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Effect of body position on bilateral EEG alterations and their relationship with autonomic nervous modulation in normal subjects

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ABSTRACT

This study investigated the effect of body position on the electroencephalogram (EEG) and autonomic nervous modulation, and the relationship between them using spectral analysis of EEG and heart rate variability (HRV). All healthy volunteers recruited had their electrocardiogram and EEG recorded for power spectral analysis. We found that when changing position from supine to upright, the EEG spectral components below the α band, such as δ and θ bands, were significantly decreased while the EEG spectral components above the α band, such as β, γ and ω bands, were significantly increased in both scalps. Correlation analysis showed that the θ rhythm of both scalps might be associated with the control of HR, the α and β rhythms of right scalp might be associated with vagal modulation, and the γ rhythm of left scalp might be associated with sympathetic modulation of the subject. Thus, some EEG components might be associated with the autonomic nervous modulation of the subject during positional change. There might be a mechanism located in the brain-stem which jointly controls both autonomic influences on heart rate and EEG activation.

Power spectral analysis is often used in the assessment of physiological signals. Many studies have made use of power spectral analysis of heart rate variability (HRV) and electroencephalography (EEG); however, few studies have dealt with the spectral analysis of both HRV and EEG at the same time to explore the relationship between the frequency components in EEG signals and autonomic nervous modulation.

It has been shown that body position can influence not only the modulation of autonomic nervous activities [3,7–9], but also the central nervous system [2,5,17]. For instance, right lateral decubitus position can lead to the highest vagal modulation and the lowest sympathetic modulation among three recumbent positions in healthy subjects and patients with coronary artery disease [7] or acute myocardial infarction [9]. The effects of body positions on autonomic nervous modulation in pregnant women have also been evaluated [8]. On the other hand, it has been shown that the change in heart rate (HR) paralleled β activity of EEG when changing position from supine to upright [5]. Caldwell et al. found a significant difference in EEG arousal between upright and standing positions when the sleep-deprived subjects were counteracting fatigue [2]. A correlation between the low-frequency component and arterial blood pressure and middle cerebral artery flow velocity in supine and head-up tilting has also been reported [4].

Since the change in body position can affect not only the autonomic nervous modulation of the subject but also the electric activities of scalp waves, we hypothesized that the autonomic nervous modulation of the subjects changes in accordance with the change in the electric activities of the scalps when the position was changed. In the present study, the effect of body position on HRV and EEG was evaluated, and the association between autonomic nervous modulation and scalp activities when changing the position from supine to upright was assessed in healthy adult subjects.

Young healthy adult subjects were recruited from the community. All subjects were requested to refrain from alcohol or caffeinated beverages for at least 12 h before taking the record of EEG and ECG signals. In order to avoid interference on EEG and ECG signals, subjects who were smokers, had major diseases or were taking medication were excluded from the study. Institutional Review Board of the hospital has approved this study, and written informed consent was obtained from each subject before the study.

Both supine and upright positions were assumed in random order by each subject. When the supine position was assumed, the subject lay down on the examination bed with both eyes closed. When the upright position was assumed, the subject sat in a chair with back support. After adapting to the environment for 3 min in either position, the EEG and ECG signals were recorded

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simultaneously using a multi-channel recorder (Alice® 5, Respironics Inc., PA, USA) with sampling frequency 200 Hz for 15 min.

The EEG signals were recorded from C3 to C4 scalp foci according to the international electrode 10-20 placement system, and the signals were acquired to generate the power spectrum by means of fast Fourier transform (MathSoft Inc., Cambridge, MA, USA). Since the subject were asked to change position from supine to upright, the leads on the scalp that would not be affected by changing position were preferred. Therefore, the C3 and C4 on both side of the Cz point was chosen as the representative scalp electrodes of each side of the scalp for signals acquisition. Electromagnetic interference at 60 Hz was filtered by recording apparatus before the calculation of spectrum EEG measures. The power spectrum of EEG was divided into the following frequency bands: delta wave (δ, 0.5–4 Hz), theta wave (θ, 4–8 Hz), alpha wave (α, 8–14 Hz), beta wave (β, 14–35 Hz), gamma wave (γ, 35–45 Hz) and omega wave (ω, 45–100 Hz). The total power of EEG (TP_{EEG}) was defined as the power within the frequency range of 0–100 Hz.

For the comparison of specific frequency component between both scalps, the power of frequency band x, Px, was normalized by TP_{EEG}, $nPx = 100^{*}Px/TP_{EEG}$, where 'x' stands for the frequency band to be analyzed, and the unit for nPx is normalized unit (nu).

The method used for data acquisition of ECG signals and signal processing has been described elsewhere [3,7–9], and adhered to the standards of HRV [18]. In brief, the digitized ECG signals were retrieved to measure the consecutive RR intervals, which are the time intervals between successive pairs of QRS complexes, using the software developed for detecting R wave. All artifacts or ectopic beats were removed and the resultant missing data (<5% per record) were replaced by interpolated beats derived from the nearest valid data. If the percentage of deletion was more than 5%, then the data of the patient was excluded from the study. The last 512 stationary RR intervals were obtained for HRV analysis.

The HR and the mean, standard deviation (SD_{RR}) and root mean square successive difference (RMSSD) of 512 RR intervals were used as the HRV measures in the time domain. The areas of the spectral peaks in the power spectrum of the same 512 RR intervals within the frequency range of 0.01–0.40 Hz, 0.01–0.04 Hz, 0.04–0.15 Hz and 0.15–0.4 Hz were defined as the total power (TP_{HRV}), very low-frequency power (VLFP), low-frequency power (LFP) and high-frequency power (HFP), respectively.

It has been suggested that the power within the frequency range of 0.04–0.4 Hz can be used for the normalization of LFP and HFP [18]. Since this frequency range covers only the frequency ranges of LFP and HFP, but not VLFP, it may not be suitable for the normalization of VLFP. Therefore, we used the TP_{HRV} whose frequency range were 0.01–0.4 Hz to normalize the VLFP, LFP and HFP in this study. The normalized HFP (nHFP = HFP/TP) was then used as the index of vagal modulation, the normalized LFP (nLFP = LFP/TP) as the index of sympathetic and vagal modulation, the normalized VLFP (nVLFP = VLFP/TP) as the index of rennin–angiotensin activity and vagal withdrawal, and the ratio of LFP to HFP (LHR = LFP/HFP) as the index of sympathovagal balance [11,16,19].

Wilcoxon signed rank test (SigmaStat Statistical Software, SPSS Inc., Chicago, IL, USA) was employed to compare the HRV measures between supine and upright positions. The spectral EEG measures among supine and upright positions on bilateral scalps were compared using Friedman repeated measure ANOVA on ranks. Pairwise multiple comparisons were performed using Tukey's test. Values are expressed as median and interquartile range (IQR).

The percentage change in the spectral measures of EEG and HRV in each subject when the position was changed from supine to upright was calculated using the following formula:

$$\%X = \frac{X_u - X_s}{X_s} \times 100\%$$

where "X" stands for the spectral HRV or EEG measure to be analyzed, and the subscripts "s" and "u" stand for supine and upright positions, respectively. Pearson product moment analysis was used to assess the correlations between the percentage changes in HRV measures and the percentage changes in EEG measures when the position was changed from supine to upright. A p value < 0.05 was considered statistically significant.

Thirty-four young healthy adult subjects (M/F = 17/17) participated in this study. Table 1 lists the general characteristics of these subjects. The power spectra of RR intervals and bilateral scalp EEG from a representative subject in supine and upright positions are shown in Fig. 1. This representative subject had increased RMSSD, HFP and nHFP as well as decreased HR and LHR in supine position, as compared with those in upright position.

In the time domain, the RMSSD was significantly decreased while the HR was significantly increased in the upright position (Table 2). In the frequency domain, the HFP and nHFP were significantly decreased, while the nVLFP and LHR were significantly increased in the upright position (Table 2).

When the position was changed from supine to upright, the Pα and nPα on both scalps were not changed significantly; however, the high-frequency components of EEG including Pβ, Pγ, Pω, nPγ, and nPω on both scalps were increased significantly (Table 3). In contrast, the low-frequency components of EEG including nPδ, nPθ were significantly decreased, while the nPβ of right scalp was significantly increased, when the position was changed from supine to upright (Table 3).

Table 4 tabulates the correlation coefficients of significant correlations between the percentage change in HRV measures and the percentage change in spectral EEG measures when the position was changed from supine to upright. In the time domain, the percentage change in HR correlated significantly and negatively with the percentage change in nPθ on both scalps. Similarly, the percentage change in nPα of left scalp correlated significantly and positively with the

Table 1
General characteristics of the study subjects ($n = 34$).

Gender (M/F)	17/17
Age (year)	27.3 ± 3.4
Height (cm)	167.0 ± 7.5
Weight (kg)	63.0 ± 13.0
BMI (kg/m^2)	22.4 ± 3.1
SBP (mmHg)	111.0 ± 14.6
DBP (mmHg)	73.5 ± 9.8

BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure.

Table 2
Effect of position on time and frequency domain HRV measures ($n = 34$).

	Supine position	Upright position	p Value
HR (bpm)	65.5 (61.6–72.7)	75.2 (71.9–82.8)	<0.001
SD_{RR} (ms)	45.0 (35.6–66.2)	43.7 (28.9–59.6)	0.097
CV_{RR} (%)	5.2 (4.4–6.6)	5.4 (4.1–6.9)	0.321
RMSSD (ms)	35.7 (30.7–57.4)	27.4 (22.5–40.7)	<0.001
TP_{HRV} (ms)	808.3 (529.3–1658.0)	773.0 (344.4–1487.0)	0.188
VLFP (ms)	230.2 (149.4–455.4)	265.8 (139.0–546.8)	0.483
LFP (ms)	251.7 (151.0–571.2)	257.3 (129.3–468.3)	0.356
HFP (ms)	293.2 (182.0–586.1)	162.2 (101.0–331.1)	0.002
nVLFP (nu)	29.2 (21.8–40.6)	37.4 (26.9–46.9)	0.011
nLFP (nu)	29.4 (23.9–38.5)	33.4 (23.4–42.9)	0.732
nHFP (nu)	38.1 (22.9–49.1)	23.0 (14.1–39.1)	0.014
LHR	0.8 (0.5–1.8)	1.6 (0.7–2.4)	0.012

HR, heart rate; bpm, beats per minute; SD_{RR}, standard deviation of RR intervals; CV_{RR}, coefficient of variation of RR intervals; RMSSD, root mean squared successive difference; TP_{HRV}, total power of heart rate variability; VLFP, very low-frequency power; LFP, low-frequency power; HFP, high-frequency power; nVLFP, normalized VLFP, nLFP, normalized LFP; nHFP, normalized HFP; LHR, low-/high-frequency power ratio.