赫伯-黃轉換於心率變異度及腦波的應用

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馬偕護專--生醫訊號分析理論與實務研習營

8/17/2010

Abstract:

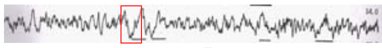
Spectral analysis on heart rate variability (HRV) has been a widely accepted linear method in the assessment of autonomic nervous system (ANS), in which HRV reveals a delicate balance between the two antagonistic parts of ANS: sympathetic and parasympathetic activities. However, a major problem on analyzing HRV via spectral method is related to nonstationarities, e.g., mean and standard deviation vary with time. The presence of nonstationarities makes the traditional spectral method assuming stationary signals not reliable. To resolve the difficulties related to nonstationary behaviors, Hilbert-Huang transform (HHT), a new time-frequency representation method of signal analysis, developed by Huang et al. is based on nonlinear chaotic theories and has been designed to extract dynamic information from nonstationary signals at different time scales. In this talk, I will present the depth of sleep is related to changes in autonomic control, in which continuous HHT analysis of the electroencephalogram (EEG) and HRV was performed in twelve patients with obstructive sleep apnea (OSA). The sympathovagal index, i.e., low-/high-frequency power ratio of HRV (LF: 0.04-0.15 Hz; HF: 0.15-0.40 Hz), was significantly and negatively correlated with delta power of EEG (0.5-4.0 Hz). In addition, vagal regulation was positively related to the depth of sleep. Compared to the results of normal subjects, I may conclude that OSA patients can be characterized by concurrent sympathetic activation and vagal withdrawal. Therefore, HHT offers a clear quantitative analysis to study the interaction between cerebral cortical and autonomic activities.

Contents

1. **Y.-H. Shiau** "Does well-harmonized homeostasis exist in heart rate fluctuations? Time series analysis and model simulations" Autonomic Neuroscience: Basic and Clinical, 146 (2009) 62.
2. **Y.-H. Shiau** "Nonlinear measures on heart rate variability: A clinical tool or not?" Autonomic Neuroscience: Basic and Clinical, 152 (2010) 119.

1. Introduction to sleep stages

stage W to stage I



stage II

stage III

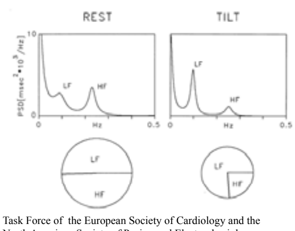
stage IV

Name		Stage	Properties of EEG
active wake (AW)		W	α wave is dominant
rapid eye movement (REM)		REM	similar to stage I
NREM	light sleep	I	α wave is less than 50% and θ wave appears
		II	spindle or k-complex
	deep sleep slow wave sleep(SWS) quiet sleep (QS)	III	slow wave 20%~50%
		IV	slow wave is more than 50%

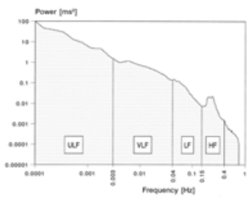
Specific wave	Properties
α wave	8 Hz < f < 13 Hz
θ wave	4 Hz < f < 7 Hz
spindle	12 Hz < f < 14 Hz
k-complex	combination of vertex sharp waves and sigma paroxysm
delta wave	0.5 Hz < f < 4 Hz slow wave: f < 2 Hz

Delta-wave power is associated with the depth of QS.

2. Spectrum analysis on heart rate variability (HRV)



Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, Circulation 93 (1996) 1043-1065



Spectrum analysis on HRV during graded orthostatic tilt, where LF: 0.04-0.15 Hz and HF: 0.15-0.4 Hz.

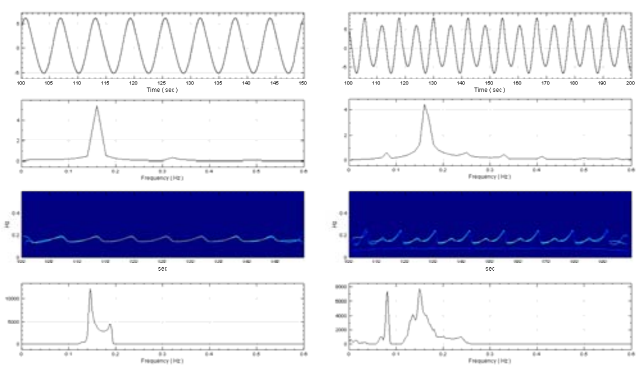
RR (Hz)	0.03	0.08	0.10	0.13	0.25	0.50
SDNN (ms)	71±32	66±40	73±41	67±43	57±37	55±24
RMSSD (ms)	37±22	39±30	48±37	50±44	50±54	47±40
pNN50 (%)	12±13	12±16	16±17	16±18	19±27	21±25
LF (a.u.)	570±290	609±337	692±354	615±336	412±184	399±221
HF(a.u.)	468±343	437±386	496±364	482±371	596±529	437±432
R	1.5±0.7	1.7±0.6	1.7±0.7	1.5±0.4	0.9±0.3	1.2±0.4

J. D. Schipke et al., Journal of Clinical and Basic Cardiology 2 (1999) 92-95

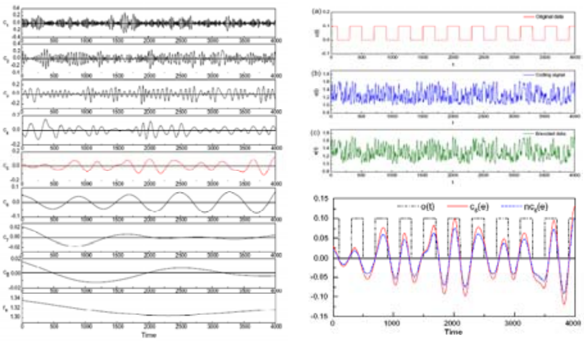
Effect of six different respiration rates (RR) on measurements of HRV, where R is the ratio between LF and HF.

3. Why HHT is better than FFT to analyze physiologic signals? Nonstationary behaviors

Lorenz model:
$$\dot{x} = -y - z$$
$$\dot{y} = x + ay$$
$$\dot{z} = b + z(x - c)$$



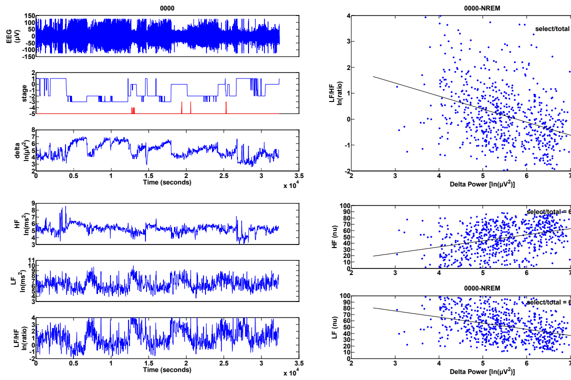
Using HHT to detect embedded sources in nonstationary time series



Y.-H. Shiau et al, Optics Communications 283 (2010) 1909-1916

4. Relationship between delta power and HRV during sleep

4.1 FFT analysis on normal subjects

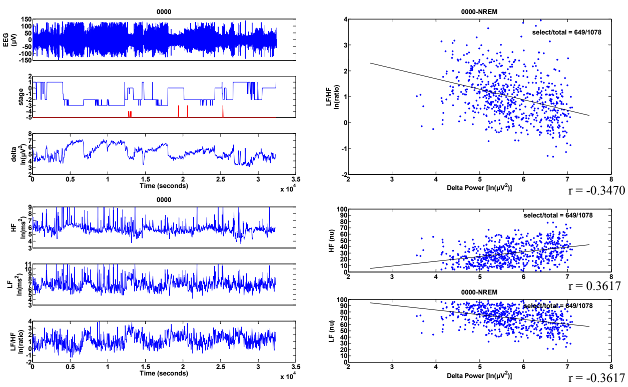


r = -0.3472

r = 0.3503

r = -0.3503

4.2 HHT analysis on normal subjects

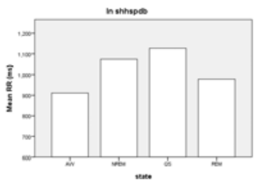


r = -0.3470

r = 0.3617

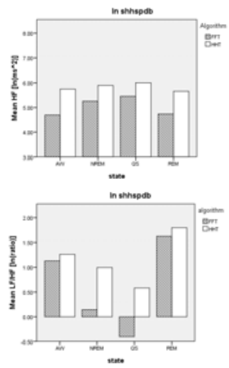
r = -0.3617

4.3 Comparisons between FFT and HHT results



	AW	QS	REM
RR (ms)			
Mean	848 ± 114	1044 ± 119[c]	885 ± 140
r	− 0.23 ± 0.26	0.08 ± 0.27[c]	− 0.28 ± 0.36
HF [ln(ms²)]			
Mean	5.77 ± 0.56	6.50 ± 0.65[c]	5.58 ± 0.97
r	0.00 ± 0.25	0.03 ± 0.22	0.01 ± 0.30
LF/HF [ln(ratio)]			
Mean	1.50 ± 0.39	0.27 ± 0.59[c]	1.22 ± 0.53
r	0.27 ± 0.18	− 0.33 ± 0.08[c,d]	0.20 ± 0.28

[a] Results are expressed as means ± SD.
[b] AW, active wakening; QS, quiet sleep; REM, rapid eye movement sleep; RR, R–R intervals; HF, high-frequency power; LF/HF, low-frequency power to HF ratio; r, correlation coefficient with delta power of EEG.
[c] $P < 0.05$; significantly different from AW.
[d] $P < 0.05$; significantly different from zero value, for r only.



Cheryl C.H. Yang et al., Neuroscience Letters 329 (2002) 213-216

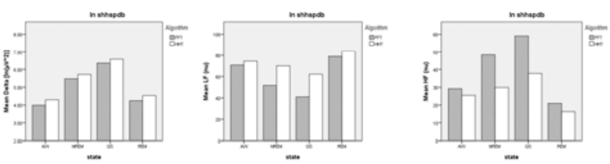


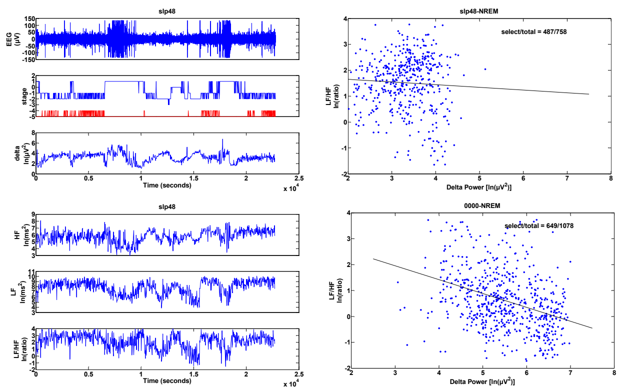
Table 3. Spectral analysis of the HRV in different sleep stages (n=11).

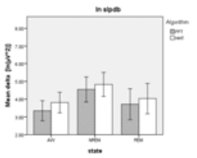
	Wakefulness	Stage 2 non-REM	Stage 4 non-REM	REM sleep
LF/HF	1.03 ± 0.9**	1.07 ± 0.82**	0.98 ± 0.79**	2.40 ± 1.96
REL.VLF (%)	18.6 ± 9.9	16.2 ± 9.2*	16.2 ± 6.5*	26.0 ± 13.8
LF (n.u.)	0.43 ± 0.16	0.42 ± 0.17*	0.40 ± 0.18**	0.55 ± 0.21
HF (n.u.)	0.57 ± 0.16	0.58 ± 0.17*	0.60 ± 0.18**	0.45 ± 0.21

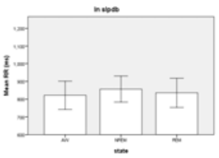
REL.VLF = the power of the VLF spectral band divided by the total power; LF (n.u.), HF (n.u.) – the LF and HF component in normalized units = the power of these components divided by the total power minus the VLF band; *P<0.05, **P<0.01 (difference from REM sleep)

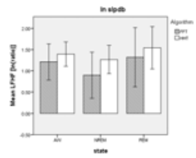
P. Busek et al., Physiol. Res. 54 (2005) 369-376

5. FFT and HHT results for OSA patients

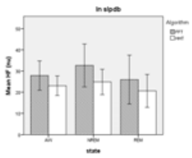


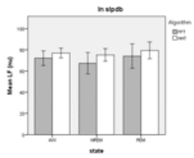

Mean delta [ln(μV)²] ↓


Mean RR (ms) ↓


Mean LF/HF [ln(ratio)] ↑

1. Mean delta [ln(μV)²] ↓
2. Mean RR (ms) ↓
3. Mean LF/HF [ln(ratio)] ↑
4. Mean HF(nu) ↓
5. Mean LF(nu) ↑


Mean HF(nu) ↓


Mean LF(nu) ↑

Fast Fourier Transform (linear)

Table 1. HRV and its correlation with delta power of EEG in OSA subject [a,b]

	AW	NREM	REM
Delta [ln(μV²)]			
Mean	3.35±0.57	4.55±0.70*	3.72±0.87
RR (ms)			
Mean	821.76±81.46	856.58±74.95	835.53±84.42
r	-0.33±0.22	-0.03±0.22	-0.09±0.25
HF [ln(ms²)]			
Mean	4.94±0.71	5.93±0.59*	5.46±0.89
r	-0.01±0.19	0.11±0.24	0.06±0.22
LF [ln(ms²)]			
Mean	6.35±0.48	6.95±0.51	6.90±0.80
r	0.17±0.20	-0.05±0.23	0.15±0.35
LF/HF [ln(ratio)]			
Mean	1.21±0.43	0.90±0.54	1.32±0.70
r	0.17±0.22	-0.13±0.21*	0.08±0.31
HF (nu)			
Mean	27.86±6.92	32.66±10.12	25.92±11.57
r	-0.15±0.22	0.13±0.20*	-0.06±0.31
LF (nu)			
Mean	72.14±6.92	67.33±10.12	74.08±11.57
r	0.15±0.22	-0.13±0.20*	0.06±0.31

Hilbert-Huang Transform (linear)

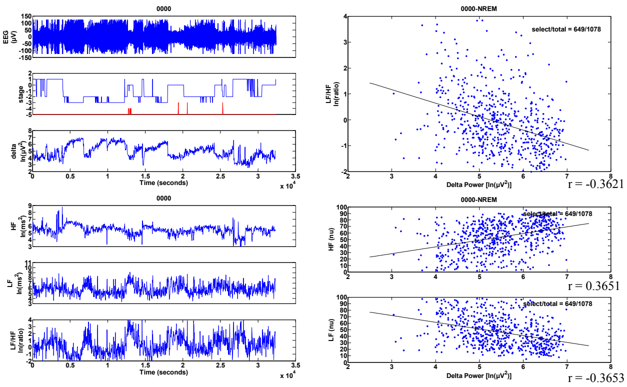
Table 1. HRV and its correlation with delta power of EEG in OSA subject [a,b]

	AW	NREM	REM
Delta [ln(μV²)]			
Mean	3.81±0.58	4.83±0.68*	4.03±0.85
RR (ms)			
Mean	821.76±81.46	856.58±74.95	835.53±84.42
r	-0.32±0.23	-0.06±0.24	-0.10±0.33
HF [ln(ms²)]			
Mean	6.00±0.66	6.77±0.50*	6.41±0.83
r	0.08±0.18	0.07±0.22	0.08±0.28
LF [ln(ms²)]			
Mean	7.39±0.55	8.04±0.50	7.95±0.90
r	0.14±0.17	-0.02±0.19	0.13±0.36
LF/HF [ln(ratio)]			
Mean	1.39±0.29	1.27±0.33	1.54±0.50
r	0.09±0.19	-0.12±0.19	0.05±0.30
HF (nu)			
Mean	23.05±4.62	24.84±5.97	20.61±7.79
r	-0.07±0.19	0.13±0.18	-0.04±0.29
LF (nu)			
Mean	76.95±4.62	75.16±5.97	79.39±7.79
r	0.07±0.19	-0.13±0.18	0.04±0.29

[a] Results are expressed as mean ± SD
[b] AW, active wakening; QS, quiet sleep; REM, rapid eye movement sleep; RR, R-R intervals; HF, high-frequency power; LF, low-frequency power; LF/HF, LF to HF ratio; r correlation coefficient with delta power of EEG.
* $P < 0.05$; significantly different from AW.

Using cubic spline interpolation for the resampling process could improve above-mentioned results.

FFT analysis on normal subjects (cubic spline)

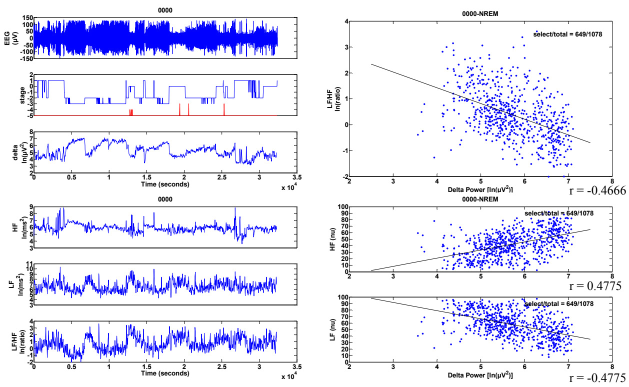


r = -0.3621

r = 0.3651

r = -0.3653

HHT analysis on normal subjects (cubic spline)

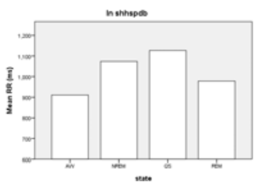


r = -0.4666

r = 0.4775

r = -0.4775

Comparisons between FFT and HHT results (cubic spline)



	AW	QS	REM
RR (ms)			
Mean	848 ± 114	1044 ± 119[c]	885 ± 140
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Mean	5.77 ± 0.56	6.50 ± 0.65[c]	5.58 ± 0.97
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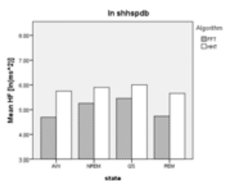

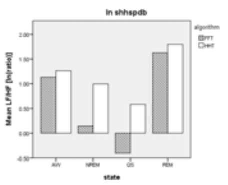

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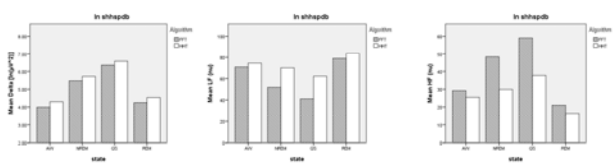

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LF (n.u.)	0.43 ± 0.16	0.42 ± 0.17*	0.40 ± 0.18**	0.55 ± 0.21
HF (n.u.)	0.57 ± 0.16	0.58 ± 0.17*	0.60 ± 0.18**	0.45 ± 0.21

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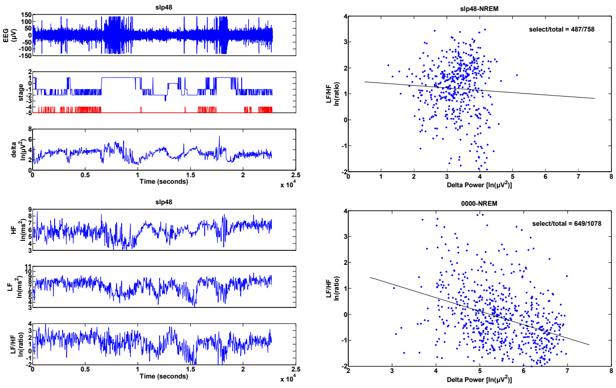
FFT and HHT results for OSA patients (cubic spline)



Fast Fourier Transform (cubic spline)

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Mean	821.76±81.46	856.58±74.95	835.53±84.42
r	-0.33±0.22	-0.03±0.22*	-0.09±0.25
HF [ln(ms²)]			
Mean	5.24±0.71	6.26±0.58*	5.80±0.92
r	-0.01±0.19	0.12±0.25	0.06±0.24
LF [ln(ms²)]			
Mean	6.39±0.49	6.99±0.52	6.94±0.80
r	0.17±0.20	-0.05±0.23	0.15±0.35
LF/HF [ln(ratio)]			
Mean	0.97±0.44	0.62±0.52	1.04±0.69
r	0.17±0.22	-0.14±0.21*	0.08±0.30
HF (nu)			
Mean	31.73±7.58	37.55±10.24	30.39±12.45
r	-0.16±0.23	0.14±0.20*	-0.07±0.31
LF (nu)			
Mean	68.27±7.58	62.45±10.24	69.61±12.45
r	0.16±0.23	-0.14±0.20*	0.07±0.31

[a] Results are expressed as mean ± SD

[b] AW, active wakening; QS, quiet sleep; REM, rapid eye movement sleep; RR, R-R intervals; HF, high-frequency power; LF, low-frequency power; LF/HF, LF to HF ratio; r correlation coefficient with delta power of EEG.

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Mean	5.77 ± 0.56	6.50 ± 0.65[c]	5.58 ± 0.97
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[d] $P < 0.05$; significantly different from zero value, for r only.

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Thanks for your attention