 24 h were largely modified by the level of physical activity regardless of the night or day shifts in 10 healthy female nurses (22). In this study, menstrual cycle was not taken into consideration. Chung *et al.* found that it is more similar to the present study (4), in which 12 young female shift nurses were enrolled for repeat measures of female sex hormones, 24 h physical activity, and HRV at three points: their menses, follicular, and luteal phases. The study found that the diminished parasympathetic activity and the increased sympathetic activity were shown in the follicular phase compared with the luteal phase while endogenous sex hormones levels remained normal cyclic variation. Our present study employed a strict 30 h SD condition and four autonomic tests to simulate daily activities. Male participants were also enrolled as a reference. We found that autonomic system reacts differently among different menstrual cycle and sex after SD. In FF, sympathetic activity rises after SD; on the other hand, in FL and M, acute SD tends to activate parasympathetic tone. Baroreflex responsiveness showed no difference before and after SD or among the three groups.

Biological explanation is that luteal phase is evolved as adaptation for reproduction. The current result showed that during this phase, the basal sympathetic tone is higher than the follicular phase. In FL, 30 h SD diminished sympathetic response during daily activities, which might help economize energy expenditure (18). Accordingly, female nurses might be inappropriate to be deprived of sleep in mid-luteal phase. Additionally, studies have proven that night shift suppresses the ovarian function by affecting the circadian rhythm of melatonin and prolactin and thus cause menstrual irregularity (21) and miscarriage (1).

In male, Furlan *et al*. found that reduced values of the indexes of cardiac sympathetic modulation during night work suggestive of a reduced cardiac sympathetic modulation were present when the job task was performed at night compared with the values observed when the work was performed during morning and evening (11). However, another study with conflicting result showed that circadian pattern of HRV seems to be predominantly related to sleep and wakefulness and remains independent of night-day cycle (10). In the current study, restricted 30-hour SD is prone to activate cardiac vagal tone in the male population.

HRV has been considered as one of the best non-invasive tools in evaluating cardiac autonomic function since 1990 (5). In our study, the cardiac autonomic activity was evaluated under four physical stimuli. Sitting rest is considered as the baseline. DB assesses respiratory sinus arrhythmia. Deep inspiration inhibits carotid sinus receptor, reduces vagal activity and increases the heart rate. As breathing out, the autonomic response is on the contrary (30). VM blocks venous return as blowing and increases the heart rate. After the pressure is relieved, the heart rate typically increases shortly and a reflex bradycardia begins because the carotid sinus is activated by enhanced venous return and subsequent stroke volume (6, 16). Standing-up stimulates baroreceptor because of blood pooling in the lower body (12). These four conditions simulate physical stimulation to cardiac autonomic system in our everyday activities.

Small sample size is a limitation of this study. However, the statistical significance is achieved. In addition, plasma level of catecholamine was not assessed. Further comprehensive study to assess ANS may be needed to consolidate the conclusion.

In conclusion, SD tends to augment vagal activity in FL and M while activates sympathetic activity in FF. Moreover, the degree of LF/HF change (%) is negatively correlated with PCO_2 change (%). Compared to FF, SD-triggered cardiac sympathetic activation and possible hyperventilation are blunted in FL. The study provides further insight into the physiology of acute SD in different sex and menstrual phases, and may provide reference in shifts arrangement in the female workers.

Acknowledgments

This work was supported by the Chang Gung Medical Research Program (grant number CMRPG5B0021, CMRPG391203 and CMRPD1A0132), National Science Council of Taiwan (grant number NSC 100-2314-B-182-004-MY3), and Healthy Aging Research Center, Chang Gung University (grant number EMRPD1A0841). The authors would like to thank the volunteers for their enthusiastic participation.

References

1. Axelsson, G., Lutz, C. and Rylandr, R. Exposure to solvents and outcome of pregnancy in university laboratory employees. *Brit. J. Ind. Med*. 41: 305-312, 1984.
2. Baker, F.C. and Driver, H.S. Circadian rhythms, sleep, and the menstrual cycle. *Sleep Med.* 8: 613-622, 2007.
3. Cappuccio, F.P., Stranges, S., Kandala, N.B., Miller, M.A., Taggart, F.M., Kumari, M., Ferrie, J.E., Shipley, M.J., Brunner, E.J. and Marmot, M.G. Gender-specific associations of short sleep duration with prevalent and incident hypertension: the Whitehall II Study. *Hypertension* 50: 693-700, 2007.
4. Chung, M.H. and Yang, C.C.H. Heart rate variability across the menstrual cycle in shift work nurses. *J. Exp. Clin. Med*. 3: 121-125, 2011.
5. Cygankiewicz, I. and Zareba, W. Heart rate variability. *Handb. Clin. Neurol.* 117: 379-393, 2013.
6. Ducla-Soares, J.L., Santos-Bento, M., Laranjo, S., Andrade, A., Ducla-Soares, E., Boto, J.P., Silva-Carvalho, L. and Rocha, I. Wavelet analysis of autonomic outflow of normal subjects on head-up tilt, cold pressor test, Valsalva manoeuvre and deep breathing. *Exp. Physiol.* 92: 677-686, 2007.
7. Edell-Gustaffson, U.M. Insufficient sleep, cognitive anxiety and health transition in men with coronary artery disease: a self-report and polysomnographic study. *J. Adv. Nurs*. 37: 414-422, 2002.
8. Ewing, D.J., Martyn, C.N., Young, R.J. and Clarke, B.F. The value of cardiovascular autonomic function tests: 10 years experience in diabetes. *Diabetes Care* 8: 491-498, 1985.
9. Faraut, B., Boudjeltia, K.Z., Vanhamme, L. and Kerkhofs, M. Immune, inflammatory and cardiovascular consequences of sleep restriction and recovery. *Sleep Med. Rev*. 16: 137-149, 2012.
10. Freitas, J., Lago, P., Puig, J., Carvalho, M.J., Costa, O. and de Freitas, A.F. Circadian heart rate variability rhythm in shift workers. *J. Electrocardiol*. 30: 39-44, 1997.
11. Furlan, R., Barbic, F., Piazza, S., Tinelli, M., Seghizzi, P. and Malliani, A. Modifications of cardiac autonomic profile associated with a shift schedule of work. *Circulation* 102: 1912-1916, 2000.
12. Furlan, R., Jacob, G., Palazzolo, L., Rimoldi, A., Diedrich, A., Harris, P.A., Porta, A., Malliani, A., Mosqueda-Garcia, R. and Robertson, D. Sequential modulation of cardiac autonomic control induced by cardiopulmonary and arterial baroreflex mechanisms. *Circulation* 104: 2932-2937, 2001.
13. Goldstein, D.S., Levinson, P. and Keiser, H.R. Plasma and urinary catecholamines during the human ovulatory cycle. *Am. J. Obstet. Gynecol*. 146: 824-829, 1983.
14. Guasti, L., Grimoldi, P., Mainardi, L.T., Petrozzino, M.R., Piantanida, E., Garganico, D., Diolisi, A., Zanotta, D., Bertolini, A., Ageno, W., Grandi, A.M., Cerutti, S. and Venco, A. Autonomic function and baroreflex sensitivity during a normal ovulatory cycle in humans. *Acta Cardiol.* 54: 209-213, 1995.
15. Huang, S.C., Wong, M.K. Alice, Lien, H.Y., Tang, F.T., Fu, T.C., Lin, Y. and Wang, J.S. Systemic vascular resistance is increased and associated with accelerated arterial stiffening change in patients with chronic cervical spinal cord injury. *Eur. J. Phys. Rehabil. Med.* 49: 41-49, 2013.
16. Huang, S.C., Wong, M.K. and Wang, J.S. Systemic hypoxia affects cardiac autonomic activity and vascular hemodynamic control modulated by physical stimulation. *Eur. J. Appl. Physiol*. 106: 31-40, 2009.
17. Ito, H., Nozaki, M., Maruyama, T., Kaji, Y. and Tsuda, Y. Shift work modifies the circadian patterns of heart rate variability in nurses. *Int. J. Cardiol*. 79: 231-236, 2001.
18. Jung, C.M., Melanson, E.L., Frydendall, E.J., Perreault, L., Eckel, R.H. and Wright, K.P. Energy expenditure during sleep, sleep deprivation and sleep following sleep deprivation in adult humans. *J. Physiol*. 589: 235-244, 2011.
19. Meisinger, C., Heier, M., Löwel, H., Schneider, A. and Döring, A. Sleep duration and sleep complaints and risk of myocardial infarction in middle-aged men and women from the general population: the MONICA/KORA Augsburg cohort study. *Sleep* 30: 1121-1127, 2007.
20. Minson, C.T., Halliwill, J.R., Young, T.M. and Joyner, M.J. Influence of the menstrual cycle on sympathetic activity, baroreflex sensitivity, and vascular transduction in young women. *Circulation* 101: 862-868, 2000.
21. Miyauchi, F., Nanjo, K. and Otsuka, K. Effects of night shift on plasma concentrations of melatonin, LH, FSH and prolactin, and menstrual irregularity. *Sangyo Igaku (Jpn. J. Indust. Health)* 34: 545-550, 1992.
22. Saeki, Y., Atogami, F., Takahashi, K. and Yoshizawa, T. Reflex control of autonomic function induced by posture change during the menstrual cycle. *J. Auton. Nerv. Syst*. 66: 69-74, 1997.
23. Sato, N. Miyake, S., Akatsu, J. and Kumashiro, M. Power spectral analysis of heart rate variability in healthy young women during the normal menstrual cycle. *Psychosom. Med*. 57: 331-335, 1995.
24. Subbalakshmi, N.K., Basha, A. and Ramesh, B. Impact of acute respiratory stress on cardiac autonomic control in young healthy subjects explored by time and frequency domain methods. *Chinese J. Physiol.* 52: 299-305, 2009.
25. Tochikubo, O., Ikeda, A., Miyajima, E. and Ishii, M. Effects of insufficient sleep on blood pressure monitored by a new multi-biomedical recorder. *Hypertension* 27: 1318-1324, 1996.
26. Urban, J.H., Bauer-Dantoin, A.C. and Levine, J.E. Neuropeptide Y gene expression in the arcuate nucleus: sexual dimorphism and modulation by testosterone. *Endocrinology* 132: 139-145, 1993.
27. Wang, J.S., Jen, C.J., Lee, H.L. and Chen, H.I. Effects of short-term exercise on female platelet function during different phases of the menstrual cycle. *Arterioscler. Thromb. Vasc. Biol*. 17: 1682-1686, 1997.
28. Williams, J.K., Kim, Y.D., Adams, M.R., Chen, M.F., Myers, A.K. and Ramwell, P.W. Effects of estrogen on cardiovascular responses of premenopausal monkeys. *J. Pharmacol. Exp. Ther*. 271: 671-676, 1994.
29. Wingard, D.L. and Berkman, L.F., Mortality risk associated with sleeping patterns among adults. *Sleep* 6: 102-107, 1983.
30. Yasuma, F. and Hayano, J. Respiratory sinus arrhythmia: why does

the heartbeat synchronize with respiratory rhythm? *Chest* 125: 683-690, 2004.
31. Zhang, B. and Wing, Y.K. Sex differences in insomnia: a meta-analysis. *Sleep* 29: 85-93, 2006.
32. Zhong, X., Hilton, H.J., Gates, G.J., Jelic, S., Stern, Y., Bartels, M.N., Demeersman, R.E. and Basner, R.C. Increased sympathetic and decreased parasympathetic cardiovascular modulation in normal humans with acute sleep deprivation. *J. Appl. Physiol*. 98: 2024-2032, 2005.