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# NEW ALGORITHM FOR EVALUATING CARDIO RESPIRATORY SYNCHRONIZATION UNDER ZEN MEDITATION AND VARIOUS MENTAL-STRESS STATES

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## ABSTRACT

### Background

This paper presents new graphical algorithms for illustrating the efficiency of cardio respiratory interactions at different levels of mental stress.

### Methods

Seven, Zen-meditation practitioners (experimental group) and fifteen normal controls at different levels of mental stress were studied. Synchrogram analysis based on the relationship between R-peak phase and respiratory cycle can access the performance of cardio respiratory interactions. Ranked R-peak phase alignment (RRPA) and R-peak linearization (RPL) synchrogram proposed in this study provide a long-term overview of the quality and performance of cardio respiratory functioning and respiratory sinus arrhythmia (RSA) performance. RRPA characterizes the global behavior of R-peak phases of the synchrogram by linear regression of ranked R-peak phases. RPL synchrogram provides another overview of the RSA behavior. RPL synchrogram is composed of piecewise linear lines formed by linear regression of the normalized R-peak phases in one respiratory cycle. Time-domain HRV (heart rate variability) and RSA are evaluated as the referenced indicators.

### Results

HRV and RSA analysis shows breathing regulation at 8 breaths per minute effectively relieves the mental stress. The effect of breathing regulation is better than the normal relaxation rest. Zen-meditation practitioners exhibit prominently better performance on cardio respiratory synchronization and RSA behavior. Zen meditation induces a better regulation scheme for stabilizing the cardio respiratory functioning

### Conclusions

RRPA portrait makes the cardio respiratory synchronization behavior more visible than conventional synchrogram. The deviation of the first and the last R-peak phases in different respiratory cycles allow us to track the regularity and stability of cardio respiratory interactions.

**KEYWORDS:** Zen Meditation; Cardio respiratory Interaction; Heart Rate Variability; Respiratory Sinus Arrhythmia; Electrocardiograph; Synchrogram

## 1. INTRODUCTION

Stress is a common problem in modern life. More people are practicing heart-to-heart imprint sealing (HHIS) Zen meditation in Taiwan for stress relief. Effectiveness of meditation on stress manipulation has aroused the attention of researchers.

HHIS Zen meditation completely differs from those widely practiced meditation techniques. HHIS Zen follows the principle that heart dominates brain and mind, unlike the other meditations mainly based on body-mind intervention. Pioneering findings in the scientific study of HHIS Zen meditation were reported in [1-2]. Recently, more evidences revealed the heart-brain interactions significantly affected the health conditions [3]. The heart is more than simply a blood pumping device. For thousands of years, Zen practitioners have been devoted their practice to disclosing the *spiritual heart* inside the organ heart [2]. Through years of Zen-meditation practice, practitioners have their brain functions totally reformed into a so-called *detached* brain dominated by the spiritual heart. The heart-dominant state is activated by fetal-like respiration and ignition of mailunslocating at the glands or nerve plexuses. Cardio respiratory functioning becomes important to explore the mechanism.

The interaction between human cardiac and respiratory systems has been widely studied. These two systems act as two individual oscillators coupled by particular mechanisms. Respiratory sinus arrhythmia (RSA) demonstrates such kind of cardiorespiratory interactions. RSA is a natural variation in heart rate correlating with the respiratory cycle, that is, heart rate increases during inspiration and decreases during expiration. Consequently, RSA behavior is mostly correlated with the characteristic of heart rate variability (HRV) [4-5]. The effects of various meditation techniques on RSA and HRVhave been examined [6-11]. Major activities in LF ranges were reported in the study of Kundalini Yoga and Chinese Chi [7-8], Zazen meditation [9], and concentration meditation group [10]. Nijjar addressed the significant changes in LF and HF norm as the indicator of improved sympatho-vagal balance [6].

Synchronization is a particular phenomenon that occurs due to the interaction of two or more self-sustained oscillators [12]. In 1998, Schäfer et al. [13] developed the technique of phase synchronization of chaotic oscillators [14], called *synchrogram*, to analyze the non-stationary bivariate data. They found cardio respiratory synchronization of several locking ratios (ratios of heartbeat frequencies to respiratory frequencies) occurring in young healthy athletes at rest. Cardio respiratory phase synchronization (CRPS) can explore the low-cognitive conditions, including anesthesia [15], drowsiness [16], and sleep [17]. Advanced Zen-meditation practitioners exhibit a consistently high degree of cardio respiratory phase synchronization, even during rapid breathing [18]. Despite the increasing researches on CRPS, the scheme of quantifying the degree of cardio respiratory synchronization (CRS) is still obscure. This paper aims to present some alternative approaches for characterizing the interaction between cardiac and respiratory systems. Experienced Zen practitioners and normal, healthy control sat different mental-stress levels were involved. To assess the feasibility of new approaches, time-domain HRV parameters are analyzed for comparison.

## MATERIALS AND METHODS

This study involved two groups of voluntary subjects, 7Zen-meditation practitioners and 15 normal controls under different mental-stress levels. Cardio respiratory functioning is evaluated by the phase relation between R peaks of ECG (electrocardiograph) and respiratory cycles, with time-domain HRV parameters as the reference.

The advanced practitioners were in the age range of 51 – 62 years, with HHIS Zen-meditation experience of 19.6 years on average. The control group includes 15 normal, healthy volunteers (non smokers, non drinkers), without any meditation experience, in the age range of 20 – 24 years. All procedures are consistent with the Declaration of Helsinki and were approved by the Institutional Review Board of National Chiao Tung University (Application number: NCTU-REC-103-050).

Each subject provided written informed consent (in accordance with the Helsinki Declaration) to the study. Zen practitioners practiced HHIS Zen meditation during a 30-minute recording. In the analysis, the entire course is equally divided into five sessions. Experimental protocol for the controls involves 5 sessions, 10-min eyes-closed rest (Rest 1) (8-min CAT (continuous attention task) test (CAT 1) (8-minute breathing control at 8 breaths/min (BC) (8-min CAT test (CAT 2) →6-min eyes-closed rest (Rest 2), constituting an overall 40-minute recording.

In CAT test, the target pattern is a 3 (3 checkerboard composed of five white squares and four black squares. Various checkerboard patterns formed by shuffling black and white squares successively appear on the screen for 2 seconds. The subject responds by pressing a button whenever the checkerboard pattern is identical to the previous one. Totally 240 patterns are presented with 40 repetitions in the 8-minute CAT test. Each flashed pattern may appear at any one of six sections on the screen. Total number of correct responses (*C*) is recorded after the CAT test. The performance of mindful concentration of the subject is evaluated by the error index (*E*) [19].

$$E = \frac{40 - C}{40} + \frac{2I}{200} \qquad \text{Eq. (1)}$$

Where *I* indicates the number of incorrect responses.

## Signal Acquisition

NeXus-10 recording system (Mind Media B.V., The Netherlands) was employed to collect the ECG and respiratory signals, digitized at the sampling rate of, respectively, 256 Hz and 32 Hz.

To avoid muscular art facts, ECG Lead II Chest Placement modified from the bipolar limb-lead II configuration was applied. Reference electrode is placed on the left mid-clavicular line, lead + is placed at the end of the left rib cage and aligned with the reference electrode, and lead (is placed on the right mid-clavicular line.

## Evaluation of HRV Parameters

Sympathetic nerve increases the heart rate (HR) and decreases HRV by stimulating the sinoatrial (SA) and atrioventricular (AV) nodes; while parasympathetic nerve slows down HR and increases HRV. Psychological and mental stress reduces HRV [20]. Both physiological cardiovascular models and the development of new clinical characteristics benefit from HRV analyses [21].

This study analyzed the time-domain HRV based on the statistical properties of the R-peak to R-peak intervals between successive normal heartbeats, called the normal-to-normal (NN) intervals. Consider a set of $N$'s NN intervals, $RR_i$, $i = 1, \dots, N$. The standard HRV parameters are computed by the following equations [22].

*Standard deviation of all NN intervals (msec)*

$$SDNN = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(RR_i - \overline{RR})^2} \qquad \text{Eq. (2)}$$

where $\overline{RR}$ is the average of NN intervals

*Root mean square of differences between adjacent NN intervals (m sec)*

$$RMSSD = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N-1}(RR_{i+1} - RR_i)^2} \qquad \text{Eq. (3)}$$

*Percentage of number of pairs of adjacent NN intervals differing by more than 50 m sec (%):*

$$pNN50 = \frac{NN50}{N-1} \times 100\% \qquad \text{Eq. (4)}$$

Where $NN50$ is the number of pairs of adjacent intervals differing by more than 50 msec.

**Quantification of RSA**

RSA has been widely used as an index to signify the phenomenon of heart rate variation in accordance with respiration activity. In recent years, this theory was further expanded to encompass a wide range of hypotheses regarding physical, psycho physiological and even social functioning in humans [23]. Although RSA decreases with age, adults in excellent cardiovascular health may have a more pronounced RSA. RSA also becomes less prominent in individuals with diabetes and Cardiovascular Disease

Different methods for quantifying RSA have been proposed [24]. Distinctions among these methods are mainly the assumption of RSA mechanism and its correlation with respiration. Time-domain RSA analysis evaluates the amplitude of heart-rate fluctuations regulated by the breathing cycle. This study employed the peak-valley method that computes the difference between the longest heartbeat interval during expiration ( $RR^{Ex}_{j,\max}$ ) and the shortest heartbeat interval durin] inspiration ( $RR^{In}_{j,\min}$ ) [25]-[26]. At the $j^{\text{th}}$ respiratory cycle, RSA (m sec) is quantified by

$$RSA_j = RR^{Ex}_{j,\max} - RR^{In}_{j,\min} \qquad \text{Eq. (5)}$$

The percentage of normal RSA cycles (p RSA) proposed in this study indicates the probability of respiratory cycles that conform with the RSA behavior of increasing (decreasing) hear rate at inhalation (exhalation). Accordingly, pRSA (%) is the ratio of normal respiratory cycles to total respiratory cycles in a given time interval

**Cardio Respiratory Synchrogram**

The phenomenon of synchronization is considered as an adjustment of rhythms, via specific manner of interaction, among distinctive self-sustained oscillators [12]. Such an interaction can lead to the locking of their phases. Synchronization thus may be interpreted by the phase locking at the *n*-to-*m* rhythmic relation.

$$\varphi_{n,m} = n\phi_1 - m\phi_2 = \text{const} \qquad \text{Eq. (6)}$$

It indicates the synchronization of *m* cycles of oscillator 1 (respiratory system) with *n* cycles of oscillator 2 (cardiac system).

To construct, then: *c*ardio respiratory synchrogram (CRSG), the first step is to detect the R peaks of ECG and the positive peaks of respiratory signal. Two adjacent respiratory peaks are considered to form a complete cycle with the phase increase of 2π.The normalized relative phase of each R peak within the integer multiples (*m*) of respiratory periods may be determined. The CRSG is constructed by sketching the normalized relative phase $\psi_m(t_{k_2})$ of respiratory signal at time $t_{k_2}$ identified as the time of the R peak of ECG. Figure 1 illustrates the CRSGs for cardiac-to-respiratory cycles of *n*: 1, *n*: 2, and *n*: 3, where *n* indicates the possible number of cardiac cycles within *m* respiratory periods. Apparently, synchronization is more observable for*m*: 3 CRSG, particularly in the range of 0 – 10 (Rest 1), 18 – 26 (BC), and last few minutes (Rest 2).

### Ranked R-Peak Phase Alignment (RRPA) Graph

RRPA proposed in this study is to assess the behavior of *R-peak phases* of the synchrogram by linear regression of ranked R-peak phases. The $i^{\text{th}}$ R-peak phases between successive respiratory peaks are connected by linear regression. Each piecewise line linearizes the rank-*I* R-peak phases in one respiratory cycle. Since the numbers of R peaks in each respiratory cycle are not the same, the higher ranked R peaks may fail to form a complete connection of all the line segments. RRPA portrait makes the CRS behavior more visible than synchrogram (Figure 1).

A macroscopic RRPA (MA RRPA) graph can be constructed by linear regression of all the ranked-*I* piece wise lines over the same experimental session. More parallel lines indicate more ranks of R-peak phases and, accordingly, better cardio respiratory synchrony when respiration becomes much slower and more regular.

### R-Peak Phase Linearization (RPL) Synchrogram

RPL synchrogram is composed of piecewise linear lines formed by linear regression of the normalized R-peak phases in one respiratory cycle. Figure 2 illustrates the RPL synchrograms for 1-minute segment in each of five sessions. RPL synchrogram of BC session reveals remarkable regularity, including 1) robust parallel alignment of breath-to-breath R-peak phases, and 2) uniform of the first R-peak phases and the last R-peak phases. On the other hand, RPL synchrograms of CAT sessions are poorly aligned with rather irregular lengths among different respiratory cycles.

## RESULTS

This study proposes two schemes of graphical illustration, RRPA graph and RPL synchrogram, for exploring CRS behaviors for Zen-meditation practitioners and normal controls. Quantitative HRV parameters (SDNN, pNN50, and RMSSD) and RS Aare calculated as reference.

### HRV and RSA for Control Group

Lower heart rate occurs in either Rest 1 (10 subjects) or Rest 2 (5 subjects) session, whereas the highest heart rate occurs mostly in the CAT sessions (8 in CAT 1 and 6 in CAT 2). Student t-test is conducted in session pairs (Rest 1, CAT 1), (CAT 1, BC), (BC, CAT 2), (CAT 2, Rest 2) and (Rest 1, CAT 2), to investigate the effect of different sessions (interventions) on the quantitative parameters of the control group. RR and HRV parameters of BC session exhibit statistically significant difference compared with which of CAT 1 and CAT 2 sessions (Table 1).

Table 2 lists the sessional average of HRV parameters (SDNN, pNN50 and RMSSD) and RSA analysis (RSA and pRSA) for each control subject. Larger SDNN, indicated by underline, occurs mostly in the BC (9 subjects) and Rest 2 (4 subjects) sessions. As reported in clinical studies, SDNN smaller than 50 m Sec indicates a higher risk of cardiac problem. SDNN also reflects the level of activity of the autonomic nervous system. Value of pNN50 greater than 3% is considered a normal indication [21]. Largest pNN50 mostly appears in the Rest 1, 2 and BC sessions. Breathing control at a lower rate (8 breaths/min) may enhance the correlation between the cardiac and respiratory rhythms. On the other hand, people under high mental stress often have a poor cardio respiratory functioning.

RMSSD and pNN50 highly correlate with a correlation coefficient greater than 0.86 except a07, a09 and a15. A higher RMSSD indicates the better enhancement of cardiac parasympathetic activity and RSA activity [27-28].

In the results of RSA analysis, highest RSA ranges from 38.6 to 178.5 m Sec consistently occurs in the BC session for all 15 control subjects. On the other hand, 14 out of 15 subjects have the lowest RSA (-10.6 – 43.2 m Sec) at the CAT session with high mental stress. The value of p RSA in some sense reflects the rate of natural rhythmic correlation between cardiac and respiratory oscillators. The largest p RSA occurs at either the BC session (6 subjects) or the Rest session (9 subjects). The smallest p RSA occurs mostly in CAT sessions (10 subjects). Group average RSA’s four different sessions are 32.3 m Sec (Rest 1), 12.7 m Sec (CAT 1), 95.4 m Sec (BC), 15.3 m Sec (CAT 2) and 35.4 m seas (Rest 2). Group average p RSA’s four different sessions are 87.0% (Rest 1), 80.0% (CAT 1), 87.3% (BC), 75.1% (CAT 2) and 79.4% (Rest 2). Both RSA and p RSA reflect a significantly larger increase from CAT 1 to the BC session than which from CAT 2 to Rest 2 sessions.

## HRV and RSA for Experimental Group

All Zen-meditation practitioners have decreased heart rate throughout the 30-minute practice: 71→69, 70→67, 71→66, 89→86, 63→62, 79→78, and 75→73 beats/min. Six out of seven have rather slow respiration (11, 14, 12, 12, 11, 13, and 19 breaths/min).HRV parameters and RSA results of all the seven practitioners are listed in Table 3. The age range of experimental group is 51-62, of which the normal SDNN is about 27-32 (m sec). All practitioners except c04 have good performance on the ANS balance. Higher SDNN indicates higher sympathetic activities. The overall average values of SDNN of experimental group are lower than which of the control group. Apparently, Zen meditation process induces more parasympathetic tones than sympathetic tones.

A wider RSA range (3.8 to 91.1 m sec)is observed among seven practitioners. According to our investigation, low RSA is caused by the transition of respiration from normal abdominal breathing to so-called *fetal* breathing [2] that prepares the practitioners for entering into HHIS Zen meditation. Constantly high p RSA’s reflecting the enhanced cardio respiratory synchronization. The average p RSA of the entire group is 89.1%, higher than which of the control group at BC session (87.3%).

## Cardio Respiratory Synchrogram

The ratio of heart rate to respiratory rate is relevant with the *n*: *m*in synchrogram analysis. Group average ratios for controls in different sessions are5.4 (Rest 1), 4.4 (CAT 1), 8.6 (BC), 4.4 (CAT 2) and 5.4 (Rest 2), which is 5.75 for Zen-meditation group. On average, the experimental group has higher ratios than the normal controls.

In synchrogram analysis, best cardio respiratory synchronization occurs at 7 : 1 (Rest), 9 : 1 (BC) and 5 : 1 (CAT) for the controls, which is 8 : 1 for the Zen-meditation practitioners. The ratio provides the guideline for regulating the cardiac to respiratory rhythms to achieve better health condition.

### Ranked R-Peak Phase Alignment (RRPA) Graph

Figure 3 illustrates the ma RRPA graphs for randomly selected four Zen-meditation practitioners (left) and control subjects (right).RRPA graphs for practitioners align in substantial parallelism indicating prominent synchronization of cardio respiratory interaction. In the control subjects, those lines connecting the higher rank R-peak phases (closer to 2π) become more irregular and away from parallelism, particularly in the CAT 1 and CAT 2 with high mental stress. Some control subjects failed to attain cardio respiratory synchronization even at rest. Nevertheless, RRPA of BC session exhibits outstanding parallelism, showing the favorable effect of respiration at 8 breaths/min on enhancing the CRS.

### R-Peak Phase Linearization (RPL) Synchrogram

Figure 4 displays the overview of the entire 40-minute RPL synchrograms for selected four Zen-meditation practitioners (left) and control subjects (right). Note that line density directly reflects the respiratory rate since heart rate varies little among different sessions. Line density is higher in CAT1 and CAT 2, with poor parallelism. The BC session

Exhibits rather sparse distribution of lines, yet, with better parallelism. Shorter lines out of alignment in both CAT sessions indicate the inharmonious interaction between cardiac and respiratory rhythms. In Zen-meditation group and BC session of control group, most lines extend over the 2πrange and exhibit prominent parallelism. RPL synchrograms of Zen-meditation group showing rather uniform line density in the entire 30-minutemay imply a consistently steady cardio respiratory synchronization in the entire Zen-meditation course.

## DISCUSSIONS

Remarkable parallel alignment of all ranked R-peak phases in RRPA graph (Figure 3) may provide an indication of superior cardio respiratory synchronization. Line crossings and swap of ranked orders at higher R-peak ranks are associated with high mental stress. As illustrated in Figure 5, running RSA (m sec) fluctuates with the degrees of regularity of RPL synchrogram. In general, coarsely parallel alignment of RPL synchrogram is associated with higher RSA. Almost all control subjects (except a05) had SDNN increase remarkably from CAT 1 to BC session; whereas only seven subjects exhibited increased SDNN from CAT 2 to Rest 2 session. The results provide substantial evidence on the importance of regulating the respiratory rate at 8 – 9 breaths/min for the novices to better balance the ANS and calm the brain and mind for entering into Zen meditation.

## CONCLUSIONS

Two graphical schemes are proposed to characterize the cardio respiratory interactions of Zen-meditation practitioners and normal controls at different mental-stress levels. RRPA graph and RPL synchrogram tactfully correlate with RSA behavior. Up to present, no consistent scheme has been proposed for evaluating RSA performance. Graphical interpretation may provide a quick overview of the time-varying performance on cardio respiratory interaction and RSA behavior. These analytical schemes allow us to further investigate how the cardiac and respiratory oscillators collaborate together to activate the heart-brain transition process in preparation for entering into deep HHIS Zen meditation. Breathing regulation at 8 breaths per minute effectively relieves the mental stress caused by continuous attention task. Average values of p RSA are 87.0% (Rest 1), 79.9% (CAT 1), 87.3% (BC), 75.1% (CAT 2), and 79.4% (Rest 2) for control group and 89.1% for experimental group. In spite of the older age group, Zen-meditation practitioners have remarkably coherent performance on cardio respiratory interactions.

Based on RRPA scheme, deviations of the first (lowest-ranked) and the last (highest-ranked) R-peak phases reflect the cardio respiratory synchronization performance. The smallest standard deviation (first: 0.17 – 0.31 rad, last: 0.17 – 0.35 rad) occurs in the BC session for all the subjects, while the largest standard deviation (first: 0.32 – 0.69 rad, last: 0.31 – 0.70 rad) mostly occurs in either CAT 1or CAT 2session. In Zen-meditation group, the standard deviations of the first (last) R-peak phases are mostly in the range of 0.16 – 0.41 (0.18 – 0.44) rad. Accordingly, Zen meditation induces a better regulation scheme for stabilizing the cardio respiratory functioning. Moreover, line density of RPL synchrogram of Zen-meditation group is comparatively rather uniform in the entire course. It may infer the stationary cardio respiratory synchronization.

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### List of Abbreviations

**RRPA:** Ranked R-peak phase alignment

**RPL:** R-peak linearization

**RSA:** Respiratory sinus arrhythmia

**HRV:** Heart rate variability

**HHIS:** Heart-to-heart imprint sealing

**CRPS:** Cardio respiratory phase synchronization

**CRS:** Cardio respiratory synchronization

**BC:** Breathing control

**SDNN:** Standard deviation of all NN intervals (m sec)

**RMSSD:** Root mean square of differences between adjacent NN intervals (m sec)

**pNN50:** Percentage of number of pairs of adjacent NN intervals differing by more than 50 m sec (%)

### Declarations

- Ethics approval and consent to participate: All procedures are consistent with the Declaration of Helsinki and were approved by the Institutional Review Board of National Chiao Tung University (Application number: NCTU-REC-103-050). Each subject provided written informed consent (in accordance with the Helsinki Declaration) to the study.
- Competing interests: We declare that we have no conflicts of interest in the study.

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## APPENDICES

**Table 1: Effect of Different Sessions on HR, RR, SDNN, Pnn50 and RMSSD. Symbol * Indicates Statistically Significant Difference between Two Sessions with P Value Less Than 0.05**

| Session Pair<br>Parameter | Rest – CAT 1 | CAT 1 – BC | BC – CAT 2 | CAT2 – Rest 2 |
|---|---|---|---|---|
| HR | | | | |
| RR | * | * | * | * |
| SDNN | | * | * | |
| pNN50 | | * | * | * |
| RMSSD | | * | * | * |

**Table 2: Average Values of SDNN (M sec), Pnn50 (%), RMSSD (M sec), RSA (M sec) and Prsa (%) in Each Session for 15 Control Subjects**

| Subject Session | SDNN (msec) | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | a01 | a02 | a03 | a04 | a05 | a06 | a07 | a08 | a09 | a10 | a11 | a12 | a13 | a14 | a15 |
| **Rest 1** | 84.52 | 36.53 | 91.75 | 40.89 | 46.07 | 30.9 | 60.48 | 42.59 | 63.22 | 37.43 | 49.21 | 45.54 | 41.28 | 44.92 | 45.77 |
| **CAT 1** | 53.88 | 42.92 | 61.82 | 54.26 | 59.25 | 31.44 | 49.88 | 59.12 | 63.53 | 42.8 | 52.21 | 60.38 | 35.09 | 55.47 | 50.79 |
| **BC** | 75.6 | 58.98 | 92.14 | 64.85 | 58.76 | 53.71 | 89.04 | 63.09 | 91.05 | 53.94 | 72.85 | 67.03 | 59.24 | 59.47 | 54.13 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CAT 2** | 46.52 | 58.27 | 54.27 | 49.53 | 74.96 | 36.63 | 60.77 | 56.04 | 68.23 | 47.66 | 48.2 | 53.25 | 49.26 | 48.99 | 48.42 |
| **Rest 2** | 73.04 | 78.58 | 91.38 | 46.83 | 62.32 | 60.97 | 55.82 | 72.8 | 64.82 | 42.16 | 56.71 | 46.74 | 46.6 | 38.99 | 60.05 |
| **pNN50 (%)** | | | | | | | | | | | | | | | |
| **Rest 1** | 39.45 | 4.06 | 18.94 | 9.39 | 13.28 | 0.85 | 19.70 | 8.59 | 15.63 | 12.99 | 17.71 | 18.24 | 3.11 | 27.20 | 13.67 |
| **CAT 1** | 29.08 | 5.30 | 16.51 | 18.10 | 21.24 | 1.52 | 26.22 | 14.94 | 9.83 | 20.27 | 20.90 | 14.93 | 1.42 | 23.90 | 17.95 |
| **BC** | 30.00 | 11.12 | 33.20 | 20.82 | 11.59 | 4.87 | 29.86 | 26.25 | 11.18 | 16.41 | 31.93 | 26.83 | 10.34 | 19.53 | 16.16 |
| **CAT 2** | 22.58 | 4.67 | 8.07 | 14.42 | 20.11 | 2.69 | 27.68 | 18.23 | 10.33 | 22.28 | 17.80 | 12.84 | 3.43 | 22.66 | 16.92 |
| **Rest 2** | 28.04 | 11.64 | 25.23 | 8.87 | 11.68 | 6.82 | 35.62 | 20.62 | 11.20 | 18.57 | 35.04 | 11.62 | 6.86 | 27.94 | 17.84 |
| **RMSSD (msec)** | | | | | | | | | | | | | | | |
| **Rest 1** | 63.81 | 23.86 | 42.45 | 29.48 | 33.12 | 18.35 | 39.69 | 31.22 | 38.31 | 32.36 | 37.31 | 36.44 | 22.49 | 42.24 | 34.59 |
| **CAT 1** | 51.02 | 26.10 | 35.94 | 37.73 | 40.69 | 17.62 | 42.67 | 35.17 | 42.73 | 37.58 | 39.35 | 36.37 | 20.81 | 39.64 | 37.31 |
| **BC** | 62.24 | 30.01 | 52.26 | 37.82 | 32.26 | 24.09 | 58.29 | 44.38 | 38.51 | 37.57 | 54.44 | 47.00 | 30.78 | 36.63 | 34.73 |
| **CAT 2** | 41.71 | 25.04 | 26.94 | 35.39 | 38.56 | 21.27 | 48.84 | 36.86 | 32.32 | 42.86 | 37.32 | 32.55 | 22.07 | 38.73 | 36.50 |
| **Rest 2** | 50.70 | 31.81 | 45.27 | 31.92 | 31.56 | 29.04 | 50.48 | 43.05 | 34.20 | 36.07 | 50.11 | 32.09 | 26.25 | 42.16 | 35.73 |
| **RSA (msec)** | | | | | | | | | | | | | | | |
| **Rest 1** | 96.3 | 17.2 | 87.9 | -6.0 | -6.6 | 25.8 | 5.8 | 55.8 | 39.3 | 14.4 | 62.2 | 9.2 | 43.1 | 17.1 | 23.1 |
| **CAT 1** | 45.9 | 10.2 | 40.1 | -10.6 | 1.5 | 18.1 | -1.5 | 13.9 | -1.7 | 11.1 | 21.1 | 3.5 | 21.6 | -2.9 | 20.4 |
| **BC** | 157.6 | 38.6 | 161.1 | 64.8 | 44.7 | 66.6 | 175.7 | 113.3 | 43.7 | 45.0 | 178.5 | 79.0 | 91.2 | 65.9 | 105.6 |
| **CAT 2** | 43.2 | 19.7 | 31.3 | -7.9 | 16.0 | 26.6 | -4.6 | 12.2 | 6.6 | 7.4 | 24.1 | 5.1 | 29.6 | 5.6 | 14.4 |
| **Rest 2** | 91.2 | 30.9 | 35.2 | -8.6 | 21.1 | 51.6 | 1.9 | 66.5 | 20.7 | 7.5 | 74.9 | 9.1 | 45.1 | 14.5 | 68.7 |
| **pRSA (%)** | | | | | | | | | | | | | | | |
| **Rest 1** | 73.3 | 89.0 | 71.4 | 82.4 | 76.9 | 89.1 | 73.4 | 94.1 | 83.3 | 96.5 | 97.8 | 96.3 | 93.7 | 96.9 | 91.4 |
| **CAT 1** | 69.4 | 81.0 | 72.8 | 64.4 | 75.7 | 84.9 | 72.6 | 85.3 | 66.9 | 95.0 | 79.1 | 82.2 | 92.6 | 92.5 | 85.5 |
| **BC** | 52.8 | 81.3 | 87.7 | 90.0 | 81.7 | 90.5 | 89.4 | 91.6 | 85.7 | 90.4 | 92.2 | 97.1 | 91.6 | 98.6 | 89.4 |
| **CAT 2** | 68.9 | 56.8 | 54.2 | 66.9 | 70.1 | 81.2 | 80.0 | 85.5 | 48.9 | 93.3 | 69.3 | 85.7 | 86.9 | 94.9 | 83.5 |
| **Rest 2** | 65.6 | 64.8 | 69.4 | 74.1 | 44.7 | 65.6 | 90.0 | 83.1 | 81.0 | 94.4 | 97.6 | 85.6 | 90.3 | 99.1 | 86.2 |

**Table 3: Average Values of SDNN (Msec), Pnn50 (%), RMSSD (Msec), RSA (Msec) and Prsa (%) For Zen-Meditation Practitioners**

| Subject<br>HRV / RSA | c01 | c02 | c03 | c04 | c05 | c06 | c07 |
|---|---|---|---|---|---|---|---|
| SDNN (msec) | 38.19 | 31.83 | 51.79 | 12.25 | 47.01 | 51.77 | 40.60 |
| pNN50 (%) | 3.85 | 3.29 | 14.25 | 0.00 | 11.17 | 10.01 | 10.56 |
| RMSSD (msec) | 24.90 | 24.35 | 34.14 | 6.59 | 36.35 | 31.95 | 31.58 |
| RSA (msec) | 42.1 | 3.8 | 52.9 | 11.6 | 91.1 | 30.7 | 10.6 |
| pRSA (%) | 91.7 | 94.5 | 83.9 | 90.0 | 88.8 | 79.3 | 95.6 |

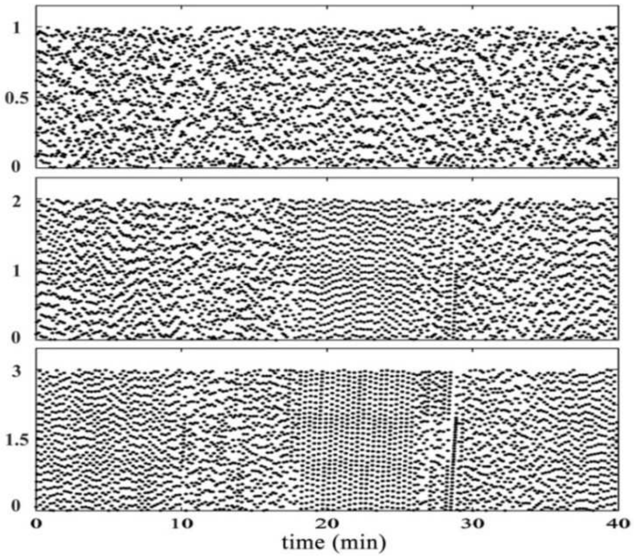

**Figure 1: Cardio Respiratory Synchrograms for Cardiac-To-Respiratory**

**Cycles of *N* : 1, *N* : 2, and *N*: 3 (From Top)**

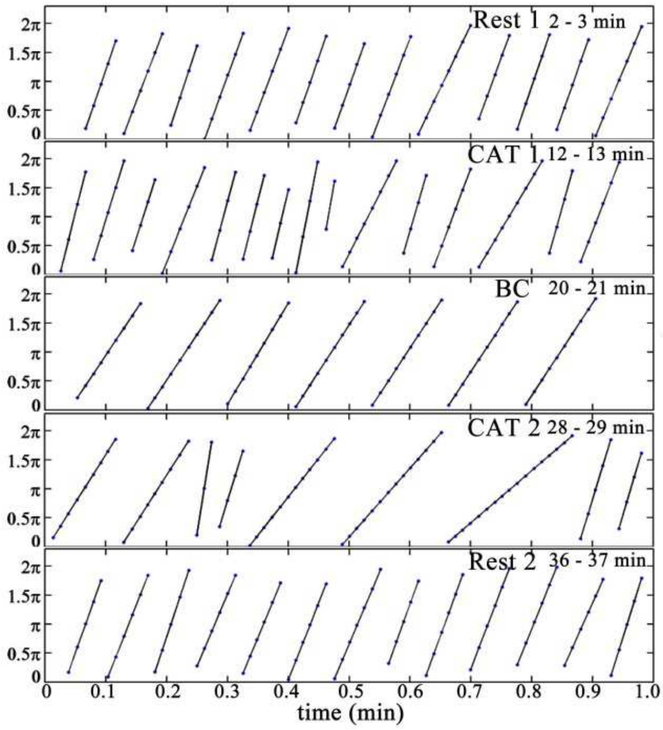

**Figure 2: R-Peak Phase Linearization (RPL) Synchrogram for 1-Minute Segment in Each of Five Sessions**

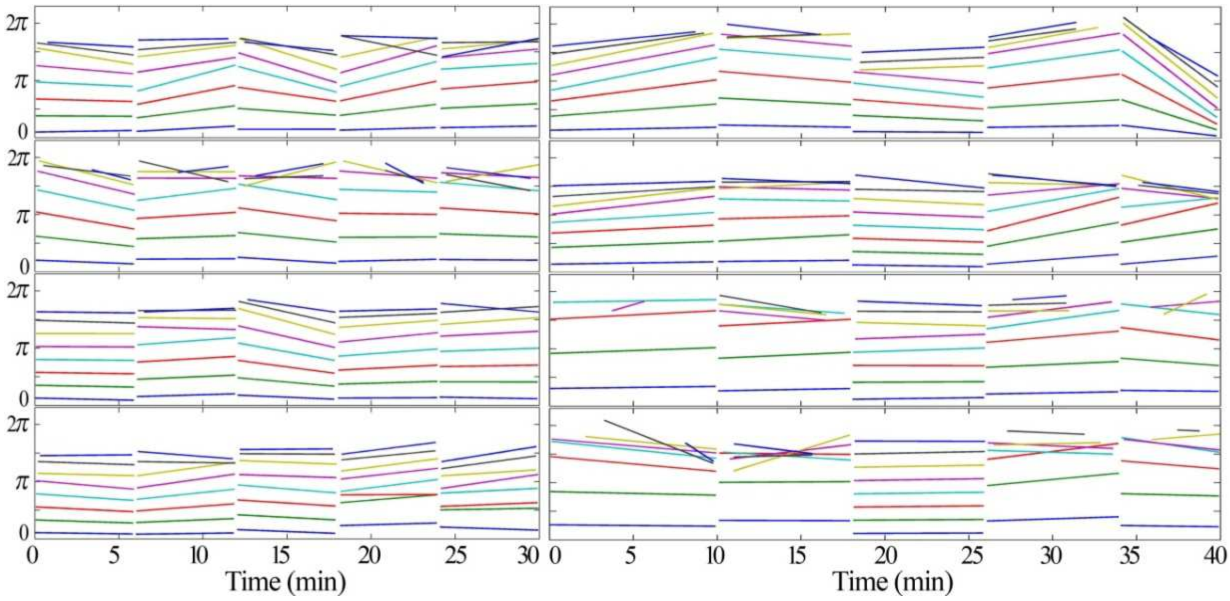

**Figure 3: Macroscopic RRPA Graphs For Randomly Selected (A) Four Practitioners (From Top, C01, C02, C04, and C05), and (B) Four Control Subjects (From Top, A01, A03, A05, and A07)**

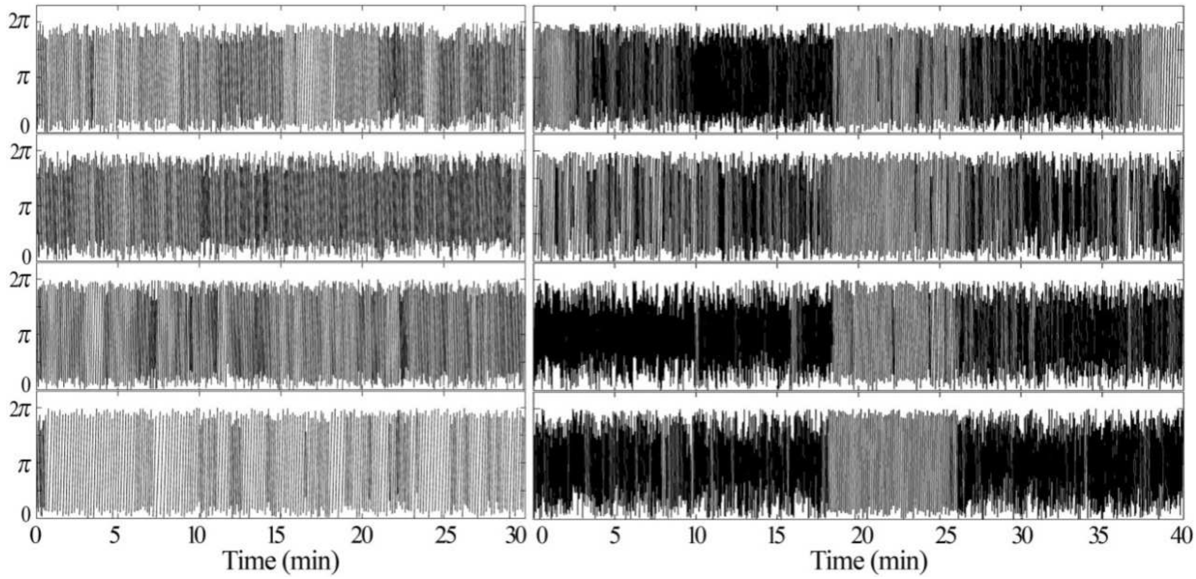

Figure 4: RPL Synchrograms for Randomly Selected (A) Four Practitioners (From Top, C01, C02, C04, and C05), and (B) Four Controls (From Top, A01, A03, A05, and A07)

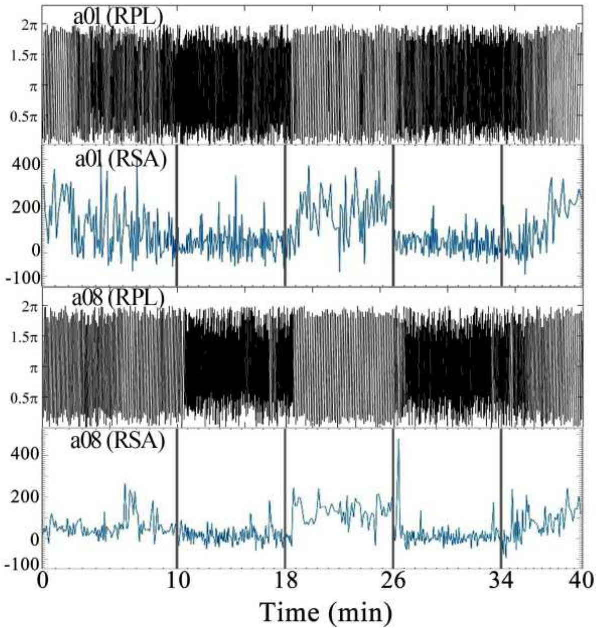

Figure 5: RPL Synchrogram and Running RSA for A01 and A08