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Comparison of Respiratory Sinus Arrhythmia between Zen-meditation and Control Groups

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Abstract

Background: This research aims to develop new methods to investigate the cardiorespiratory interaction of Zen-meditation practitioners (Zen-meditation group) and healthy ordinary young people (control group) by quantitatively evaluating respiratory sinus arrhythmia (RSA) behavior.

Methods: Twenty-five voluntary controls and seven Zen-meditation practitioners were recruited. The experimental protocol involved five sessions of different mental-stress levels (control group) and five sessions of Zen-meditation practice (experimental group). Forty minute ECG and respiratory signals were recorded for each control subject; thirty for each experimental subject. By detecting R peaks, heart-rate sequence is constructed. Two methods are proposed to evaluate RSA behavior based on cycle-to-cycle synchronization between heart-rate and respiratory sequence.

Results: Based on the proposed method of computing for a RSA coefficient, the control group average for each session was 0.70 (Rest I), 0.65 (continuous attention task, CAT I), 0.75 (BC), 0.63 (CAT II) and 0.70 (Rest II); whereas the Zen-meditation group average was 0.81 (S1), 0.84 (S2), 0.84 (S3), 0.86 (S4) and 0.81 (S5), all superior to the control group. The average RSA normal rate in the Zen-meditation group (91.03%) remarkably surpassed the control group (80.48%) in the Rest sessions.

Conclusions: Using the time-domain HRV (heart-rate variability) as a reference, our methods, RSA coefficient and RSA normal rate, provide more reliable and direct estimate of RSA behavior than the conventional peak-valley method computing the inspiratory–expiratory difference in R-to-R interval of ECG. Moreover, results of the proposed methods confined in a specified range (RSA coefficient between 0 and 1, RSA normal rate between 0% and 100%) facilitate the interpretation of the quantitative RSA behavior. In the RSA analysis, breathing control sessions using anthropic interventions induced more prominent RSA activity in the control group. Nevertheless, HHIS Zen meditation, with excellent qi circulation activated by the ten-mailuns system, naturally (in the way of do-nothing) elicits superior RSA performance, better than sophisticated breathing control.

Keywords
Cardiorespiratory interaction; Zen meditation; RSA (respiratory sinus arrhythmia); HRV (heart-rate variability); RRI (R-to-R interval); SDNN (standard deviation of normal RRI's)

1. Introduction

The interaction between human cardiac and respiratory systems has been widely studied for many decades [1-9]. These two systems have been found to be two individual oscillators coupled by particular mechanisms. One well-known phenomenon, respiratory sinus arrhythmia (RSA), demonstrates such cardiorespiratory interactions. RSA characterizes the phenomenon of heart rate modulated by the breathing pattern or, more precisely, the increased (decreased) heart rate during inhalation (exhalation). Prominent RSA indicates better efficiency of pulmonary air exchange. RSA is pronounced in children but gradually decreases with age. Nonetheless, enhanced RSA expression was reported in such groups like athletes [10] and Yoga practitioners [11]. RSA also reflects the parasympathetic modulation of the heart, often observed in meditation practitioners, that associates the complex nervous regulation with emotional and cognitive processing [12].

Meditation nowadays is widely acknowledged as one important technique in the field of either mind-body intervention or energy medicine after having been proved to benefit human health and wellness in various aspects according to extensive, profound research compiled since the 1960s [2, 13-18]. Meditation is described as a wakeful hypo-metabolic state of parasympathetic dominance that is corroborated by such physiological indicators as the reduction of heart rate, blood pressure, and respiratory rate, significant increase in plasma melatonin levels, and better regulation of cortisol level [18]. Among various meditation techniques, Heart-to-Heart Imprint Sealing (HHIS) Zen meditation originating from orthodox Zen lineage reveals an extraordinarily unique way of practice emphasizing the disclosure of true-self wisdom [13, 19, 20]. Targeting the liberation of the true self (also called true heart or true nature) inside the heart organ , HHIS Zen-meditation practitioners have been experiencing various evolutionary states of heart perception and respiratory reformation, for example, pre-born, fetal breathing by concentrating on the MingSe mailun inside the navel (illustrated in Figure 1). More than mere brain-neuroplasticity, HHIS Zen meditation completely changes the normal brain traits [13, 19, 21] and regenerates a new brain with superior self-healing capabilities for various physical, psychological and mental ailments. Besides the upgraded brain function, remarkable change in cardiorespiratory interactions is often experienced by Zen-meditation practitioners through years of practice [2]. According to our post-experimental interview with the advanced practitioners, activation of the inner energy of *Mailun* in the course of Zen-detachment practice often induces noticeable physiological-mental reformation, including an efficient mechanism of regulating cardiorespiratory interaction in order to alternate the dominant role between brain and heart. Accordingly, the reformation of brain functioning and cardiorespiratory interactions is crucial in Zen-meditation practice.

According to the principal practice scheme, HHIS Zen meditation is exclusively heart dominant. By activating the ten-*Mailun* system (Figure 1) in HHIS Zen meditation, practitioners disclose the unique brain functioning scheme, documented in Diamond Sutra, for transcending the physical and conscious states and entering the spiritual world through the heart [21]. Cardiorespiratory interaction (CRI) plays an important role in the course of transcendence. This study developed some innovative schemes to RSA behavior that provides a widely accepted indicator for characterizing the CRI.

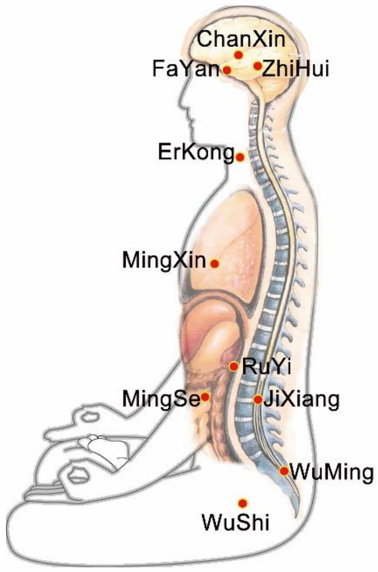


Figure 1 Ten-mailuns system (side view).

RSA has been widely used as an index to signify the phenomenon of heart rate variation in accordance with respiration activity, primarily maneuvered by the vagus nerve in the way that inspiration (expiration) inhibits (stimulates) vagus-nerve activity and accordingly increases (decreases) the heart rate. In recent years, this theory was further expanded to encompass a wide range of hypotheses regarding physical, psychophysiological, and even social functioning in humans.

Different methods for evaluating RSA have been proposed [22], with the major distinctions on the assumption regarding the operational definition of RSA and the dependence of RSA on respiration. As a consequence, unit of measurements differ according to different physical meanings. In a time-domain analysis, RSA is typically estimated in the scale of milliseconds (msec). Time-domain methods provide a straightforward, physiologically correlated mechanism for evaluating RSA. The relationship between the amplitude of heart rate fluctuations and the respiratory cycle is often used to assess RSA behavior. For instance, the peak-valley method computes the inspiratory–expiratory difference in RRI (R-to-R interval of ECG); that is, the difference of RRI between the fastest heart rate during inspiration and the slowest heart rate during expiration [23, 24]. The peak-valley method indirectly evaluates the RSA although it is simple. We propose two innovative methods for directly quantifying RSA based on the heart rate and respiratory rhythms.

2. Methods

To evaluate the RSA of Zen-meditation practitioners and ordinary controls, we propose two new schemes based on the relation between waveform patterns of respiratory signals and heart-rate sequences derived from ECG.

2.1 Voluntary Subjects and Experimental Protocols

Two groups were investigated and compared in this study. The experimental group involved 7 HHIS Zen-meditation practitioners with the average Zen-meditation experience of 19 years, in the age range of 51 – 62 years. The control group included 25 ordinary volunteers without any Zen-meditation experience, in the age range of 20 – 24 years. Cardiorespiratory functioning rapidly decays with age. The purpose of recruiting the control volunteers in a younger age range was to corroborate the slow-down of the cardiorespiratory aging process of the Zen-meditation practitioners. The control group played the role of acting as the younger and healthier reference, instead of the pair-wise comparing group.

Zen-meditation practitioners simply practiced HHIS Zen meditation during the 30-minute recording of which the record was equally divided into five sessions. Data analysis was conducted for five six-minute segments, labeled by to S5. Control subjects underwent five sessions: (Rest I) 8-minute eye-closed rest; (CAT I) first 8-minute CAT (continuous attention task); (BC) 8-minute guided breathing at 8 breaths/min; (CAT II) second 8-minute CAT; and (Rest II) 6-minute eye-closed rest. The five-session protocol was designed to investigate the effect of breathing regulation (in the BC session) on manipulating the weakened cardiorespiratory interactions caused by heavy mental loads in the CAT sessions, since breathing regulation is an important practice for Zen-meditation novices. In the inter-group comparison, only the results of control resting and Zen-meditation states were compared.

The CAT test assesses the ability to maintain an alert state within an interval of 8 minutes [25]. In the test, different checkerboard patterns formed by shuffling four black and five white squares are flashed onto the computer screen, randomly at one of six blocks, at an interval of 2 seconds (Figure 2). The voluntary subject is requested to respond by pressing a button whenever two consecutive patterns are the same. A total of 240 patterns are presented with 40 repetitions.

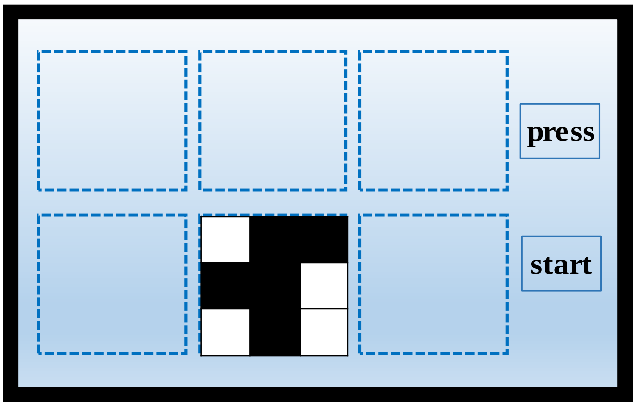


Figure 2 Screen display setting in CAT test. Each pattern flashes onto one of six blocks. The subject responds by pressing the button 'press' whenever two consecutive patterns are the same.

The number of correct responses (*C*) and incorrect responses (*I*) are recorded. The performance reflecting *state of alertness* is evaluated by the error index (*E*) below.

$$E = \frac{40 - C}{40} + \frac{2I}{200} \quad (1)$$

2.2 ECG and Respiratory Signal Acquisition

In addition to the economics and easy implementation, recording of ECG and respiratory signals provides access to multi-facet indicators of cardiorespiratory interactions. This study employed the NeXus-10 ii recording system (TMS International BV) to collect ECG and respiratory signals. ECG and respiratory signals were recorded simultaneously at the sampling rate of256 Hz and 32 Hz, respectively. To avoid the interference caused by muscular artifacts (electromyogram, or EMG), bipolar limb-lead II configuration was modified so that ECG electrodes were not placed on the limbs as usually employed. Reference electrode was placed on the left mid-clavicular line, lead + was placed at the end of the rib cage and aligned with the reference electrode, and lead – was placed on the right mid-clavicular line. Such ECG electrode configuration is called the *ECG lead II chest placement*.

The activities of respiration accompanying the chest/abdominal movement were recorded using a piezo-electric transducer (NX-RSP1A, TMS International BV) wrapped around the chest (control group) or around the belly passing the navel (Zen-meditation practitioners). The electrical conductivity of the transducer varies linearly with the chest/abdominal circumference associated with respiration that generates the up-and-down waveform pattern during inspiration and expiration.

2.3 RSA Analysis

The conventional method (RSA parameters) and the new methods (RSA coefficient and RSA normal rate) proposed in this study. We developed all of the algorithms and computer programs at our research laboratory, the Biomedical Engineering Research Laboratory of National Chiao Tung University. Results of RSA analysis are compared between HHIS Zen meditation practitioners and ordinary controls.

2.3.1 RSA Parameters

Based on the heart rate acceleration during inspiration and deceleration during expiration, the conventional method quantifies RSA by

$$\text{RSA parameter} = \max\{\text{RRI}_{ex}\} - \min\{\text{RRI}_{in}\}, \quad (2)$$

where RRI_{ex} (RRI_{in}) is the R-to-R interval during expiration (inspiration).

2.3.2 RSA Coefficient

The RSA coefficient evaluates the cross correlation between the amplitude of R-to-R interval (RRI) and the respiratory patterns within each respiratory cycle. Figure 3 illustrates the flow chart of evaluating the RSA coefficient. The cross correlation is computed by the inner product of the i^{th} respiratory cycle defined by ($t_{v,i-1}$ $t_{p,i}$ $t_{v,i}$) and the RRI waveform within the same duration. The three time indexes represent the ending time of previous expiration ($t_{v,i-1}$), current inspiration ($t_{p,i}$), and current expiration ($t_{v,i}$). A high RSA coefficient represents noticeable RSA behavior that, accordingly, reflects efficient cardiopulmonary functioning and better cardiorespiratory interactions.

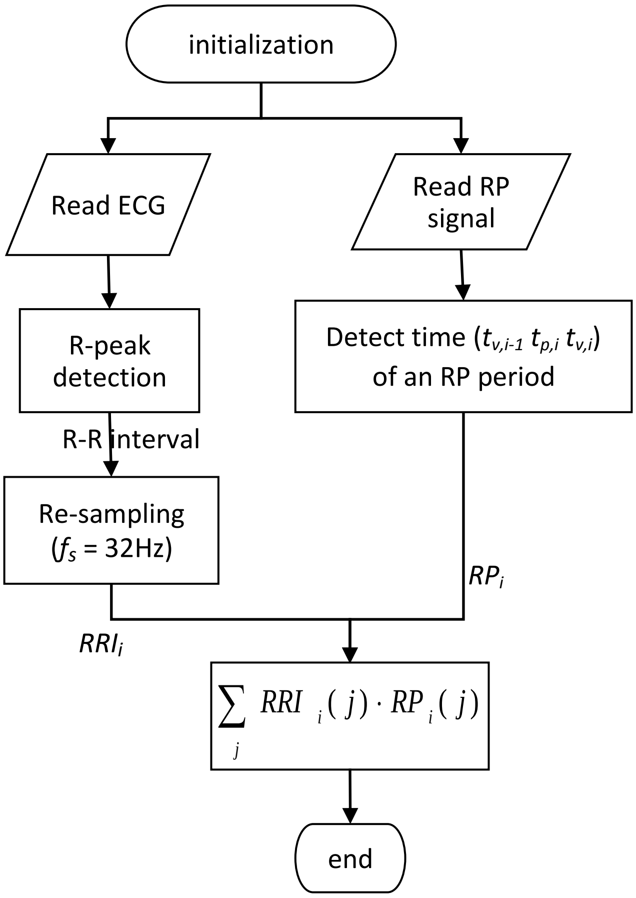


Figure 3 Flow chart of evaluating the RSA coefficient.

In the algorithm, RRI_i and RP_i indicate the *i*th cycle of RRI and RP (respiration) sequences, respectively.

2.3.3 RSA Normal Rate

The RSA normal rate evaluates the percentage of HR-RP synchronized cycles (N_n) as below,

$$RSA\% = \frac{N_n}{N_n + N_{ab}} \times 100\% \tag{3}$$

where N_n is the number of HR-RP synchronized cycles and N_{ab} is the number of HR-RP unsynchronized cycles. The flow chart of computing RSA normal rate is shown in Figure 4. The HR-RP synchronized cycle is determined by the non-negative cross correlation coefficients in the inspiration (ς_{in}) and expiration (ς_{ex}) period, as illustrated in Figure 4.

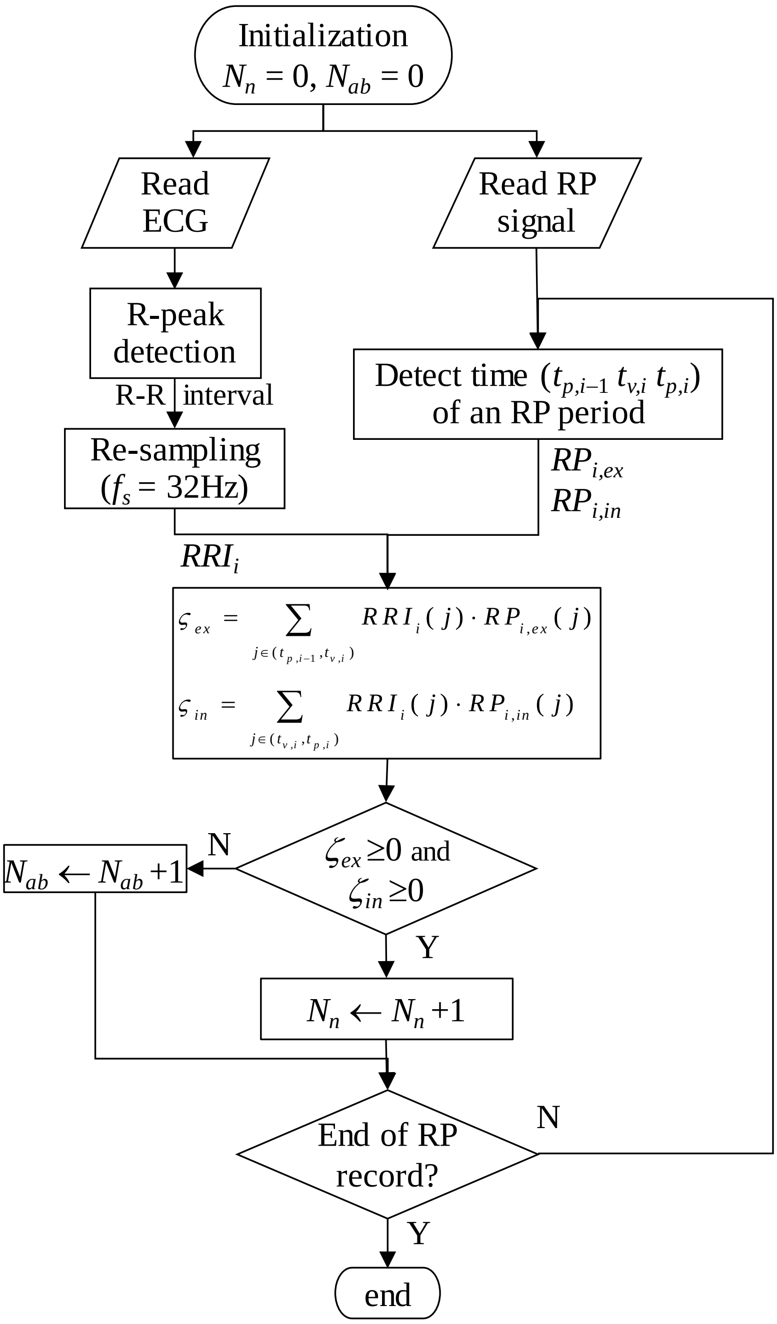


Figure 4 Flow chart of evaluating RSA normal rate.

3. Results

The twenty-five voluntary controls are labeled as a01 – a25, and the seven Zen-meditation practitioners are labeled as b01 - b07. For background references, Table 1 lists the group average for heart rate, respiratory rate and SDNN (standard deviation of normal RRI's) at different sessions. SDNN is the time-domain estimation of the heart rate variability (HRV). The normal-to-normal (NN) R-peak intervals are represented by RRI_i, i = 1, …, N. SDNN is computed below.

$$SDNN = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(RRI_i - \overline{RRI})^2} \quad (4)$$

Table 1 Average heart rates, respiratory rates and SDNN for each group at different sessions.

	Control					**Zen meditation**				
	Rest I	**CAT I**	**BC**	**CAT II**	**Rest II**	**S 1**	**S 2**	**S 3**	**S 4**	**S 5**
HR Beats/min	70.9	72.5	72.5	73.5	72.2	73.9	71.7	71.3	69.7	70.4
RR* Breaths/min	14.8	17.5	8.5	17.6	15.2	10.3	12.1	12.8	13.4	13.0
SDNN msec	59.3	57.4	76.9	59.0	72.0	40.0	40.4	38.2	49.1	37.6

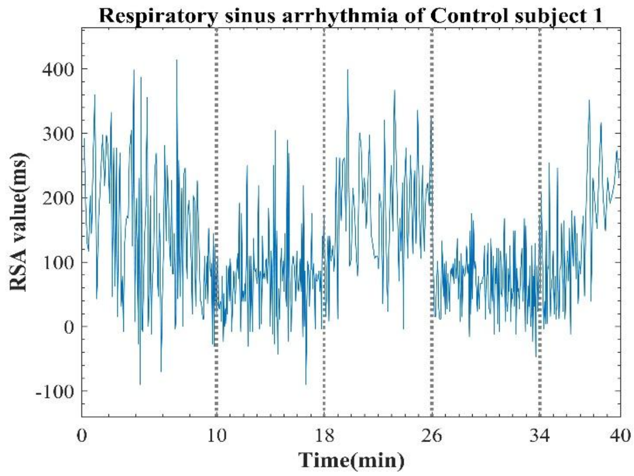
*: Respiratory rate.

Zen-meditation respiration is remarkably slower than resting respiration of the control group. Lower SDNN was anticipated for the elder Zen-meditation group. SDNN characterizes the strength of autonomic nerve activity. Higher SDNN indicates higher sympathetic activities. The average SDNN of the Zen-meditation group (41.6 msec) is lower than that of the control group at rest (65.65 msec). Apparently, the Zen-meditation process induces more parasympathetic tones than sympathetic tones. The remarkably low SDNN were often observed in HHIS Zen practitioners at deep meditation with rather low metabolic rates.

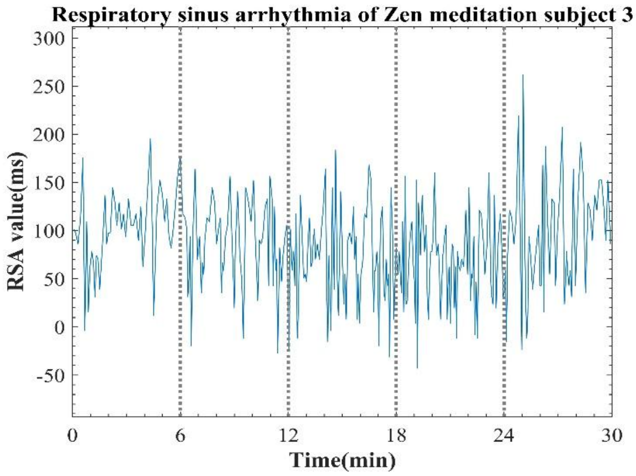
The results of quantifying RSA behaviors by RSA parameters, RSA coefficients and RSA normal rate are summarized in the following sections, accompanied with a systematic comparison between the control and experimental groups.

3.1 RSA Parameter

Figure 5(a) displays the time-varying RSA parameter evaluated for every respiratory cycle. As anticipated, empirical results often fluctuate vigorously, particularly in the high-resolution illustration based on the scale of respiratory cycle. Nevertheless, such fluctuation displays periods of apparent trends. RSA oscillates at a lower level of 74.31 msec and 68.95 msec, respectively, in the CAT I (10 – 18 minute) and CAT II (26 – 34 minute) sessions; whereas RSA oscillates at a higher platform (169.76 msec) in the BC (18 – 26 minute) session. The RSA parameter at rest surges up or down with the sessional average of 134.10 msec (Rest I) and 123.72 msec (Rest II).



(a)



(b)

Figure 5 Running measurement of RSA parameter for (a) control subject, and (b) Zen-meditation subject.

In Figure 5(b), Zen-meditation RSA constantly fluctuates at a platform throughout the entire five HHIS-meditation sessions. On the other hand, resting RSA fluctuates about the baseline drifting up and down, instead of a constant baseline. Average RSA parameter of each Zen-meditation participant (b01: 64.10 msec, b02: 45.58 msec, b03: 82.67 msec, b04: 17.95 msec, b05: 98.78 msec, b06:73.95 msec, b07: 54.83 msec) deviates quite a lot among individuals. The group average (62.55 $\pm$ 26.42 msec) is slightly lower than that of the resting RSA parameter of the control group (Rest I: 71.98 $\pm$ 37.41 msec, Rest II: 78.79 $\pm$ 34.89 msec). In consideration of the large age difference between the two groups, the Zen-meditation group exhibits distinctively sound RSA behavior.

Figure 6 illustrates the sessional averages of RSA parameter (in msec) for each individual control subject. The group average for each session is 71.98 msec (Rest I), 57.43 msec (CAT I), 140.51 msec (BC), 58.42 msec (CAT II) and 78.79 msec (Rest II). RSA remarkably boosts up in the BC session and quickly descends in the CAT sessions. RSA parameter increases in all 25 control participants in transition from CAT I to BC and decreases in all controls in transition from BC to CAT II.

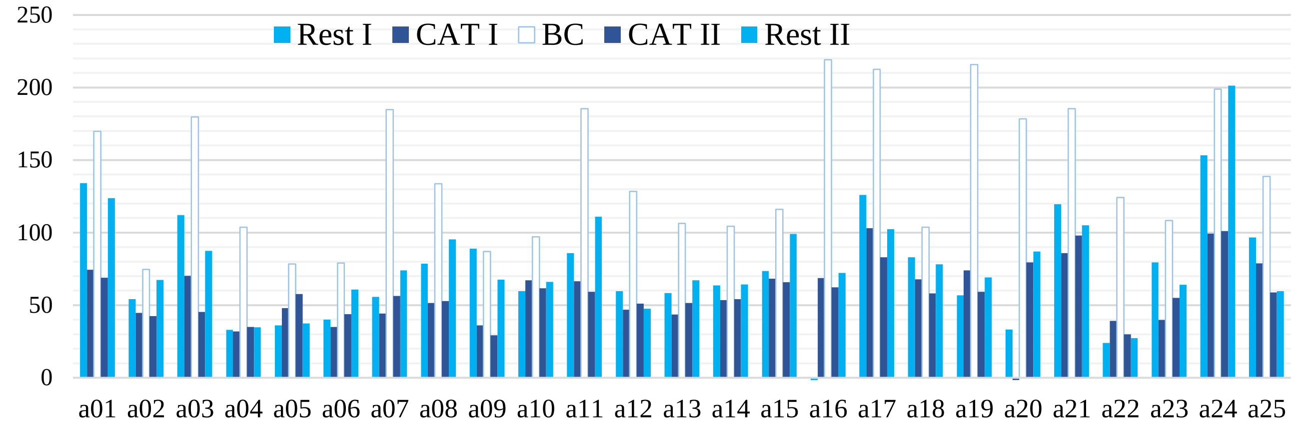


Figure 6 Sessional averages of RSA parameter (in msec) for each participant.

3.2 RSA Coefficient

The RSA coefficient proposed in this paper measures the cycle-to-cycle synchronization between HR and RP sequences. Accordingly, the RSA coefficient rather directly reflects the RSA behavior. On the other hand, RSA parameter cannot access such cyclic correlation based on the evaluation of the difference of R-to-R intervals between the longest and shortest heartbeat. Figure 7 illustrates the sessional average RSA coefficient for each control subject. The group average for each session is 0.70 (Rest I), 0.65 (CAT I), 0.75 (BC), 0.63 (CAT II) and 0.70 (Rest II). Five horizontal lines in Figure 7 show the average RSA coefficient for the Zen-meditation group in each session (S1: 0.81, S2: 0.84, S3: 0.84, S4: 0.86, S5: 0.81). The results of RSA coefficient demonstrate the superior RSA performance of Zen-meditation practitioners in comparison with the young, healthy non-practitioners.

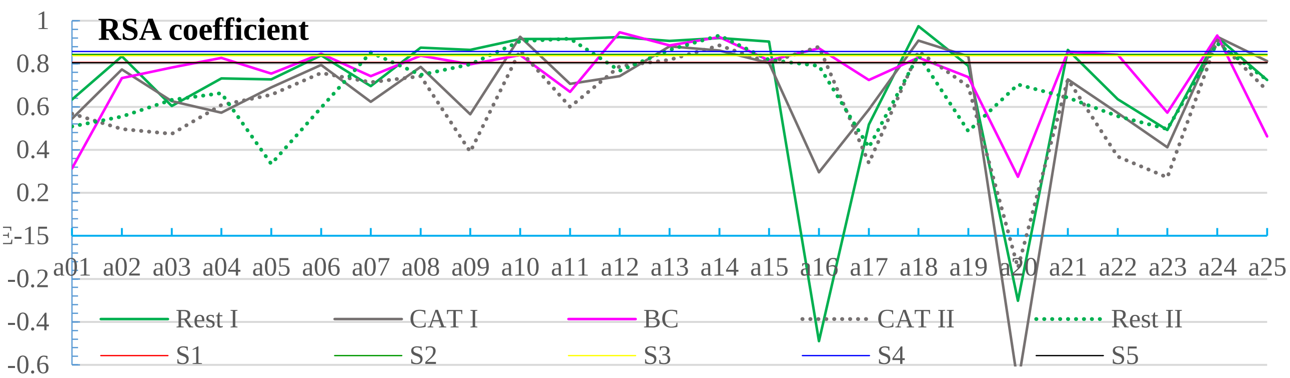


Figure 7 Sessional average of RSA coefficient for each control subject (Rest I, CAT I, BC, CAT II and Rest II) and sessional averages of RSA coefficient for the entire Zen-meditation group (S1 – S5).

3.3 RSA Normal Rate

For each respiratory cycle, the correlation coefficient is used to evaluate the degree of synchronization between RP and HR waveform. Figure 8 illustrates the sessional average RSA coefficient for each control subject. Figures 7 and 8 reflect the close coincident relation between RSA coefficients and RSA normal rate proposed in this paper.

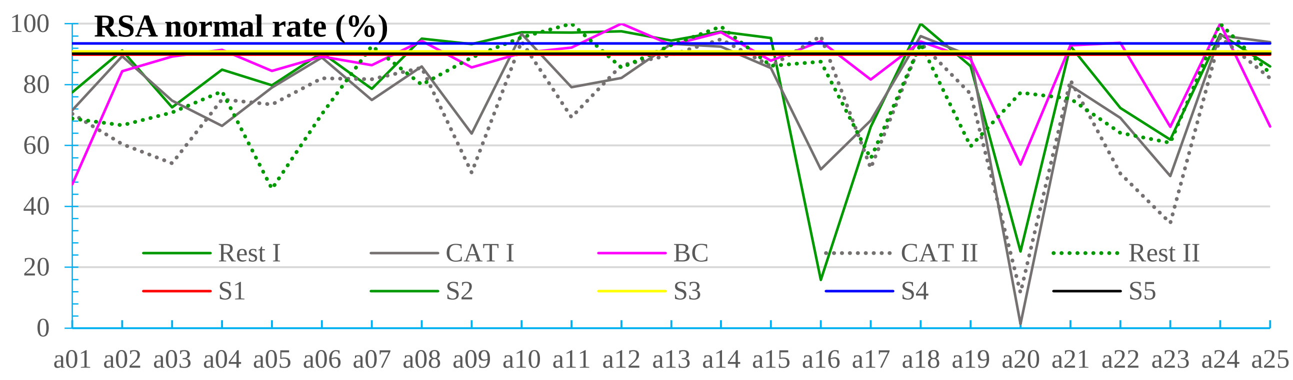


Figure 8 Sessional average of RSA normal rate (%) for each control subject in Rest I, CAT I, BC, CAT II and Rest II session and which for the entire Zen-meditation group in S1 – S5 session.

The control-group average for each session is 81.81% (Rest I), 76.82% (CAT I), 85.78% (BC), 73.21% (CAT II) and 79.16% (Rest II). Five horizontal lines in Figure 8 show the average RSA normal rate for the Zen-meditation group in each session (S1: 89.91%, S2: 90.55%, S3: 90.95%, S4: 93.53%, S5: 90.19%). Apparently, average RSA normal rate in Zen-meditation group (91.03%) remarkably surpasses that of the control group (80.48%) in the Rest sessions.

4. Discussion

Practitioners of HHIS Zen meditation enable the optimal regulation of all the organ systems into a perfect harmonic state. Abdominal respiration is the fundamental practice for novice practitioners to regulate heart rate rhythms and accordingly, the autonomic nervous system that further harmonizes the qi resonance in the meridian channels. Qi is the vital force or life energy circulating in the meridian network through the human body. Qi energy may be effectively enhanced by some particular style of respiration, bodily movement or deliberate guidance. Qi energy is suppressed by heavy mental activity. In different mental-stress states, breathing regulation at 8 breaths per minute (BC session) evidently enables the efficient boost-up of RSA behavior. In contrast, CAT requiring high mental alertness quickly disrupts the synchronization between respiratory rhythm and the heart-rate variation. The Zen-meditation group exhibited outstanding RSA behavior, even better than the control group undergoing BC intervention. Only 7 experimental volunteers were investigated because of the difficulty of recruiting the advanced HHIS Zen practitioners. Based on the unpaired student's t test, the results reveal a statistically significant difference between Zen meditation and control groups (rest session) with p values of 0.0343 (RSA parameter) and 0.0011 (RSA coefficient).

"The doorway to true nature is in the heart, and the key to the door is the spiritual entity," instructed current Zen patriarch Wu Jue Miao Tian. The major differences between HHIS Zen meditation and most meditation techniques is reflected in the scheme of "without-mind versus with-mind" and "heart-dominant versus heart-irrelevant." The essential mechanism of exchanging the dominant role between brain and heart is based on the strengthened cardiorespiratory interaction through abdominal respiration and ten-mailuns activation. As illustrated in Figure 1, the ten mailuns which correspond to the ten spiritual realms are the doorways (passages) that connect the physical life to the spiritual entity and finally to the true nature of reality. Human knowledge is still very limited to the materialistic understanding of brain and heart particularly in the scope of anatomy and physiology. Practitioners hence practice ten-mailuns HHIS Zen meditation to reform the brain and revitalize the physical body. The so-called "heart-driven" brain refers to the fact that advanced HHIS Zen practitioners can perceive and interpret the wisdom emerging from the true heart inside the organ heart. As a consequence, RSA properties may provide scientific clues for understanding the transition of cardiorespiratory functioning from an ordinary to a heart-dominant state.

5. Conclusions

This paper presents new methods for quantitatively evaluating RSA behavior of HHIS (heart-to-heart imprint sealing) Zen-meditation practitioners and ordinary, healthy volunteers at various mental-stress levels. The methods mainly quantify the cycle-to-cycle synchronous quality, for each respiratory cycle, between the respiratory pattern and heart-rate rhythm. In order to compare the performance between the conventional method and our methods for evaluating RSA, the widely used SDNN is adopted as a reference. The group sessional average of each parameter is considered as a five-dimensional feature vector to compute the phase difference between each RSA feature vector and SDNN. Let the feature vector of RSA and SDNN be denoted by $\vec{r} = (r_1, r_2, r_3, r_4, r_5)$ and $\vec{s} = (s_1, s_2, s_3, s_4, s_5)$ respectively, with the r_i (s_i) corresponding to the group average of the RSA (SDNN) feature in the i^{th} session. The feature phase difference, $\Delta\theta_f$, between RSA and SDNN feature vector is computed by

$$\Delta\theta_f = \cos^{-1}\left(\frac{\vec{\boldsymbol{r}} \circ \vec{\boldsymbol{s}}}{\|\vec{\boldsymbol{r}}\| \cdot \|\vec{\boldsymbol{s}}\|}\right) \tag{5}$$

The argument inside the inverse cosine function in equation 5 evaluates the inner product of two feature vectors divided by the product of two vector lengths.

Table 2 lists the feature vectors and feature phase difference (in degree). The rightmost column contains the feature phase differences between the SDNN vector and the RSA vector in the same row.

Table 2 RSA and SDNN feature vectors for different experimental sessions and feature phase differences between RSA and SDNN feature vectors.

Control	***Rest II***	***CAT II***	***BC***	***CAT II***	***Rest II***	$\Delta\theta_f$ (°)
RSA parameter	71.98	57.43	140.51	58.42	78.79	14.92
RSA coefficient	0.70	0.65	0.75	0.63	0.70	4.49
RSA normal rate	81.81	76.82	85.78	73.21	79.16	5.38
SDNN	59.26	57.38	76.92	58.95	72.03	
Zen-meditation	**S 1**	**S 2**	**S 3**	**S 4**	**S 5**	
RSA parameter	71.54	69.63	59.28	58.03	54.29	5.12
RSA coefficient	0.81	0.84	0.84	0.86	0.81	1.64
RSA normal rate	89.91	90.55	90.95	93.53	90.19	1.62
SDNN	39.98	40.38	38.15	40.11	37.59	

A smaller phase difference indicates that the RSA feature vector is in better accordance with the SDNN vector; consequently, it provides a more reliable estimate in characterizing the RSA behavior as influenced by different interventions. Our algorithm closely tracks the point-to-point synchronization behavior between RRI (R-to-R interval) and respiratory patterns that provide the quantitative scheme for realizing the qualitative description of RSA phenomenon (heart beat accelerates during inspiration and decelerates during expiration). In addition to the capability of direct and reliable assessment, our methods of evaluating RSA are superior in the interpretation of the results. The RSA coefficient range of 0 – 1 and RSA normal rate range of 0% – 100% provide a clear-cut indicator of *good* or *bad* performance that is inaccessible by the conventional RSA method.

To make a comparable inter-group comparison, the control results of CAT sessions are excluded. As summarized in Table 3, the group averages of heart rate, respiratory rate and three RSA measures are computed for 1) control session Rest I & II; 2) control session BC; and 3) all five Zen-meditation sessions (S1 – S5), identified by P(R), P(B) and P(S) for which P denotes the term evaluated.

Table 3 Comparison of sessional average between Zen-meditation group and control group.

Parameter session	Heart rate (HR, beat/min)	Respiratory rate (RR, breath/min)	RSA parameter (RSA1, msec)	RSA coefficient (RSA2)	RSA normal rate (RSA3, %)
R: Control (Rest I&II)	71.54	14.99	75.39	0.697	80.48
B: Control (BC)	72.54	8.54	140.51 *	0.753	85.78
S: HHIS Zen (S1 – S2)	71.39	12.32	62.55	0.830	91.03

Notice that HR (B) is higher than HR (R) and HR (S) although RR (B) is the lowest one. Higher heart rates may be caused by the enforced respiration in the BC session that somehow makes the control subjects uneasy. In the control group, extraordinarily large RSA1 (B) (marked by * in Table 3) reveals the influence of anthropic interventions on RSA that also spotlights the issue of the conventional RSA measurement. HHIS Zen practitioners have rather slower natural respiration (RR (S): 12.32 breath/min) than ordinary healthy controls at rest (RR(R): 14.99 breath/min). RSA quantifies the natural variation of heart rate that occurs during a breathing cycle [26-32]. Highly Mentallydemanding tasks seriously interfere with such natural HR rhythmic patterns, resulting in lowest RSAs. Coincidently, highest respiratory rates occur in CAT sessions (CAT I: 17.5 breath/min, CAT II: 17.6 breath/min, Table 1).

Even though the group average RSA2(B) > RSA2(R) and RSA3(B) > RSA3(R), not every subject in the BC session attained the highest RSA normal rate. Many controls could not relax due to attention to the computer-generated cues used to guide respiration in the BC sessions, as demonstrated in Figure 9, which plots thenumber of controls having the maximum (inner circle) and minimum RSA normal rate in each of the five sessions. In the HHIS Zen-meditation group, the RSA coefficient and RSA normal rate both corroborate better RSA behaviors in comparison with the control group in the BC sessions: RSA2(S) > 110% RSA2(B), RSA3(S) > 105% RSA3(B).

Notice that the control group (age 20-24 years) is rather young compared to the HHIS Zen-meditation group (age 51-62 years). Aging is considered to be an important factor causing deterioration in the structure and function of pulmonary circulation [33]. The normal SDNN range is about 27-32 msec at the age of those in the HHIS Zen group. As shown in Table 2, a SDNN of 38 – 40 msec reflects an excellent performance on the autonomic nervous system for the Zen practitioners. With respect to cardiorespiratory interaction characterized by RSA, HHIS Zen practitioners exhibit even better performance than healthy ordinary young people; this may imply the slow-down of cardiopulmonary aging through Zen-meditation practice.

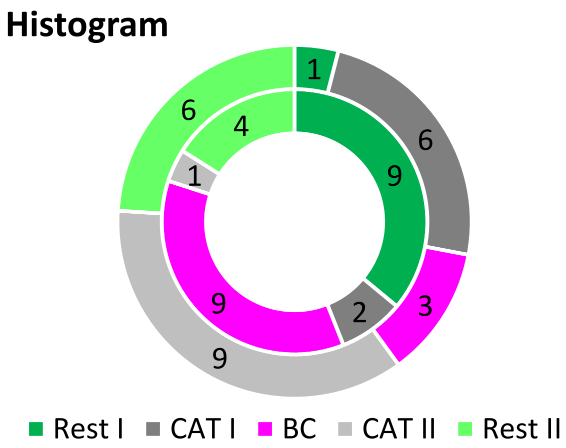


Figure 9 Histogram of max (inner) and min RSA normal rate in each control session.

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Author Contributions

Pei-Chen Lo supervised this study and wrote the manuscript. Wu Jue Miao Tian supervised the HHIS Zen meditation and provided the background knowledge of the mechanism of HHIS Zen meditation. Bo-Ting Lyu analysed the data and made all the figure illustrations for the results.

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Competing Interests

There exists no conflict of interest in this study.

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