

## Inward-attention meditation increases parasympathetic activity: a study based on heart rate variability

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### ABSTRACT

Phenomenon of the heart rate variability (HRV) during various meditation techniques has been reported. However, most of these techniques emphasized the skill of slow breathing ( $< 0.15$  Hz). This paper reports our study on HRV during meditation which emphasizes inward attention. Inward attention has been an important approach for the Zen-meditation practitioners to enter into transcendental consciousness. Two groups of subjects were investigated, 10 experimental subjects with Zen-meditation experience and 10 control subjects without any meditation experience. We analyzed HRV both in time and frequency domains. The results revealed both common and different effects on HRV between inward-attention meditation and normal rest. The major difference of effects between two groups were the decrease of LF/HF ratio and LF norm as well as the increase of HF norm, which suggested the benefit of a sympathovagal balance toward parasympathetic activity. Moreover, we observed regular oscillating rhythms of the heart rate when the LF/HF ratio was small under meditation. According to previous studies, regular oscillations of heart rate signal usually appeared in the low-frequency band of HRV under slow breathing. Our findings showed that such regular oscillations could also appear in the high-frequency band of HRV but with smaller amplitude.

Heart rate variability (HRV) represents the beat-to-beat changes in heart rate. It reflects the modulation of autonomic nervous system (ANS) on heart rate. Clinical application of HRV was first reported in 1965 by Hon and Lee (6). The reduction in HRV has been found to be correlated with several diseases (1, 5, 6, 8, 19). With power spectrum analysis, the fluctuations of heart rate were divided into four frequency bands (24) which correspond to different physiological phenomena. The high-frequency (HF, 0.15–0.4 Hz) and low-frequency (LF, 0.04–0.15 Hz) components are the two that are better understood and mostly used. The HF component is mainly con-

tributed by parasympathetic modulation. The LF component corresponds to mixed sympathetic and parasympathetic modulation. And the LF/HF ratio is considered as an indicator of sympathovagal balance (4).

In regard to the significance of HRV in cardiovascular and autonomic functions, various interventions were studied to discover the way to regulate it. White (27) studied the effects of relaxing music on heart rate variability and found relaxing music could decrease the heart rate and increase the high-frequency heart rate variability. Lehrer *et al.* (12) developed a biofeedback system which could help practitioners to induce a resonant RSA (respiratory sinus arrhythmia) by slow breathing. Tiller *et al.* (25) found that positive emotions could alter the HRV and lead to either the *entrainment* or *internal coherence* mode of heart function. Other mechanisms like yoga (17), qigong (10) and meditation were also studied.

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A number of literatures have extensively reported that meditation practice affected various physiological and mental functions (3, 7, 9, 13, 18, 21, 23, 26). Meditation effects on heart rate variability also have been investigated (2, 11, 15, 16, 22). However, most studies have been focused on the skill of slow breathing. In 1999, Peng *et al.* (16) observed very prominent low-frequency ( $\sim 0.1$  Hz) RSA in heart rate during specific forms of Chinese Chi and Kundalini yoga meditation. In their later study (15), same phenomenon was also observed in two forms of meditation with different respiration techniques. In 2005, Cysarz and Büssing (2) observed prominent in-phase RSA, caused by low-frequency breathing, during Zazen meditation and Kinhin meditation. These studies showed that meditation techniques characterized by slow breathing ( $< 0.15$  Hz, less than 9 breaths in one minute) could result in very prominent and regular oscillations in the LF band of HRV.

This study mainly explored the effects of inward-attention meditation. Inward attention has been an important approach for Zen practitioners to enter into transcendental consciousness. Practitioners concentrate their mind on a specific chakra (an energy spot inside the body) to release themselves from uncontrollable, wild thoughts and to enter into a calm-mental state. Heart rate variability under this meditation scheme was studied both in time and frequency domains in this study.

## MATERIALS AND METHODS

**Subjects.** Two groups of subjects were studied in this work. The experimental group included 10 experienced Zen-meditation practitioners (3 female and 7 males, mean age  $27.0 \pm 2.4$  years; mean meditation experience  $6.0 \pm 3.2$  years); the control group included 10 non-meditators (1 female and 9 males, mean age  $26.2 \pm 3.6$  years). All subjects had no cardiac, pulmonary, and other chronic diseases according to their medical records. Also, all subjects were non-smokers, neither caffeine addicts nor alcohol addicts. Each subject provided written informed consent (in accordance with the Helsinki Declaration) to the study.

**Procedure.** Because the human cardiac function is regulated differently by ANS in a day, the experiments were conducted during the same period (3:30pm to 5:00pm) to ensure similar states of ANS for all subjects. The experiments comprised two sessions. During Session 1 (baseline phase),

subjects of both groups rested, in a head-up back-tilt position with eyes closed, for 10 min. During Session 2, subjects of control group continued resting for 20 min; while experimental subjects began meditating for 20 min. Experimental subjects, following their routine meditation convention, meditated at full- or half-lotus posture, with eyes closed. During meditation, practitioners concentrated their mind on “Zen Chakra” locating inside the third ventricle of human brain. All subjects breathed spontaneously in both sessions.

**Signal acquisition.** The electrocardiogram (ECG) and respiration signals were recorded simultaneously at 1000 Hz sampling rate using PowerLab/16SP recording system (ADInstruments, Sydney, Australia). ECG signal was recorded using Lead I of standard bipolar limb leads, and the respiratory signal was recorded using a piezo-electric transducer (Model 1132 Pneumotrace II (R); UFI, Morro Bay, CA, USA) wrapped around the belly covering the navel.

**Heart rate variability analysis.** In this study, we analyzed HRV in time domain and frequency domain. Before HRV analysis, the R peaks of ECG signal were detected automatically by computer algorithm and reviewed manually. The R-R intervals (in ms) were then calculated to construct the RR tachogram (R-R interval series). In time-domain analysis, the R-R interval series were used. Frequency-domain analysis based on Fourier transform assumes equal sampling period of the series (that is, uniform sampling process). However, RR tachogram constructed from R-R intervals explicitly is a non-uniform sampled sequence. Therefore, before frequency-domain analysis, we resampled the RR tachogram using cubic spline interpolation at 4 Hz to re-construct a uniform-sampled RR-interval sequence.

Table 1 lists the HRV parameters to be analyzed with their abbreviations. All the parameters were calculated using 5-minute window without overlap throughout the recordings.

**Respiration rate.** Since the respiration rate significantly affects HRV (20), we considered it as an important reference in HRV research. To determine the respiration rate, respiration signal was first filtered by a 0.04–0.4 Hz bandpass filter to reduce the baseline drift and high-frequency noise. Then the inspiration-phase peaks of filtered respiratory signal were detected. For each 5-minute segment, the mean respiration rate (breaths/min) was calculated by count-

**Table 1** Parameters of HRV analysis applied in this study

Parameter	Units	Description
Time domain		
Mean HR	beats/min	Mean heart rate
SDNN	ms	Standard deviation of NN intervals
RMSSD	ms	Root-Mean-Square of the differences between adjacent NN intervals
Frequency domain		
LF	ms <sup>2</sup>	Power in low frequency band (0.04–0.15 Hz)
HF	ms <sup>2</sup>	Power in high frequency band (0.15–0.4 Hz)
LF norm	%	LF/(LF + HF) × 100
HF norm	%	HF/(LF + HF) × 100
LF/HF		LF/HF

ing the numbers of inspiration-phase peaks and dividing by 5.

*Statistical analysis.* Before statistic analysis, the mean values of parameters were calculated for each subject in each session by averaging results derived from 5-minute segments. We used SPSS (version 12.0 for Windows) for statistical analysis. Two-way ANOVA (2 groups × 2 sessions) with repeated measures was used to evaluate the statistical differences between groups (inter-group) and between sessions (inter-session) for each parameter. Two main effects (group and session) and the interaction effect (group × session) were verified. When two-way ANOVA revealed significant interaction, we performed simple effects analysis for each group and also for each session. The statistically significant level was set at 0.05, and comparisons were two tailed.

## RESULTS

Fig. 1 displays three typical heart rate signals during experiments, together with the respiration signals and their power spectra. Fig. 1a presents the results of a control subject at rest; while Figs. 1b and 1c plot the results of two experimental subjects during meditation. For the control subjects at rest, the mean value of LF/HF ratio was about 1.5 and the oscillations of their heart rate signals were much irregular (Fig. 1a). For the experimental subjects during meditation, most of them exhibited lower level of LF/HF ratio (< 1), compared to the control subjects during rest. In this state, the heart rate signals revealed segments of regular oscillations (Fig. 1b). A couple of experimental subjects presented a very low level of LF/HF ratio (< 0.3) and the oscillations of their heart rate signals were much regular as shown in Fig. 1c.

The results of HRV analyses and respiration rate

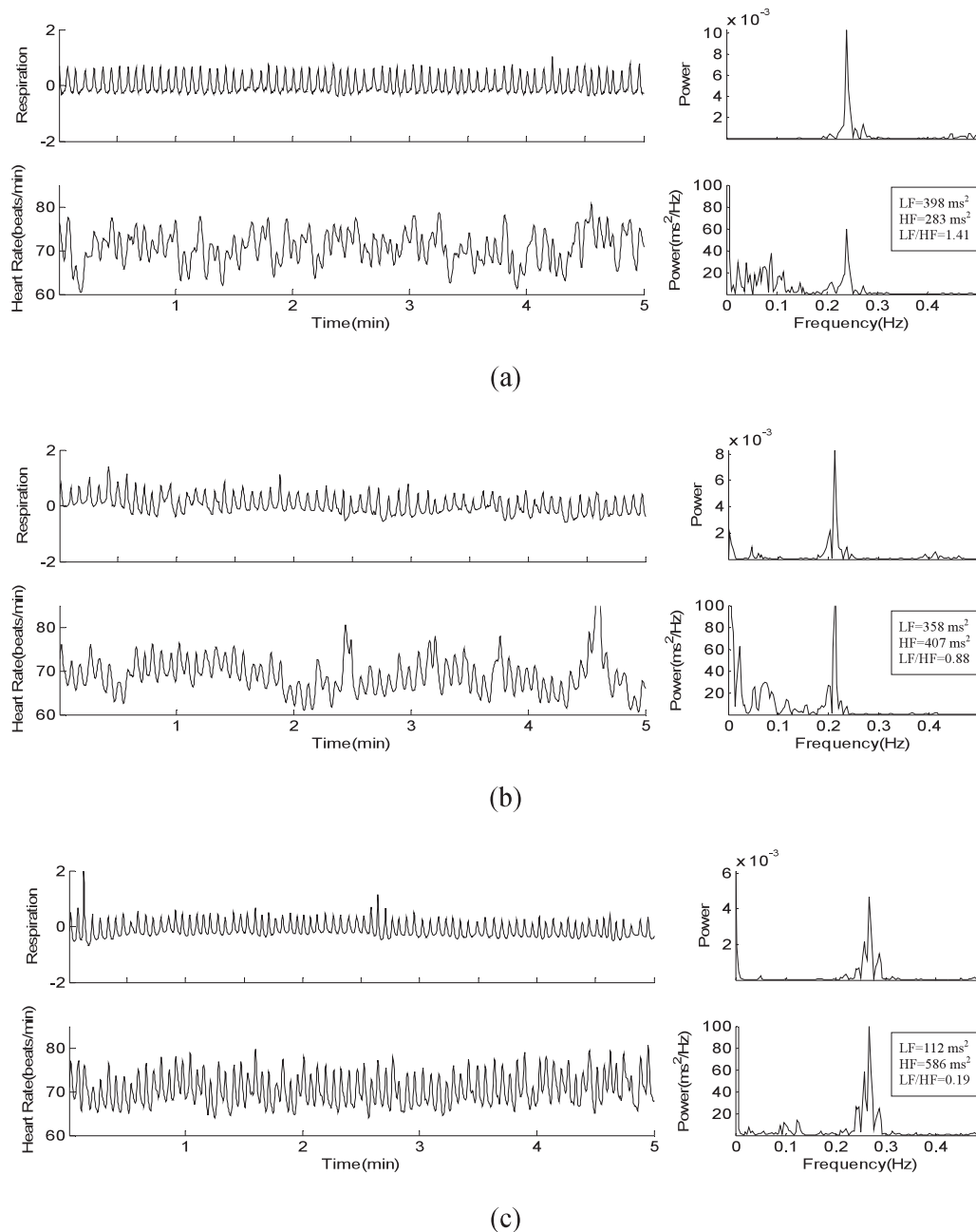
are summarized in Table 2. The mean values of respiration rates do not show significant difference between groups and between sessions by two-way ANOVA analysis. Hence in this study, we can exclude the effect of respiration rate on HRV. We further compared the HRV results in the following subsections.

### *Time-domain HRV parameters*

We observed significant interaction (group × session) effects for Mean HR [ $F(1,18) = 7.39, P = 0.014$ ] and SDNN [ $F(1,18) = 4.71, P = 0.044$ ], which suggested a significant difference between groups in session effects. Further tests of simple effects revealed that there was a significant increase of mean heart rate for experimental subjects from Session 1 to Session 2 [ $F(1,18) = 6.51, P = 0.02$ ], but no significant difference for the control subjects. And experimental subjects had a significantly higher mean heart rate than control subjects during Session 2 [ $F(1,36) = 7.73, P = 0.009$ ]. There appeared a significant increase of SDNN only for control subjects from Session 1 to Session 2 [ $F(1,18) = 6.64, P = 0.019$ ]. And control subjects had a significantly higher SDNN than experimental subjects during Session 2 [ $F(1,36) = 5.15, P = 0.029$ ]. There existed neither significant main effect nor interaction effect for parameter RMSSD.

### *Frequency-domain HRV parameters*

There were significant session effects for LF power [ $F(1,18) = 8.01, P = 0.011$ ] and HF power [ $F(1,18) = 10.09, P = 0.005$ ]. For both groups, the LF power and HF power both significantly increased from Session 1 to Session 2. There were significant interaction (group × session) effects for LF norm [ $F(1,18) = 6.39, P = 0.021$ ], HF norm [ $F(1,18) = 6.39, P = 0.021$ ] and LF/HF [ $F(1,18) = 5.33, P = 0.033$ ]. Further tests of simple effects revealed that there were



**Fig. 1** Three typical heart rate and simultaneous respiratory signals during rest and meditation; on the right are their power spectra: (a) a control subject during rest in which presented normal LF/HF level, (b) an experiment subject during meditation in which presented low LF/HF level, and (c) another experimental subject during meditation in which presented very low LF/HF level.

significant decreases of LF norm [ $F(1,18) = 9.62$ ,  $P = 0.006$ ] and LF/HF [ $F(1,18) = 5.94$ ,  $P = 0.025$ ], and a significant increase of HF norm [ $F(1,18) = 9.62$ ,  $P = 0.006$ ] for experimental subjects from Session 1 to Session 2. During Session 2, experimental subjects had significantly lower LF norm [ $F(1,36) = 5.94$ ,  $P = 0.02$ ] and LF/HF [ $F(1,36) =$

$5.19$ ,  $P = 0.029$ ], and significantly higher HF norm [ $F(1,36) = 5.94$ ,  $P = 0.02$ ] than control subjects.

## DISCUSSION

In this study, we observed several segments of regular oscillations in heart rate signals during inward-

**Table 2** Mean values and standard deviations of heart rate variability parameters and respiration rate during two experimental sessions for control and experimental groups

	Control Group (n = 10)		Experimental Group (n = 10)		Group effect	Session effect	Interaction effect
	Session 1 (Baseline)	Session 2 (Rest)	Session 1 (Baseline)	Session 2 (Meditation)			
Respiration rate (breaths/min)	16.1 ± 3.0	16.1 ± 2.9	15.0 ± 2.0	15.1 ± 2.4	NS	NS	NS
Mean HR (beats/min)	67.4 ± 6.7	65.6 ± 5.7	70.7 ± 8.2	74.3 ± 7.2	NS	NS	0.014*
SDNN (ms)	53.3 ± 13.0	60.8 ± 16.7	48.3 ± 10.7	46.9 ± 13.5	NS	NS	0.044*
RMSSD (ms)	43.0 ± 17.8	47.7 ± 16.7	36.4 ± 11.8	38.1 ± 14.2	NS	NS	NS
LF (ms <sup>2</sup> )	451 ± 264	690 ± 463	286 ± 219	322 ± 342	NS	0.011*	NS
HF (ms <sup>2</sup> )	380 ± 254	469 ± 299	297 ± 165	401 ± 241	NS	0.005*	NS
LF norm (n.u.)	54.0 ± 12.2	55.2 ± 11.2	48.4 ± 16.2	40.6 ± 13.6	NS	NS	0.021*
HF norm (n.u.)	46.0 ± 12.2	44.8 ± 11.2	51.6 ± 16.2	59.4 ± 13.6	NS	NS	0.021*
LF/HF	1.37 ± 0.58	1.48 ± 0.61	1.16 ± 0.78	0.83 ± 0.53	NS	NS	0.033*

NS = not significant; \*Significant difference ( $P < 0.05$ ).

attention meditation. Similar regular oscillations were also observed in previous meditation studies (2, 11, 15, 16). Tiller *et al.* (25) called it the “entrainment mode” of heart function which can be induced under positive emotions. In these previous studies, such regular oscillations all appeared in the low-frequency (LF) band of HRV due to the slow breathing. Our study showed that this regular oscillations could also appear in the high-frequency (HF) band of HRV but with smaller amplitude. Furthermore, such regular oscillations were observed particularly at the low LF/HF ratio, that might suggest the sympathovagal balance as a key role in the occurrence of this regular oscillations. That is, when the autonomous nervous system is under parasympathetic predominance, the heart rate can be purely modulated by respiration and reveals a regular heart rate signal.

The results of two-way ANOVA analysis showed significant differences in several HRV parameters. Those indicated that there existed both common and different effects between inward-attention meditation and normal rest on heart rate variability. In respect of time-domain HRV parameters, neither inward-attention nor normal rest had effects on RMSSD. Otherwise, normal rest had a significant effect of increasing the SDNN and inward-attention meditation had a significant effect of increasing the Mean HR. For frequency-domain HRV parameters, inward-attention and normal rest had the common effects of increasing the LF power and HF power. The different effects included decreases of the LF/HF ratio and LF norm as well as increase of HF norm during inward-attention meditation, which suggested a sympathovagal balance toward parasympathetic

activity (4) and reflected a certain state of relaxation. As regards the normal rest, there appeared no significant effect on LF norm, HF norm and LF/HF ratio. In the previous meditation study by Takahashi *et al.* (22), the results showed that the decrease of LF/HF ratio and LF norm were correlated to the increase of slow alpha power in the frontal cortical region which reflected enhancement of inward attention. Accordingly, the inhibitory effect on sympathetic activity (decrease in LF/HF ratio and LF norm) during meditation may be caused by the enhancement of inward attention.

In conclusion, inward-attention meditation practice appears to push the sympathovagal balance to parasympathetic predominance and induce regular oscillations in heart rate. These results may support the health benefits of meditation in conditions where sympathovagal balance toward sympathetic activity due to stress or disease.

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