Relationship between subjective assessment of sleep quality and heart rate variability during sleep

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***Abstract*—Assessment of autonomic function during sleep is gathering attention as an indicator of sleep quality that is closer to subjective assessment than that from polysomnography or actigraphy. This study examined the relationships between subjective sleep quality assessment and heart rate variability (HRV) indices, particularly those derived from a new sleep index (Hsi) that we have recently developed to detect non-REM sleep. We studied 18 sets of nighttime ECGs and the responses to sleep inventory questionnaires obtained from 5 male workers. We observed that subjective quality was associated with sleep latency estimated by Hsi and with the length of time in bed excluding the period of non-REM sleep in these subjects.**

I. INTRODUCTION

Along with the widespread use of wearable monitoring devices, the assessment of sleep quality by the analysis of heart rate variability (HRV) becomes popular. In general, increases in HRV indices associated with cardiac vagal function have been thought to reflect the good quality of sleep. Furthermore, HRV analysis during sleep may be even useful for evaluating sleep qualities that are close to those of subjective assessment, which are not detected by polysomnography or actigraphy [1].

We have recently developed a new sleep index of HRV, which is called Hsi (Fig 1) [2]. Hsi detects non-REM sleep period by utilizing the phenomena that the power spectral density of high-frequency component (HF, 0.04-0.45 Hz) concentrates into a narrow frequency band due to increased respiratory regularity accompanying non-REM sleep. In this study, we examined the relationships between subjective assessment of sleep quality and HRV with particular interests in the usefulness of Hsi.

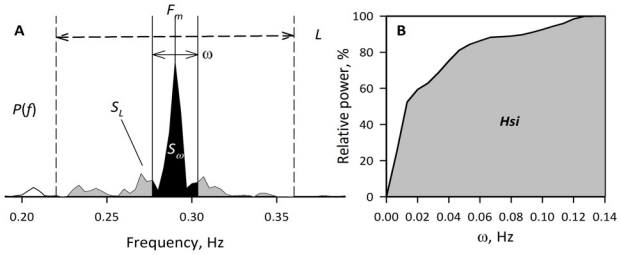

Fig 1. Computation of HF spectral concentration index: Hsi
$P(f)$: power spectrum (A); F_m: frequency of the highest spectral peak in HF band (0.15-0.45 Hz); S_L: total power within the frequency range of $F_m \pm L/2$ (L = 0.14 Hz in this study); S_ω: total power within the frequency range of $F_m \pm \omega/2$ ($0 < \omega < L$); R_ω: the ratio of S_ω to S_L.

$$R_\omega(\%) = 100 \times \frac{S_\omega}{S_L}$$

Hsi: area under the curve (AUC) of R_ω (B).

$$\text{Hsi}(\%) = \frac{1}{L}\int_0^L R_\omega d\omega$$

II. METHODS

Study subjects: We studied 5 healthy male office workers (mean age ± SD, 39 ± 10 yr, range, 26-52 yr) without health problems affecting autonomic nervous function. The protocol of this study has been approved by the Ethics Review Committee of Nagoya City University Graduate School of Medical Sciences and Nagoya City University Hospital (#60160163).

Measurements: Holter ECG was recorded for 24 h on 3-4 days in each subject during 3 weeks by an ECG recorder with built-in triaxial accelerometers (Cardy 303 pico+, SUZUKEN Co., Ltd., Nagoya, Japan). On each day of Holter ECG recording, they completed the Oguri-Shirakawa-Azumi sleep questionnaire MA version (OSA-MA sleep inventory) [3] immediately after waking in the morning. OSA-MA is a standardized sleep inventory consisted of 16 items of question with a 4-point Likert scale. It provided 5 factor scores concerning sleep qualities (Table I). A total of 18 sets of ECG during sleep and responses to sleep questionnaire thus obtained was used for this study.

Data analysis: The ECG data were processed by a Holter ECG scanner (Cardy Analyzer 05, Suzuken Co., Ltd., Nagoya, Japan) by which QRS complexes were detected and labelled automatically. Actigraphic data obtained by built-in triaxial accelerometers were digitized at 31.25 Hz per channel, from which body positions and physical activity were estimated by previously reported method [4].

Using the body position and physical activity, time in bed (TIB) for sleep was estimated and R-R interval time series during the TIB were analyzed for conventional time- and frequency-domain HRV indices and for nonlinear heart rate dynamics as short-term (4-11 beat) and long-term (>11 beats) scaling exponents α_1 and α_2 by detrended fluctuation analysis [5]. Additionally, Hsi was computed for consecutive 5-min segments, by which the time from going to bed to the point when Hsi first reached 65% was measured as Hsi latency and used as an estimate of sleep latency. Also, the total time of Hsi >65% during time in bed ($tHsi_{65}$) was calculated as an estimate of the total period of non-REM sleep.

III. RESULTS

The average of TIB was 364 ± 89 min and Hsi latency was 21 ± 18 min (Table I). As shown in Table II, TIB was correlated with the sores of less sleepiness on rising (factor 1), refreshing (Factor 4), and sleep length (Factor 5). HRV indices associated with cardiac vagal function were also correlated with less sleepiness and those in frequency domain (VLF, LF, and HF) were correlated also with sleep length. The score of

TABLE I
RESULTS OF OGURI-SHIRAKAWA-AZUMI (OSA) SLEEP INVENTORY AND HEART RATE VARIABILITY (HRV) DURING SLEEP

Variable	Mean ± SD
OSA sleep inventory	
Factor 1: Less sleepiness on rising	16.2 ± 5.9
Factor 2: Initiation and maintenance of sleep	20.9 ± 6.3
Factor 3: Frequent dreaming	23.5 ± 7.1
Factor 4: Refreshing	18.0 ± 5.6
Factor 5: Sleep length	17.0 ± 6.6
TIB, min	364 ± 89
Heart rate variability	
Heart rate, bpm	60.2 ± 4.6
SDNN, ms	107 ± 24
rMSSD, ms	41 ± 17
Scaling exponent α_1	1.2 ± 0.1
Scaling exponent α_2	0.91 ± 0.07
ULF, ln(ms^2)	7.7 ± 0.8
VLF, ln(ms^2)	7.9 ± 0.7
LF, ln(ms^2)	6.8 ± 0.7
HF, ln(ms^2)	6.0 ± 0.8
LF/HF	2.4 ± 1.0
Hsi latency, min	21 ± 18
$tHsi_{65}$, min	224 ± 71
TIB-$tHsi_{65}$, min	140 ± 36

TIB = time in bed, SDNN = standard deviation of normal-to-normal (sinus rhythm) R-R intervals, rMSSD = root mean square of R-R interval successive difference, ULF = ultra-low-frequency component power, ULF = ultra-low frequency component power, VLF = very-low-frequency component power, LF = low-frequency component power, HF = high-frequency component power, Hsi = High-frequency spectral concentration index.

TABLE II
CORRELATION BETWEEN HRV INDICES AND FACTOR SCORE OF OSA SLEEP INVENTORY

HRV indices	OSA sleep inventory factor				
	1	2	3	4	5
TIB	0.65*	-0.35	-0.46	0.49*	0.53*
Heart rate	-0.05	0.33	0.47	-0.08	0.13
SDNN	0.56*	-0.06	-0.13	0.15	0.30
rMSSD	0.61*	-0.26	-0.23	0.41	0.39
Scaling exponent α_1	-0.18	0.15	-0.08	-0.14	-0.16
Scaling exponent α_2	-0.30	0.52*	0.28	-0.28	-0.31
ULF	0.47	0.03	-0.31	0.19	0.39
VLF	0.64*	-0.45	-0.54*	0.41	0.50*
LF	0.68*	-0.23	-0.20	0.39	0.51*
HF	0.62*	-0.35	-0.24	0.46	0.56*
LF/HF	-0.18	0.37	0.22	-0.28	-0.23
Hsi latency	0.19	-0.47*	0.06	0.23	0.17

*Significant correlation coefficients.
Abbreviations are explained in the foot note to TABLE I.

initiation and maintenance of sleep (factor 2) was negatively correlated only with scaling exponentα_2 and that of frequent dreaming (factor 3) was correlated negatively with VLF.

As shown in Fig 2, positive correlations were observed between TIB-$tHsi_{65}$ and subjective sleep quality including less sleepiness, refreshing, and sleep length (factors 1, 4, and 5). As expected, the sleep latency estimated by Hsi latency showed a negative correlation with initiation and maintenance of sleep (factor 2). The $tHsi_{65}$ was negatively correlated with frequent dreaming (factor 3).

IV. DISCUSSION

We observed that HRV indices reportedly associated with cardiac vagal function were correlated with subjective sleep quality (less sleepiness, refreshing, and sleep length). This finding is in the same line with that of an earlier study using OSA-MA inventory [1] and supports the involvement of autonomic function during sleep as a determinant of subjective sleep quality. We also found the relationship between short Hsi latency and the subjective quality of sleep initiation and maintenance. This suggests importance of short sleep latency as another determinant of subjective sleep quality, which can be estimated by HRV analysis using Hsi.

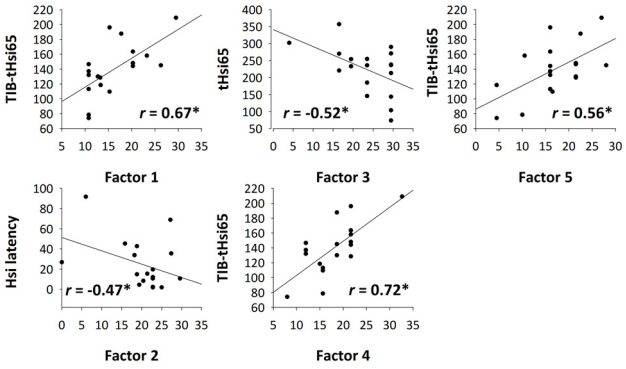

Fig. 2. Relationships between time of Hsi_{65} and factor scores of OSA sleep inventory. *Significant partial correlation coefficients (effects of age were partialed out.

Interestingly, we observed significant correlations between TIB – $tHsi_{65}$ and subjective sleep quality. This value is an estimate of the total time of REM and waking during TIB, suggesting that the length of time in bed excluding the period of non-REM sleep may be a determinant of sleep quality at least in these subjects with a relatively short sleep time.

Because this study was performed only in 5 male workers, the results cannot not be extended to different situation or other groups of subjects. Nevertheless, this study indicates the usefulness of HRV analysis including a new index of Hsi for estimating subjective sleep quality where it cannot be obtained directly, such as from big data collected through IoT networks.

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