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Effects of Long-Term Dharma-Chan Meditation on Cardiorespiratory Synchronization and Heart Rate Variability Behavior

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Abstract

Remarkable changes in cardiorespiratory interactions are frequently experienced by Chan meditation practitioners following years of practice. This study compares the results of our study on cardiorespiratory interactions for novice (control group) and experienced (experimental group) Chan meditation practitioners. The effectual co-action between the cardiac and respiratory systems was evaluated by the degree of cardiorespiratory phase synchronization (CRPS). In addition, an adaptive-frequency-range (AFR) scheme to reliably quantify heart rate variability (HRV) was developed for assessing the regulation of sympathetic–parasympathetic activity and the efficiency of pulmonary gas exchange. The enhanced HRV method, named $\mathrm{HRV}_{\mathrm{AFR}}$, can resolve the issue of overestimating HRV under the condition of slow respiration rates, which is frequently encountered in studies on Chan meditation practitioners. In the comparison of the three data sets collected from the two groups, our findings resulted in innovative hypotheses to interpret the extraordinary process of the rejuvenation of cardiorespiratory functions through long-term Dharma-Chan meditation practice. Particularly, advanced practitioners exhibit a continuously high degree of cardiorespiratory phase synchronization, even during rapid breathing. Based on our post-experimental interview with advanced practitioners, the activation of inner Chakra energy, during the course of Chan-detachment practice, frequently induces perceptible physiological-mental reformation, including an efficient mechanism for regulating cardiorespiratory interactions.

Introduction

Modern meditation is widely acknowledged as an important technique in the category of mind–body medicine following extensive, in-depth research since the 1960s[1,2] proved the effectiveness of meditation for various aspects of human health and wellness. Meditation is a wakeful hypometabolic state of parasympathetic dominance that has been corroborated by physiological indicators, such as the reduction of heart rate, blood pressure, and respiratory rate, and significant increases in plasma melatonin levels and enhanced regulation of cortisol levels.[3–5] Among meditation techniques, Chan meditation, originating from Dharma-Chan, reveals a unique method for practicing meditation through "heart-to-heart seal" enlightenment. Concentration on the heart-chakra with slow abdominal respiration has become a crucial practice for disclosing the *bodhi* (*i.e.*, enlightened wisdom) in the heart. Practitioners experience *qi* energy reforming the meridians (*i.e.*, the *qi*-flow pathway) near the heart chakra, which elicits perceptions of electric-light energy inside the heart chakra, as narrated by experienced practitioners. This phenomenon motivated us to investigate the effects of long-term Chan meditation practice on cardiorespiratory interactions.

The interaction between human cardiac and respiratory systems has been widely studied for decades. Most recently, cardiorespiratory phase synchronization (CRPS) has been demonstrated as a comprehensive scheme for reflecting certain types of interaction between the cardiac and respiratory systems. According to previous studies,[6–8] cardiorespiratory phase synchronization can characterize an effectual co-action between cardiac and respiratory systems that can better preserve energy. CRPS is most visible under conditions of low cognitive activity or low mental processes, such as during sleep[6,9] and under anesthesia,[10,11] nearly vanishing during physical strain.[6] Under Chan meditation, practitioners frequently enter into a state of transcendental consciousness with their physical bodies fully relaxed, facilitating the appearance of CPRS.

For a comparison reference, heart rate variability (HRV), analyzed using the frequency-domain method, was employed in the assessment of the regulation of sympathetic–parasympathetic

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activity. HRV that is evaluated by the power spectrum of an HR sequence is manipulated by the interactions of the sympathetic and parasympathetic nervous systems in the autonomic nervous system (ANS). The parameter P_{LF}/P_{HF}, adopted to quantify HRV, is the ratio of total power in the low-frequency (LF) range to the total power in the high-frequency (HF) range of HRV. Determining the LF and HF ranges is crucial to obtaining reliable estimates of P_{LF}/P_{HF}. The LF range from 0.04 Hz to 0.15 Hz is typically considered the marker of sympathetic activity, whereas the HF range from 0.15 Hz to 0.4 Hz is referred to as the marker of parasympathetic activity.[12–14] Recent studies have suggested that the HF component of HRV is affected by respiration.[12,15] At lower respiration rates, the HF component that reflects parasympathetic activity shifts toward the lower frequency range and overlaps with the range of the LF component that is defined for sympathetic activity. Consequently, traditional methods for HRV analysis (tHRV) that are based on fixed LF and HF ranges frequently result in over-estimations at low respiratory rates. According to our previous study (*i.e.*, the master's thesis by Shun-Min Huang, "Cardiorespiratory Phase Synchronization for Chan-Meditation Practitioners," supervised P. C. Lo, July 2010, National Chiao Tung University, Hsinchu, Taiwan), Chan meditation practitioners regularly breathe at respiration rates lower than 12 breaths/min. To achieve more reliable and meaningful evaluations of HRV, we applied a novel HRV scheme that was enhanced using an adaptive-frequency-range (AFR) design, named HRV_{AFR}, which enhances the resolution of the effects of the sympathetic and parasympathetic branches of the ANS.

Methods

Participants

Two groups of participants were recruited in this study. The experimental group comprised 10 experienced Chan meditation practitioners: 5 women and 5 men (average age, 53 years; age range, 35–64 years) with an average meditation experience of 18.4 ± 2.6 years. The control group included 8 women and 7 men who were novices (average age, 52 years; age range, 23–70 years) without any Chan meditation experience. All participants were non-smokers and non-drinkers without any cardiac or pulmonary diseases. Each participant provided written informed consent in accordance with the Helsinki Declaration for the study.

The first recording of the control group, Cntl-I data, was performed on the novices after they accomplished one to two Dharma-Chan meditation lectures. The second recording of the control group, Cntl-II data, was conducted 8 weeks following the first recording. All of the novices followed instructions for practicing Dharma-Chan meditation on a daily basis. Only one recording was performed on the experimental group (Expr data) during a 40-min Chan-meditation session.

Protocol

The experimental protocol included: (1) A 10-min preparatory session, (2) a 20-min main session recording (participants were performing Chan meditation), and (3) a post-experiment interview. In the preparatory session, the participants took a brief rest after being attached to the instruments for recording electrocardiogram (ECG) and respiratory signals. Figure 1 shows the ECG electrode placement.

During the 20-min Chan meditation, the practitioners performed freestyle Chan meditation after a few minutes of breathing regulation. Thereafter, all of the participants breathed naturally throughout the meditation session.

Signal acquisition

The ECG and respiratory signals were recorded simultaneously with sampling rates of 512 and 128 Hz, respectively, using a NuXus-4 recording system (TMS International BV). To record the respiratory signals, a NX-RSP1A piezoelectric transducer was wrapped around the stomach near the navel. The ECG signal was pre-filtered by a 0.3- to 200-Hz bandpass filter, and the respiratory signal was pre-filtered by a low-pass filter with a cutoff frequency of 5 Hz. A 60-Hz notch filter was applied to both signals to remove artifacts from the power line and the surroundings. After a careful examination of all 40 data sets (*i.e.*, 15 sets in Cntl-I and Cntl-II, 10 sets in Expr), three sets of Cntl-I and Cntl-II were discarded because of their extraordinarily low respiratory rates (3–4 breaths/min). In addition, our pre-processing algorithm screened ectopic beats in the ECG signals.

Signal analysis: CRPS analysis

Figure 2 shows the strategy for analyzing the CRPS. The core scheme was the estimate of the instantaneous phase based on the Hilbert–Huang transform (HHT) approach. The HHT offers the same ability for time-frequency representations (*i.e.*, spectrograms) as accomplished by the wavelet transform (WT) method. However, the HHT does not require the selection of *a priori* functional basis. Thus, the results of the HHT exhibit a substantially sharper effect than do those of traditional time–frequency representation methods.

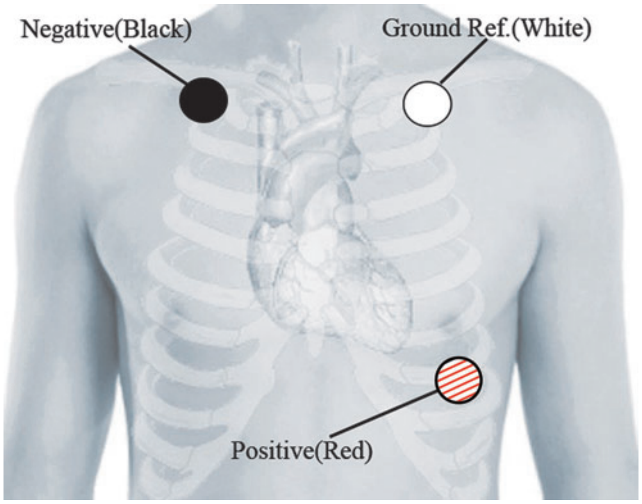

FIG. 1. Electrode placement on subjects. The negative electrode was placed between the first and the second ribs of the right chest, and the positive electrode was placed on the lower left chest, with the ground electrode placement laterally symmetrical to that of the negative electrode. Color images available online at www.liebertpub.com/rej

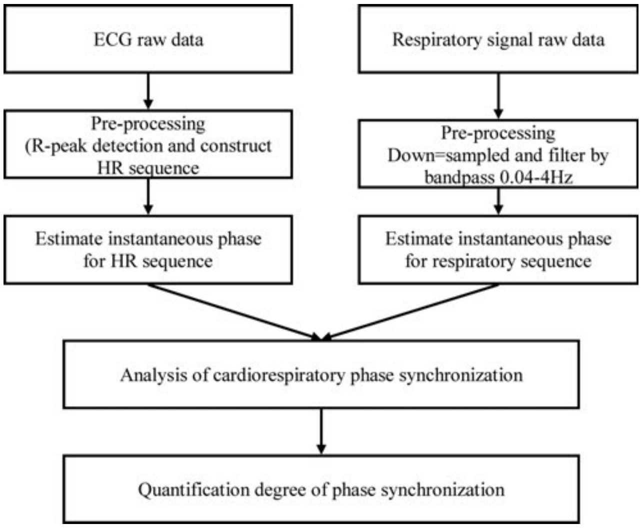

FIG. 2. Block diagram for the strategy for analyzing the cardiorespiratory phase synchronization. First, empirical mode decomposition (EMD) was applied to the heart rate (HR) sequence to extract IMF_1 ($c_1[n]$). Instantaneous phase functions $\phi_{HR}[n]$ and $\phi_{RP}[n]$ were derived by applying equations (1) to (4) to $c_1[n]$ and $RP[n]$, respectively. Then the initial estimate of cardiorespiratory phase synchronization (CRPS) was the difference between two phase functions.

The HHT has demonstrated its capability for characterizing the physical meanings of empirical data acquired in a large variety of areas, including biomedical applications, ocean engineering, seismic studies, chemistry, chemical engineering, financial applications, and image processing.[16] The extraordinary robustness of the method results from its completely empirical means of implementation.

In this study, the initial estimate of CRPS was the difference between functions $\phi_{HR}[n]$ and $\phi_{RP}[n]$, where $\phi_{HR}[n]$ and $\phi_{RP}[n]$ represent, respectively, the instantaneous phase functions of the HR and RP (respiratory) sequences. It has been reported[17] that the highest-frequency component of HR sequences reflects the influence of respiration. Therefore, we investigated cardiorespiratory phase behavior based on a decomposed IMF_1 (*i.e.*, first intrinsic mode function) of an HR sequence.[17]

The empirical mode decomposition (EMD) method was used to extract IMF_1. EMD is performed in close alignment with the waveform features of the empirical signals. No mathematical model was required as the kernel basis. The EMD method was developed from the assumption that a signal can be considered the composition of various simple, intrinsic oscillation modes. Each linear or non-linear mode has the same number of extrema and zero-crossings. Only one extremum appears between two consecutive zero-crossings. The IMFs must satisfy a given set of criteria.[16] Figure 3 shows the flow chart and algorithm for implementing the EMD in our study. After extracting IMF_1 ($c_1[n]$), instantaneous phase functions $\phi_{HR}[n]$ and $\phi_{RP}[n]$ of $c_1[n]$ and $RP[n]$, respectively, were ready to be derived. Let $g[n]$ denote either $c_1[n]$ or $RP[n]$, which is a real band-limited function or signal. The next step was to obtain the *analytic* signal of $g[n], z[n] = g[n] + j^{\hat{g}[n]}$, where the imaginary part $\hat{g}[n]$ was derived using the Hilbert transform method. In this study, the discrete Hilbert transform (DHT) method was adopted. The DHT can be computed by the convolution

$$\mathbf{H}\ [g[n]] = \hat{g}[n] = g[n] * \lambda[n], \tag{1}$$

where

$$\lambda[n] = \begin{cases} 0, n : \text{even} \\ \frac{2}{\pi n}, n : \text{odd} \end{cases} \tag{2}$$

Next, analytic signal $z[n]$ of the real discrete-time signal $g[n]$ is given by

$$z[n] = g[n] + j\hat{g}[n] = a[n] \cdot e^{j\phi[n]} \tag{3}$$

Equivalently, the imaginary part $\hat{g}[n]$ was the DHT of the real part $g[n]$. Finally, the phase function of analytic signal $z[n]$, expressed in polar form (Equation (3)), was the instantaneous phase of $g[n]$. The instantaneous phase $\phi[n]$ was ready to be computed as follows:

$$\phi[n] = \tan^{-1}\left(\frac{\hat{g}[n]}{g[n]}\right) \tag{4}$$

The instantaneous phase functions $\phi_{HR}[n]$ and $\phi_{RP}[n]$ were derived by applying Equations (1) through (4) to $c_1[n]$ and $RP[n]$, respectively. Next, the initial estimate of the CRPS was the difference between the two phase functions:

$$\varphi[n] = \phi_{RP}[n] - \phi_{HR}[n]. \tag{5}$$

Noise and other sources of interference in both the HR and RP sequences can lead to random-like "phase jumps" of $\pm 2\pi$ in $\phi_{HR}[n]$ and $\phi_{RP}[n]$. Consequently, phase difference $\varphi[n]$ cannot be constant even in the state of cardiorespiratory phase synchronization. This issue can be easily resolved by applying modulo-2π operation to $\varphi[n]$ in (5),

$$\psi[n] = \varphi[n] \bmod (2\pi) \tag{6}$$

Finally, an unbiased indicator to quantify the degree of phase synchronization (*dps*) between two systems can be designed as follows:

$$\gamma = \langle \cos\psi[n] \rangle^2 + \langle \sin\psi[n] \rangle^2 \quad 0 \le \gamma \le 1, \tag{7}$$

where brackets $\langle \ldots \rangle$ denote the average over a specified interval of N samples.[18,19] Figure 4 shows, from the top, the real part $g[n]$ and imaginary part $\hat{g}[n]$ of analytic signal $z[n]$, as derived from the HR sequence and respiratory signal, followed by instantaneous phases $\phi_{HR}[n]$, $\phi_{RP}[n]$, phase difference $\varphi[n]$, and γ of a *Cntl*-I participant. After $g[n]$ and $\hat{g}[n]$ were obtained using the DHT (Equation 3), phase functions $\phi_{HR}[n]$ and $\phi_{RP}[n]$ were computed as the arctangent of the ratio of $g[n]$ to $\hat{g}[n]$ (Eq. 4). The time evolution of γ exhibited a significant drop from the third to the ninth minutes in the course.

Theoretically, a large value of γ, particularly when approaching 1, strongly infers that $\psi[n]$ is constant, thus concluding that both time series are highly synchronized in a statistical manner.

Signal analysis: AFR HRV analysis

A recent study[12] reported on the limitations of conventional HRV analyses based on fixed LF and HF ranges. In an adaptive-frequency range HRV ($\mathrm{HRV}_{\mathrm{AFR}}$) scheme, the HF

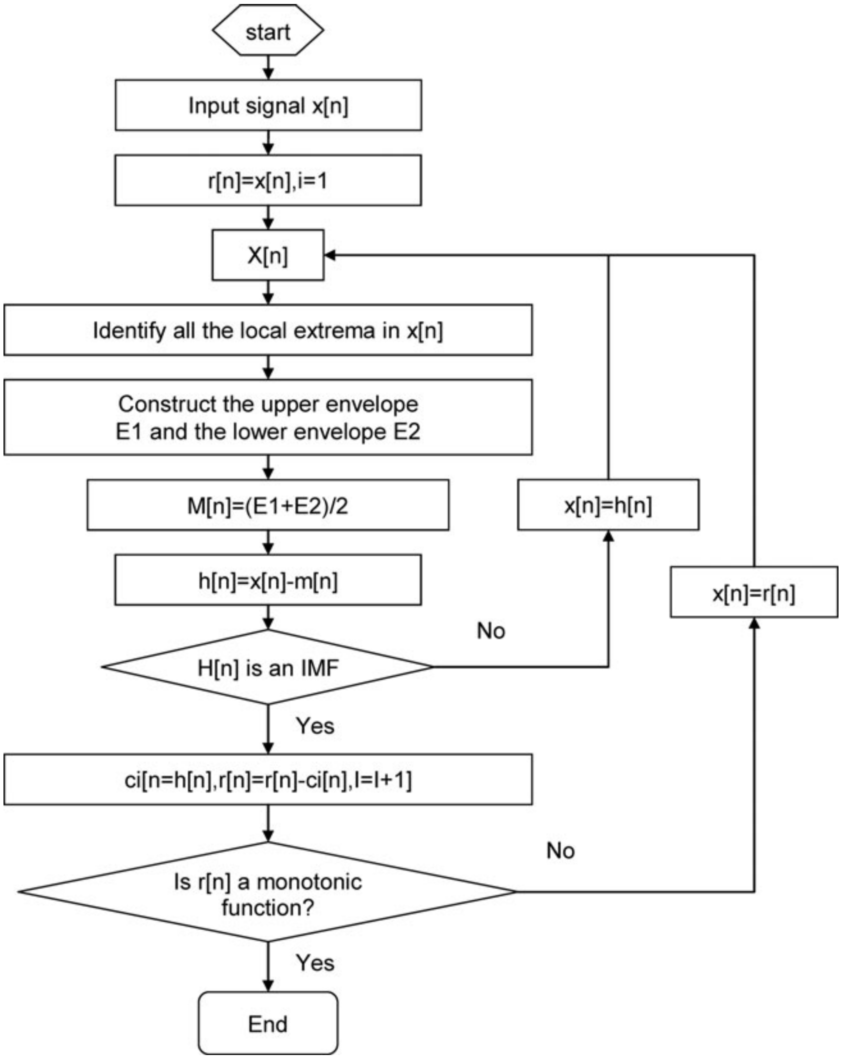

FIG. 3. Flow chart for empirical mode decomposition (EMD). The algorithm provides the logical scheme for obtaining all the intrinsic mode functions (IMFs).

range is selected according to the fundamental respiratory rate (RR_f), rather than using the conventional fixed frequency range. The RR_f is extracted from the highest peak in the time-frequency (TF) map of the CWT coefficients for respiratory signals. The HRV_{AFR} provides proper isolation of two frequency ranges and more accurate characterization of parasympathetic and sympathetic activities. An additional recent study[12] showed that the respiration peak can be used as an index of vagal activity and can isolate both branches of ANS.

An HRV_{AFR} scheme chiefly involves two steps: (1) Extracting RR_f from the CWT map of the respiratory signal, and (2) determining the HF range as 0.65 RR_f—1.35 RR_f Hz. The frequency interval between 0.65 and 1.35 RR_f Hz, denoted as HF_{AFR}, has been demonstrated as an empirically practical range for characterizing parasympathetic activity. The HF_{AFR} extends to the lower frequency interval of 0.1–0.15 Hz under a slow respiratory rate (*e.g.*, 9 breaths/min) during deep meditation. The LF range in HRV_{AFR} is, therefore, reduced to 0.04–0.1 Hz. The LF range determined using the HRV_{AFR} method was denoted as LF_{AFR}. Finally, the HRV was evaluated by the ratio LF_{AFR}/HF_{AFR}.

Results

This section presents the results of CRPS and HRV_{AFR} inspections of the three data sets (*i.e.*, Cntl-I, Cntl-II, and Expr) that were collected from the two groups. In CRPS analysis, after testing various implementation parameters to obtain a reliable estimate, we adopted a window size of 60 sec with a moving step of 5 sec.

In 2007, we began exploring the cardiorespiratory interactions of Chan meditation practitioners based on the synchrogram scheme,[20] which analyzed the phase synchronization of two interacting self-oscillatory systems, with n:m indicating the phase-locking ratio of the cardiac-to-respiratory cycles. In Cntl-I, the group-average n/m was 7.83, with individual ratios of 16:3, 5:1, 6:1, 23:1, 16:3, 19:3, 20:3, 13:2, 29:3, 9:2, 11:3, and 12:1. The group average of Cntl-II was 9.35, with individual ratios ranging from 14:3 to 24:1. In contrast, the group average of Expr was 4.88, calculated from individual ratios of 11:3, 6:1, 4:1, 7:1, 5:1, 17:3, 4:1, 11:2, 13:3, and 11:3. Phase locking can be completed within a smaller n/m ratio among advanced Chan practitioners. However, the

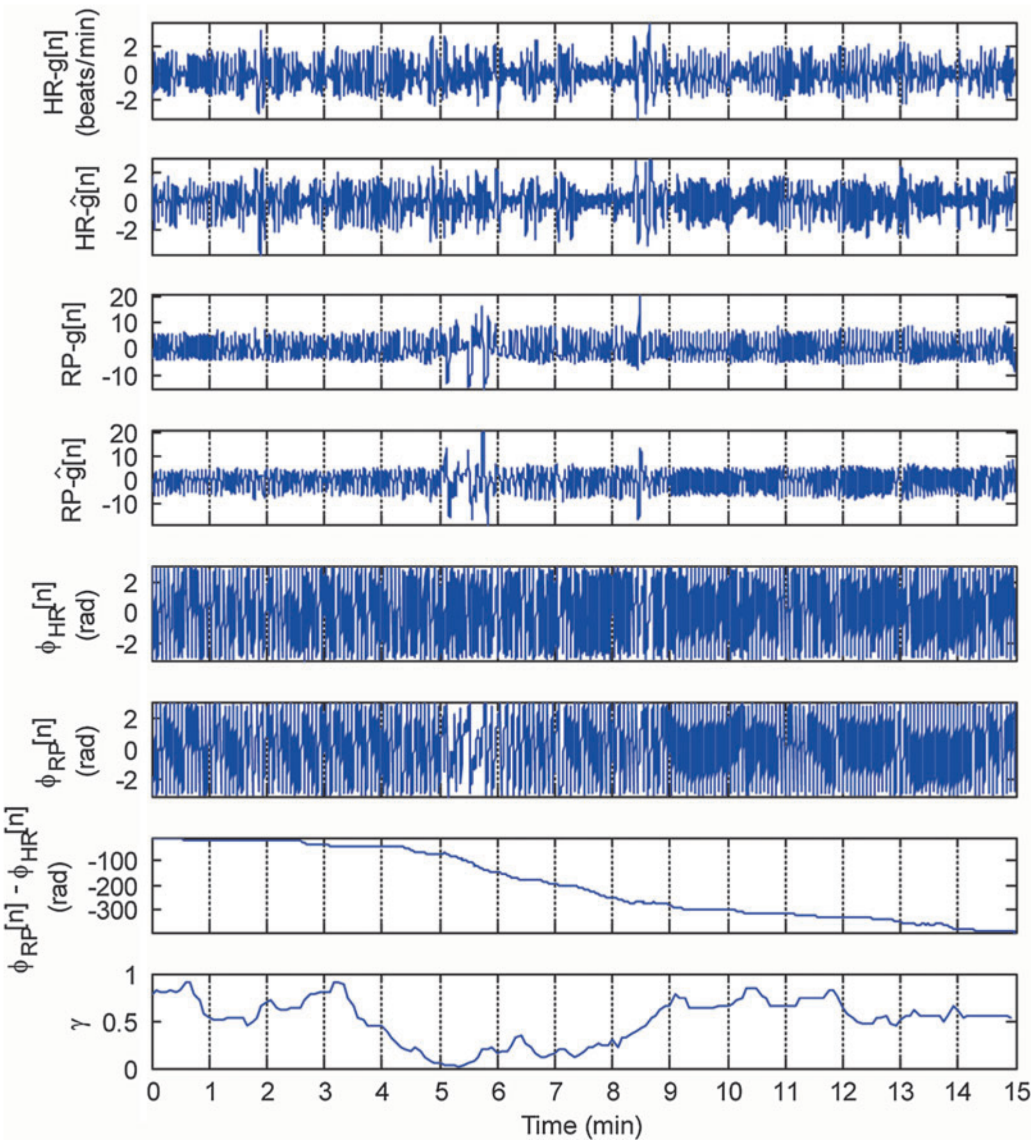

FIG. 4. Time evolution of (from top) the real part $g[n]$ and imaginary part $\hat{g}[n]$ of the analytic signal $z[n]$ derived from heart rate (HR) and respiratory sequence, followed by the instantaneous phases $\varphi_{HR}[n]$, $\varphi_{RP}[n]$, phase difference$\varphi[n]$, and γ of one Cntl-I subject. Color images available online at www.liebertpub.com/rej

synchrogram scheme is complex in its implementation. The *dps* γ presented in this study provided a simplified index for quantifying long-term CRPS.

Cardiorespiratory phase synchronization

First, *dps* γ was used in an alternative assessment of cardiorespiratory phase synchronization, including (1) a group average of γ, (2) RR-dependent γ, and (3) the effects of RR consistency on γ. The selection of these three parameters verified our initial hypothesis that was developed on the basis of the core scheme of Chan meditation practice for long-term mind–body rejuvenation. The quantitative methods employed in this study have been verified for obtaining reliable estimates with implementation parameters within a moderate range.

Group average of γ. For each group, the average and standard deviation (SD) of the γ values were calculated. The results were 0.45 ± 0.30 (Cntl-I), 0.34 ± 0.27 (Cntl-II), and 0.60 ± 0.23 (Expr), with p values in the Student t-test of 0.0929 (Cntl-I versus Cntl-II), 0.0185 (Cntl-I versus Expr), and 7.2×10^{-5} (Cntl-II versus Expr). The inter-group difference was statistically significant for the comparison between Expr and either Cntl-I or Cntl-II. Furthermore, experienced practitioners exhibited substantially higher γ values and smaller SD values than did the novices. Comparing Expr with Cntl-I, an increase of more than 30% indicated the profound and consistent effects of long-term Dharma-Chan meditation on enhancing cardiorespiratory synchronization. The intra-group comparison for the controls before and after the 8-week meditation courses (*i.e.*, Cntl-I and Cntl-II) unexpectedly exhibited a decline in cardiorespiratory synchronization, with the average γ decreasing from 0.45 to 0.36. On the basis of the post-experiment interview, the novices who were not used to abdominal breathing frequently experienced uneasiness in breathing during the meditation practice. We

Table 1. The Averages and Standard Deviations (average ± SD) of Respiratory and Cardiac Frequencies for All Subjects in Three Groups

Respiratory frequency Average ± SD (breaths/min)			*Cardiac frequency Average ± SD (beats/min)*		
Cntl-I	*Cntl-II*	*Expr*	*Cntl-I*	*Cntl-II*	*Expr*
10.76 ± 2.22	7.03 ± 1.27	15.13 ± 1.90	56.87 ± 1.36	74.41 ± 1.71	63.05 ± 1.07
11.83 ± 0.84	9.52 ± 1.07	11.66 ± 1.12	58.59 ± 1.69	68.12 ± 0.65	66.14 ± 1.01
14.34 ± 1.76	14.45 ± 1.41	17.23 ± 1.46	69.50 ± 0.82	78.47 ± 1.43	70.48 ± 1.33
4.01 ± 0.84	3.54 ± 0.73	9.75 ± 1.29	79.94 ± 1.59	80.17 ± 2.41	66.44 ± 1.21
14.76 ± 0.60	13.00 ± 0.56	16.80 ± 0.98	77.73 ± 1.17	92.67 ± 1.57	86.02 ± 1.62
10.17 ± 0.66	12.20 ± 0.77	19.67 ± 1.14	71.89 ± 0.73	78.23 ± 0.81	74.87 ± 1.59
8.31 ± 1.36	10.79 ± 2.13	17.46 ± 0.63	63.59 ± 1.19	74.78 ± 1.16	64.63 ± 3.86
12.19 ± 1.85	10.75 ± 1.65	15.67 ± 0.69	72.84 ± 0.61	66.80 ± 1.07	85.49 ± 1.67
7.79 ± 0.77	9.42 ± 0.65	18.79 ± 0.36	74.44 ± 1.56	84.15 ± 1.11	80.03 ± 1.11
13.23 ± 0.96	13.72 ± 0.84	18.61 ± 1.77	61.95 ± 1.58	67.39 ± 0.78	79.61 ± 0.57
22.89 ± 2.12	13.74 ± 2.97		88.81 ± 1.29	73.51 ± 0.89	
6.08 ± 1.31	5.52 ± 0.72		67.35 ± 1.18	76.79 ± 1.36	

called this transition period the abdominal-breathing adaptation (ABA) period. The ABA period can last for 1–3 months, within which new practitioners may exhibit ineffective cardiorespiratory functions when switching from chest-breathing habits to abdominal breathing.

One focus of this study was to differentiate natural rejuvenation following long-term Chan practice and the short-term efficacy of novice breathing manipulation. Table 1 lists the average ± SD values of the respiratory and cardiac frequencies for all participants in the three groups. The average respiratory rates were 11.36, 10.35, and 16.08 breaths/min, respectively, for Cntl-I, Cntl-II, and Expr, and the average cardiac rates were 70.29, 76.29, and 73.67 beats/min, respectively. The ratios of cardiac frequency to respiratory frequency were 6.19 (Cntl-I), 7.37 (Cntl-II), and 4.58 (Expr). The novice practitioners exhibited significantly higher ratios compared to experienced practitioners, correlating with the phenomenon observed in phase-locking ratio *n*:*m*.

RR-dependent γ. To investigate the effects of respiratory rate on cardiorespiratory interaction, we evaluated the *dps* γ for various RR ranges—slow, medium, and fast. For each participant in all three data sets (*i.e.*, Cntl-I, Cntl-II, and Expr), the results of the γ values were sorted according to ascending RR. Next, the entire RR range for each participant was divided into three sections (*i.e.*, slow, medium, and fast RR) of equal RR ranges. The resulting RR ranges differed for the carious participants. The group averages of the slow, medium, and fast RR ranges were: Cntl-I, 8.5–10.8, 10.8–11.8, 11.8–14.5 breaths/min; Cntl-II, 7.8–9.8, 9.8–10.7, 10.7–13.4 breaths/min; and Expr, 13.2–15.7, 15.7–16.5, 16.5–18.8 breaths/min. The average γ value was calculated for each RR range. The group averages of γ for the RR ranging from slow to fast rate were, respectively: Cntl-I, 0.363 ± 0.254, 0.451 ± 0.292, and 0.528 ± 0.271; Cntl-II, 0.288 ± 0.269, 0.338 ± 0.268, and 0.392 ± 0.265; and Expr, 0.563 ± 0.269, 0.606 ± 0.238, and 0.621 ± 0.198. The three groups consistently revealed a trend of increasing γ with the increasing of RR. However, a more stable and constant behavior in the cardiorespiratory interactions was observed in the Expr group (SD of three γ values less than 5.4% of the average of γ). In addition, 28 of the 38 participants exhibited a tendency of a higher γ at a faster RR during natural respiration. However, this positive correlation between the average γ and RR did not achieve statistical significance according to the Student *t*-test with the following *p* values: 0.4380 (Cntl-I, L-M), 0.5123 (Cntl-I, M-H), 0.6581 (Cntl-II, L-M), 0.6231 (Cntl-II, M-H), 0.7092 (Expr, L-M), and 0.8799 (Expr, M-H).

The three groups breathed naturally during the recording experiments. One significant phenomenon was the comparatively slow respiration observed in the control participants. According to the Cntl-I and Cntl-II records, the RR ranged from 8 to 13.5 breaths/min. However, the experienced Chan meditation practitioners breathed at higher rates during the recordings (13–19 breaths/min). These results show the poor CRPS behavior for Chan meditation novices, even during slow natural respiration. However, the experienced practitioners exhibited better performances in CRPS, although their RR values were considerably higher. This may indicate that long-term Chan meditation practice can initiate a metamorphosis process for Chan practitioners, rejuvenating their cardiorespiratory functions. Their CRPS showed healthy, stable, and consistent behavior.

Effect of RR-consistency on γ. To enter good-quality Chan meditation, novices are typically told to breathe at a nearly constant rate. Constant-rate respiration, instead of slow respiration, helps practitioners better convert a thinking state to a tranquil, and even detached, state. To investigate the effects of RR consistence on average γ, a lower-resolution RR sequence was first constructed by averaging the 5-sec RR samples without overlapping. The duration of the consistent RR (D_{cRR}) was the longest epoch containing RRs with deviations no more than ± 1 breath/min. Table 2 lists the group average ± the SDs of the γ values for $D_{cRR} \geq 2$ min and $D_{cRR} \geq 3$ min with the corresponding average respiratory rates. The experienced Chan practitioners could boost their CPRS performance (from 0.60 to 0.79, 31.67%), with steady respiration maintained for 3 min. In the same D_{cRR} (≥ 3 min) condition, the novice practitioners, prior to the Chan meditation lectures (Cntl-I), appeared to gain no benefit from breathing regulation. However, after 8 weeks of Chan meditation lectures (Cntl-II), the novice practitioners had

TABLE 2. THE GROUP AVERAGE AND SD OF γ VALUES FOR D_{cRR} $\geq$2 MIN AND D_{cRR} $\geq$3 MIN TOGETHER WITH THE CORRESPONDING AVERAGE RESPIRATORY RATES

	Cntl-I		*Cntl-II*		*Expr*	
	γ *(average ± SD)*	RR *average (breath/min)*	γ *(average ± SD)*	RR *average (breath/min)*	γ *(average ± SD)*	RR *average (breath/min)*
Average γ for the entire meditation	0.45 ± 0.30	11.36 ± 4.89	0.34 ± 0.27	10.31 ± 3.61	0.60 ± 0.23	16.08 ± 3.26
Average γ for $D_{cRR} \geq 2$ min	0.46 ± 0.30	10.11 ± 3.43	0.44 ± 0.29	10.33 ± 2.99	0.73 ± 0.23	17.47 ± 2.29
Average γ for $D_{cRR} \geq 3$ min	0.46 ± 0.30	10.19 ± 3.74	0.46 ± 0.28	10.22 ± 2.94	0.79 ± 0.23	17.83 ± 2.90

SD, Standard deviation; RR, respiratory rate.

substantially improved their cardiorespiratory interaction efficacies (from 0.34 to 0.46, 35%) using steady respiration with $D_{cRR} \geq 3$ min.

In the Expr group, the average RR for $D_{cRR} \geq 3$ min (approximately 17.8 breaths/min) exhibited an increment of 10% compared to the overall average RR (nearly 16.1 breaths/min). However, the average γ for $D_{cRR} \geq 3$ min increased by 32%. This phenomenon was even more apparent in Cntl-II, which revealed a 35% increase of the average γ for $D_{cRR} \geq 3$ min, whereas the average RR remained unchanged (10.3 and 10.2 breaths/min). Consequently, we can infer that the enhanced CPRS performance chiefly resulted from the longer duration of steady respiration, rather than a higher respiratory rate.

To investigate the tangible effects of D_{cRR}, we examined the distribution of D_{cRR} and found that, throughout the recording, the probabilities of $D_{cRR} > 3$ min were, respectively, 34.4% (Cntl-I), 29.3% (Cntl-II), and 26.7% (Expr). An intergroup comparison revealed that a larger percentage of $D_{cRR} > 3$ min (Cntl-I) did not result in better cardiorespiratory phase synchronization (larger γ). Conversely, experienced Chan meditation practitioners can maintain a steady, superior CRPS performance even with smaller percentages of $D_{cRR} > 3$ min. The high γ in the Expr group, despite being independent of RR value or D_{cRR}, clearly indicated the persistent effects of long-term Chan meditation.

HRV_{AFR}. HRV is one of the most critical schemes for studying cardiac autonomic functions. Among various HRV quantitative methods, the LF/HF ratio has been recognized as being able to reflect sympathovagal balances more reliably than other methods. The enhanced HRV_{AFR} scheme quantified using LF_{AFR}/HF_{AFR} provides a more reliable method to access the balancing behavior between sympathetic and parasympathetic functions. The group averages and SD of ratio LF_{AFR}/HF_{AFR} were 0.82 ± 0.61 (Cntl-I), 1.18 ± 1.04 (Cntl-II), and 2.4 ± 1.33 (Expr). The results of the three groups were within the normal range of 0.5–2.5.

Before beginning the Chan meditation practice, the novice practitioners appeared to have parasympathetic functions that dominated during meditation. The experienced Chan meditation practitioners exhibited elevated sympathetic activity during meditation that exceeded our expectations. However, these were within the normal HRV range. Based on the post-experiment interviews, experienced practitioners, after becoming true Chan disciples, enter "heart-to-heart sealing" resonance with a Chan master to begin the journey of enlightenment toward unification with the true self (*i.e.*,

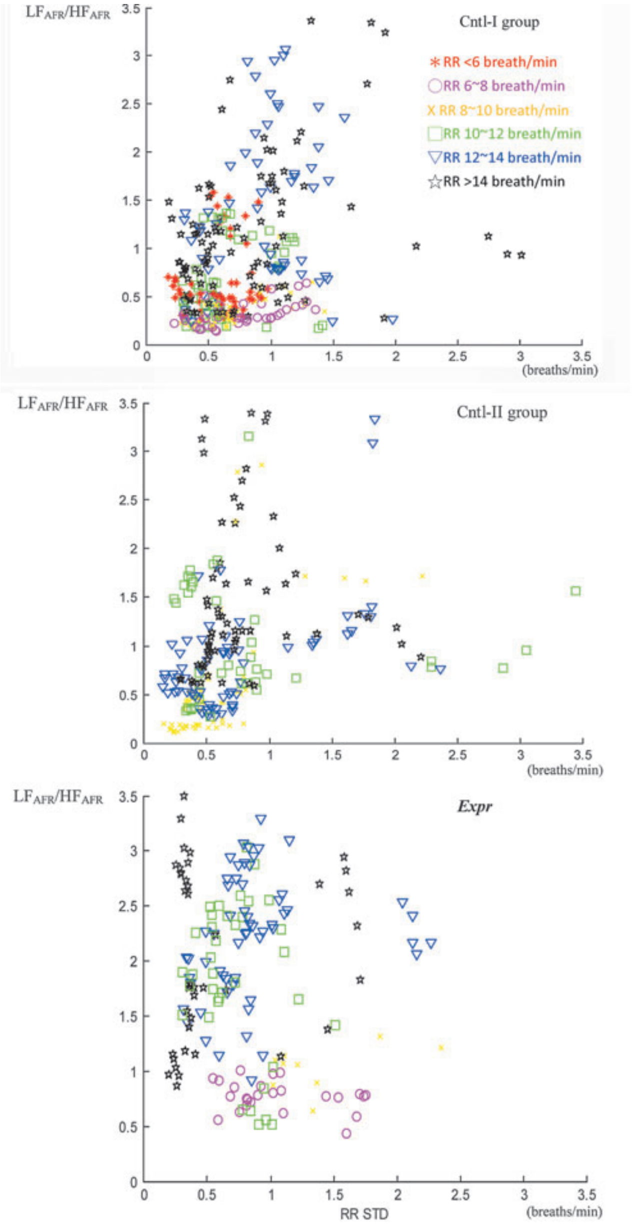

FIG. 5. LF_{AFR}/HF_{AFR} for various respiratory rate (RR) ranges (from top: Cntl-I, Cntl-II, and Expr).LF, Low frequency; HF, high frequency.

from heart–mind purification to the disclosure of true self) using the receipt of master's heart imprint. Perception of energy flux and revitalization is frequently experienced in the Heart Chakra. This phenomenon among experienced disciples may be linked to our observations of higher LF_{AFR}/HF_{AFR} during quiet Chan meditation.

Figure 5 demonstrates the dependence of LF_{AFR}/HF_{AFR} on the RR range and SD values for Cntl-I, Cntl-II, and Expr (from the top). The horizontal axis indicates the SD of RR values in the corresponding RR range. We summarize the concluding remarks drawn from the results as follows:

1. In Cntl-I, the LF_{AFR}/HF_{AFR} ratio concentrates on smaller range (<1.5) when $RR<12$ breaths/min.
2. LF_{AFR}/HF_{AFR} of Cntl-I and Cntl-II was mostly distributed between 0 and 2, whereas LF_{AFR}/HF_{AFR} of Expr was in the range between 0.5 and 3.
3. In Expr, a larger extent of LF_{AFR}/HF_{AFR} was observed for nearly all of the RR ranges, except for 6 breaths/min $<RR<8$ breaths/min.
4. The RR SD did not correlate with RR range.
5. The RR SD values for the three groups were nearly the same (1.5).

Conclusion and Discussion

Recent studies have proposed improved methods that are feasible for evaluating cardiorespiratory efficacy.[21–23] This study investigated inter-group differences between novice and advanced Chan meditation practitioners. In conclusion, we presented the results of our study on cardiorespiratory function with particular focus on the distinction between novice practitioners and experienced disciples practicing Dharma-Chan meditation. Based on the results of the three groups, Cntl-I (*i.e.*, novice practitioners with one to two meditation sessions), Cntl-II (*i.e.*, novice practitioners after 8 weeks of formal Chan meditation lectures and practice), and Expr (*i.e.*, experienced practitioners), we showed that long-term Dharma-Chan meditation can significantly improve the cardiorespiratory synchronization, particularly regarding more stabilized and constant behaviors that are insensitive to the changes and steadiness of respiratory rates. Experienced practitioners can maintain superior CRPS, even during fast respiration. This reformation of the cardiorespiratory mechanism may reveal the so-called metamorphosis process experienced by long-term practitioners. Conversely, we observed the appearance of a transient ABA period of 1–3 months that caused the novice practitioners to have slightly downgraded cardiorespiratory efficiencies.

In the HRV study, the extraordinary results of the higher LF_{AFR}/HF_{AFR} ratio in the Expr participants may indicate the state of initiating heart-to-heart sealing resonance with the Chan master when an experienced practitioner becomes a true disciple. However, this study is at a preliminary stage because, in the complex human life system, the decision of whether quantified results support a hypothesis usually cannot be made just using simple methods of data evaluation and presentation.[24] Experiments are being conducted to collect data from more Chan meditation practitioners with various experience levels. Novel methodologies are being developed to investigate cardiorespiratory synchronization based on chaotic-oscillating models.

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Author Disclosure Statement

No competing financial interests exist.

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