Zazen and Cardiac Variability

Paul Lehrer, PhD, Yuji Sasaki, MD, PhD, and Yoshihiro Saito, PhD

Objective: This study examined the effects of "tanden breathing" by Zen practitioners on cardiac variability. Tanden breathing involves slow breathing into the lower abdomen. **Methods:** Eleven Zen practitioners, six Rinzai and five Soto, were each studied during 20 minutes of tanden breathing, preceded and followed by 5-minute periods of quiet sitting. During this time, we measured heart rate and respiration rate. **Results:** For most subjects, respiration rates fell to within the frequency range of 0.05 to 0.15 Hz during tanden breathing. Heart rate variability significantly increased within this low-frequency range but decreased in the high-frequency range (0.14–0.4 Hz), reflecting a shift of respiratory sinus arrhythmia from high-frequency to slower waves. Rinzai practitioners breathed at a slower rate and showed a higher amplitude of low-frequency heart rate waves than observed among Soto Zen participants. One Rinzai master breathed approximately once per minute and showed an increase in very-low-frequency waves (<0.05 Hz). Total amplitude of heart rate oscillations (across frequency spectra) also increased. More experienced Zen practitioners had frequent heart rhythm irregularities during and after the nadir of heart rate oscillations (ie, during inhalation). **Conclusions:** These data are consistent with the theory that increased oscillation amplitude during slow breathing is caused by resonance between cardiac variability caused by respiration and that produced by physiological processes underlying slower rhythms. The rhythm irregularities during inhalation may be related to inhibition of vagal modulation during the cardioacceleratory phase. It is not known whether they reflect cardiopathology. **Key words:** Zen, cardiac variability, slow breathing, resonance, respiratory sinus arrhythmia.

HR = heart rate; RSA = respiratory sinus arrhythmia.

INTRODUCTION

The study described here was prompted by an interest in the effects of respiration on cardiac variability and an opportunity for studying the effects of Zen practice on HR variability among a group of Zen practitioners in Japan. As explained below, HR variability seems to be a marker of cardiovascular health and autonomic homeostatic control, and learned voluntary control of cardiac variability through biofeedback may have important salutary effects on autonomic health.

There is evidence that cardiovascular health is particularly robust among Zen monks. An epidemiological study found a death rate lower than average for Japanese males (1), and this was also true specifically for cardiovascular diseases. Dietary factors may play an important role in this statistic. Zen monks do not eat any fish or meats, and this may contribute to low levels of serum lipids (including low-density lipoprotein cholesterol) in this population (2). It also is possible that Zen meditative processes play a role. Indeed, respiratory maneuvers during Zazen meditation may produce HR variability changes similar to those produced during biofeedback. Zen practitioners cultivate particular skills of slow breathing to obtain major psychological ("sense of oneness") as well as physiological effects. There has thus far been no investigation of the effects of very slow breathing during Zen meditation on various frequencies of HR variability.

HR Variability

Literature on cardiac variability conventionally differentiates three bands of cardiac variability: high-frequency waves (0.15–0.4 Hz), low-frequency waves (0.05–0.15 Hz), and very-low-frequency waves (0.005–0.05 Hz) (3, 4). The high-frequency waves usually coincide with RSA, the increase and decrease in HR produced by the respiratory cycle (5). RSA is produced by a combination of respiration-induced biochemical changes, changes in intrathoracic pressure, and central vagal stimulation (6, 7). Although RSA amplitude is often considered to be an index of vagal tone, it can be dissociated from vagal influence on tonic heart rate. To explain this, Porges (8) proposed that RSA reflects homeostatic processes that *modulate* stress-induced vagal reactivity rather than reflect overall vagal tone. The oscillations may thus serve as level detectors, as in servomechanism function, for triggering a homeostatic response.

Low-frequency waves are affected by both the sympathetic and parasympathetic systems (9, 10). They are correlated with baroreflex gain (11), although other rhythms also are closely related to baroreflex activity (12, 13). Baroreflex activity modulates blood pressure (14), and projections from the baroreflexes stimulate the hypothalamus and play a central role in general autonomic homeostasis (15). Cortical effects of barore-

From the Department of Psychiatry, Robert Wood Johnson Medical School, University of Medicine and Dentistry of New Jersey (P.L.), Piscataway, NJ; Komazawa University (Y.S.); and Tokyo Seitoku University (Y.S.), Tokyo, Japan.

Address reprint requests to: Paul Lehrer, PhD, Department of Psychiatry, Robert Wood Johnson Medical School, University of Medicine and Dentistry of New Jersey, 671 Hoes Lane, Piscataway, NJ 08854-5635.

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flex activity reflecting emotional effects have been shown (16).

Very-low-frequency wave activity is less well understood. There is some evidence that it is related to regulation of vascular tone and body temperature (17–19).

Thus, cardiac variability reflects a variety of homeostatic functions that are specific for particular frequency ranges. Greater amplitude and complexity suggest a greater variety of more active homeostatic reflexes and thus may be indexes of adaptive capacity. Cardiac variability is low in a variety of conditions characterized by impaired adaptation. It is diminished in emotional disorders, such as panic disorder (20, 21), generalized anxiety disorder (22), and depression (23). It is reduced among at-risk infants (24) and among insulin-dependent diabetics (25). It is thought to be a good index of autonomic balance during surgical anesthesia (26). It has been negatively correlated with age in an adult population (27), perhaps reflecting decline in homeostatic adaptability, and positively associated with aerobic fitness (28) and general physical activity (29). It is a strong indicator of risk of mortality due to cardiac disease among cardiac patients (30, 31).

Voluntary Control of Cardiac Variability and Resonance Among Oscillation Frequencies

Breathing at approximately 6 breaths/min (the central frequency of the low-frequency wave band, 0.5–0.15 Hz) causes high-frequency waves and low-frequency waves in HR to synchronize and merge at the rate of respiration (ie, at 0.1 Hz) and to increase greatly in amplitude. Vaschillo (32) proposed that this is a "resonant frequency" effect. During biofeedback training to increase RSA amplitude, Vaschillo notes, all trainees slow their breathing to within the low-frequency wave range. He theorizes that producing voluntary increases in RSA amplitude necessarily causes a subject to breathe at his or her resonant frequency (33). In the case of breathing with a period of 10 seconds (ie, 6 breaths/min or 0.1 Hz), resonance occurs between processes involved in respiration (ie, RSA) and in those that mediate low-frequency cardiac variability (presumably including baroreflex activity), thus producing increases in RSA amplitude. Partially replicating his work, we have also found that, when undergoing biofeedback to increase the amplitude of RSA, the great majority of subjects slow their breathing to within the low-frequency wave band (34) and show large increases in amplitude of heart rate oscillations within this frequency range. Vaschillo et al. (unpublished) have noted that resonance for vascular tone tends to occur in the very-low-frequency wave range (<0.05 Hz).

Vaschillo et al. hypothesized that the increase in HR oscillation amplitude has the effect of exercising the baroreflexes. This, in turn, might be expected to improve their efficiency, thus producing greater modulation of functions affected by the baroreflex system (ie, blood pressure and, indirectly, activity in the autonomic nervous system and limbic system, through anatomical projections from the baroreceptors through the hypothalamus) (16, 35). Using the rationale that RSA biofeedback improves baroreflex efficiency, several Russian rehabilitation centers have used RSA biofeedback as a method to treat various disorders characterized by autonomic hyperreactivity, including anxiety disorders, hypertension, and asthma (36, 37).

Psychophysiological Effects of Zen Practice

The psychophysiological effects of slowed respiration have played a major role in eastern religious practices and martial arts for centuries. Isolated studies have been published showing the effectiveness of these disciplines in treating a variety of chronic illnesses. In particular, yoga has been systematically evaluated for treating asthma (38–43), drug addiction (44), musculoskeletal disorders (45), and hypertension (46, 47). Little attention has been paid to Zen practices by western investigators. Japanese investigators have described successful cases of treating "cardiac neurosis" (48) and hypertension (51) using methods of Zen breathing. Little formal psychophysiological research has been done on respiratory concomitants of Zen practice, and no research has examined the effects of Zen practice on HR variability.

Comparing the psychophysiological effects of Zen meditation in two Zen sects with different approaches to meditation allows us to partially isolate the heart rhythm effects of the slow breathing component in the practice of Zazen. Of the two major Zen sects in Japan, Rinzai and Soto, skills of breath control are given more emphasis among the Rinzai Zen. Their discipline often involves training in very slow and quiet breathing and chanting and attention to the sensations accompanying respiration. However, it should be noted that there are many similarities between the two sects and several differences independent of respiratory training, so comparing the two sects is not equivalent to laboratory control.

There is considerable variability among temples and Zen masters in terms of the exact respiratory exercises that are used. These effects have been documented in a small study of respiratory patterns among Zen monks. A study of four Soto and eight Rinzai Zen monks (50) during both quiet rest and Zen practice found slow respiration (<9 breaths/min) among four of the Rinzai monks and none of the Soto monks. The Rinzai monks breathed more slowly than the Soto monks during practice of Zazen, with almost no overlap between groups.

Hypotheses

We hypothesized that respiration would slow during Zazen, particularly among Rinzai practitioners, and that the frequency range of RSA would track respiration rate, even at very slow rates. When subjects breathed at frequencies reflecting other reflexes, we expected a commensuate increase in amplitude of cardiac oscillations at these frequencies, reflecting resonant frequency effects.

METHODS

Participants

Participants in this study were 11 Zen practitioners with various degrees of expertise and devotion to the practice of Zen. All individuals identified themselves as being very familiar with Zen practice. No attempt was made to quantify expertise in terms of breath control or any specific culturally defined category, but each individual's approximate experience with Zen and frequency of practice in Zazen breathing meditation are summarized in Table 1. Monks and nuns, all of whom were from the Rinzai sect, practiced daily for at least 4 hours. The Soto practitioners in this unrepresentative sample practiced considerably less often.

Setting

All data were collected in Japan by the senior author within a 4-week period during January and February, 1998. The conditions of data collection varied. Testing was done in the midmorning through late afternoon. Three subjects were tested in a university psychology laboratory, one in a university office, one at a mostly vacant room at a convention center (with occasional entry of various people, although this had no observable psychophysiological effect), one in a Zendo (Zen meditation hall of a temple), and the remainder in the guest house at a temple. No thermometer was available, but the laboratory tended to be overheated; the guest house, convention center, and office were at normal room temperature (except for one monk, who preferred to be tested in the guest house with the windows open at a near-freezing temperature); and the Zendo was at a near-freezing temperature. These sources of variability may have affected the results of the study in unpredictable ways.

Equipment and Software

Data were collected using an I-330 C2 Physiograph (J & J Engineering, Bainbridge Island, WA). Electrocardiographic data were acquired digitally at 512 samples/sec and were put through a lowpass filter for R wave detection, after which cardiac interbeat intervals were derived from a level detector. This equipment yielded very little artifact from movement, electromyographic, or electrocardiographic wave irregularities. However, as described below, more experienced Zen practitioners had frequent HR rhythm irregularities characterized by two beats separated by a very short R-R interval and followed by a long R-R interval. (Our recording system did not record the raw electrocardiogram, so the electrocardiographic configuration of these rhythm irregularities could not be defined.) We smoothed these patterns using MXEDIT, a program for graphic display and editing of HR variability data (50–53). Fast Fourier transformation analyses were done by the Log-a-Rhythm program (Nian-Crae, Piscataway, NJ), which has been well validated for analysis of

TABLE 1. Subject Characteristics

Initials	Date of Testing	Sex	Age	Ethnicity	Sect	Relationship With Zen
YS	1/13	M	27	Japanese	Soto	Graduate student, occasional practice since age 16
FS	1/16	M	32	Japanese	Soto	Physician, 10 years of experience, practices 4 hours/day for 1 month/year
KS	1/19	M	42	Japanese	Rinzai	Zen master, leader of a temple
EA	1/26	M	28	Japanese	Soto	Graduate student, has practiced 30 min/day for 7 years
YH	1/26	M	27	Japanese	Soto	Graduate student, practices 2 hours/week
AY	1/26	M	22	Japanese	Soto	Undergraduate student, practices occasionally, studied since childhood, father is a monk
BJ	2/1	M	25	European-American	Rinzai	Novice monk (3 months), previously studied outside temple for 3 years
JH	2/1	F	32	European-American	Rinzai	Nun for 1 year, previously studied outside temple for 8 years
MK	2/1	M	24	European-American	Rinzai	Novice monk (7 months), previously studied outside temple for 2 years
DY	2/1	M	40	European	Rinzai	Monk for 13 years
SR	2/1	M	29	European-	Rinzai	Monk for 2 years
				Mean	SD	
Average age	Rinzai			31.67	7.06	$t(9) = 1.3$, $p =$ NS
	Soto			27.20	3.56	

cardiac variability (54–56). Respiration was recorded using a strain gauge device fastened at approximately the level of the navel.

Procedure

The procedure involved the following design. Participants were recorded during 20 minutes of Zen meditation. They sat in a cross-legged position on a pillow, as they are accustomed to doing during Zazen practice. After electrodes were attached, participants were first instructed to sit quietly for 5 minutes, without speaking, and to move as little as possible to reduce the possibility of measurement artifact. During this time, they sat in the position usually assumed in Zazen meditation. Baseline measures were taken during this time. After this, they were instructed to perform Zazen exercises for a period of 20 minutes. These included "tanden breathing," in which the breath originates from the lower abdomen. Our software allowed us to record for four successive 5-minute periods during this time. Immediately afterward, an additional 5-minute recording was taken during quiet sitting. During Zazen, subjects were instructed to sit in their usual posture and to meditate, using tanden breathing, in their accustomed manner.

RESULTS

Results for all variables were analyzed using a repeated-measures design with Zen vs. rest as a repeated measure and sect (Soto vs. Rinzai) as a between-groups measure.

Age

The slightly younger age of the Soto practitioners was not significantly different from that of the Rinzai subjects (Table 1), but age was nonetheless examined as a covariate in subsequent analyses because of its strong association with cardiac variability. No differences in significance levels were caused by this adjustment, except as reported below.

Respiration Rate[1]

Our data analysis system calculated the time period of each breath and calculated respiration rate in 30-second periods. Some artifact was noted for particular breaths in these recordings. Most participants tended to breathe slowly during periods of Zazen, and small irregularities in the respiration curve occasionally caused the counting of spurious breaths during very slow breathing. We eliminated particular breaths with uncharacteristically high counts (eg, an incidence of >20 breaths/min surrounded by periods of <4 breaths/min) when this was consistent with notes taken during the session. However, we eliminated breaths very conservatively, so the figures reported here may show slightly higher respiration rates than actually occurred.

As shown in Table 2, Rinzai practitioners breathed at a slower rate than practitioners of Soto Zen ($F(1,7) = 9.32$, $p < .02$). Across all subjects, respiration rate was significantly slower during practice of Zazen than during quiet sitting periods at the beginning and end of the sessions ($F(1,9) = 16.31$, $p < .005$). The sect (Soto vs. Rinzai) by Zen (rest periods by Zen periods) interaction was not significant ($F(1,7) = 1.35$, $p =$ NS). No differences in respiration rate were noted across 30-second periods during Zazen breathing, indicating that these were stationary effects during Zazen.

Total HR Oscillation Amplitude

Total HR oscillation amplitude (ie, across all frequency bands) increased significantly during practice of Zazen (Table 3) ($F(1,9) = 37.44$, $p < .0003$). Practitioners of Rinzai Zen tended to show greater total band HR oscillation amplitude, but this result was not significant ($F(1,9) = 4.46$, $p < .07$).

Fast Wave Activity

No significant analysis of variance effects were found for absolute values of HR high-frequency wave activity (0.15–0.4 Hz). To examine the relative distribution of cardiac variability, we also calculated the variance at each frequency range as a percentage of total variance. Expressed in this way, high-frequency activity declined significantly during the practice of Zazen ($F(1,9) = 16.71$, $p < .003$). As shown below, these respiration rate–related decreases in high-frequency activity illustrate a shift to dominance of lower

TABLE 2. Respiration and HRs

Measure	Sect	Task	Mean	SD
Respiration rate	Rinzai	Sitting	7.39	3.22
	Rinzai	Zen	3.95	1.91
	Soto	Sitting	15.35	3.23
	Soto	Zen	8.59	5.55
HR	Rinzai	Sitting	82.16	5.49
	Rinzai	Zen	83.83	6.32
	Soto	Sitting	75.01	11.61
	Soto	Zen	74.92	10.78

[1] Some investigators use statistical control for respiration rate when studying cardiac variability to study autonomic processes associated with it. This was not done here because changes in respiration were the major independent variable (ie, we wished to evaluate the effects of respiration rather than control for them). It is true that when people breathe slowly, two or more physiological processes may underlie the same rhythm (eg, peripheral and central respiratory-linked processes and those reflected in low-frequency activity), so this study could not determine the precise physiological mediators of observed changes in cardiac variability.

TABLE 3. Cardiac Variability

Frequency	Sect	Task	HR[a] beats/min)[2a] Mean	SD	% Total Mean	SD
Low	Rinzai	Sitting	27.48	28.03	51.94	16.35
	Rinzai	Zen	43.91	21.62	57.94	22.64
	Soto	Sitting	6.66	4.04	35.32	7.04
	Soto	Zen	17.38	9.88	45.26	20.02
High	Rinzai	Sitting	11.05	8.75	26.59	13.32
	Rinzai	Zen	9.35	5.27	12.81	7.04
	Soto	Sitting	5.40	6.12	24.51	9.20
	Soto	Zen	7.59	8.15	18.24	7.44
Total	Rinzai	Sitting	45.40	33.48		
	Rinzai	Zen	77.09	33.30		
	Soto	Sitting	19.72	13.90		
	Soto	Zen	38.17	9.90		

[a] Values are oscillation amplitude. The low-frequency range is 0.05–0.15 Hz; the high-frequency range is 0.15–0.4 Hz.

frequency HR oscillations during slower breathing and higher amplitudes at these frequencies, as produced by Zazen.

Low-Frequency Wave Activity

On average, low-frequency wave activity (0.05–0.15 Hz) was greater among practitioners of Rinzai Zen in our sample than among those of Soto Zen (Table 3) ($F(1,9) = 5.19$, $p < .05$), although this effect was reduced to nonsignificance when the effect of age was covaried out ($F(1,9) = 4.66$, $p < .07$). Compared with the average of the quiet sitting periods between the beginning and end of the Zen session, the amplitude of low-frequency waves increased significantly during Zen breathing ($F(1,9) = 5.19$, $p < .05$), although not as a percentage of total oscillation ($F(1,9) = 1.07$, $p =$ NS).

Very-Low-Frequency Wave Activity

Interpretation of very-low-frequency wave activity is tentative because of the relatively short duration of recording (5 minutes) for each period. (At the lowest end of the range, this would yield less than two cycles per period, doubled if one considers that there were two 5-minute periods each for Zazen and ordinary sitting. Under ideal conditions, approximately 20 minutes of recording would be necessary (ie, 10 times the slowest frequency).) Therefore, cardiac activity in this range was examined only qualitatively.

TABLE 4. Cardiac Variables for Zen Master (KS)

Task	Total Variability (beats/min)[2]	HR Low-Frequency Waves (beats/min)[2]	% Total	HR High-Frequency Waves (beats/min)[2]	% Total	Mean HR
Pretest rest	8.06	4.36	54.09	0.76	9.62	78.1
Zen	38.24	6.13	17.46	1.71	3.07	85.1
Posttest rest	30.48	14.11	46.31	1.03	3.38	89.6

Qualitative Description of HR Variability

Cardiac variability during Zazen with slow breathing is illustrated in Figures 1 to 4. Figures 1 and 2 show HR variability and frequency spectrum shifts from a representative Zen practitioner (JH, a 32-year-old Rinzai Zen nun). Figure 1 is from the pre-Zazen rest period. Respiration rate was not extraordinary toward the beginning of this period, but it slowed to less than 6 breaths/min during the last minute. Shifts to such slow rates of respiration during ordinary rest were typical among the Zen monks and nuns. This period accounts for the high spectral peak at approximately 0.1 Hz. Figure 1 also shows the usual spectral power peaks in the high-frequency range (approximately 0.2 Hz) and the very-low-frequency range.

Figure 2 is the third 5-minute segment during Zazen for the same individual. Note that the highest spectral peak is approximately 2.5 times higher than during the rest period, whereas other spectral frequencies were comparatively much lower. The distribution of frequency power is narrowly distributed around 0.1 Hz, with a high amplitude of HR oscillation at this frequency.

Figure 3 shows pre-Zazen rest period data from a Zen master (KS). This individual breathed close to 6 breaths/min throughout the rest period. Note the comparative absence of high-frequency cardiac variability and the major low-frequency peak at 0.1 Hz. A very-low-frequency peak also is notable. Note the periodic occurrence of irregularities in cardiac rhythm, superimposed on the sinus rhythm, each with a short R-R interval followed by a long one.

Figure 4 shows the last 5-minute period of Zazen from KS. During this period, respiration rate was slowed to less than 1 breath/min. Cardiac variability at this time occurred almost exclusively within the very-low-frequency range (Figure 4), with a power of more than 13 times greater than at rest. An increase in HR also occurred during Zazen in this subject (Figure 4 and Table 4). The effects on mean HR were not transient. During the 5-minute post-Zazen rest period, HR climbed further to 89.6 beats/min. Almost no high-frequency waves occurred during Zazen, reflecting a shift in RSA to the very-low-frequency wave range. It is notable that low-frequency wave activity also appeared to shift to this band for reasons not readily

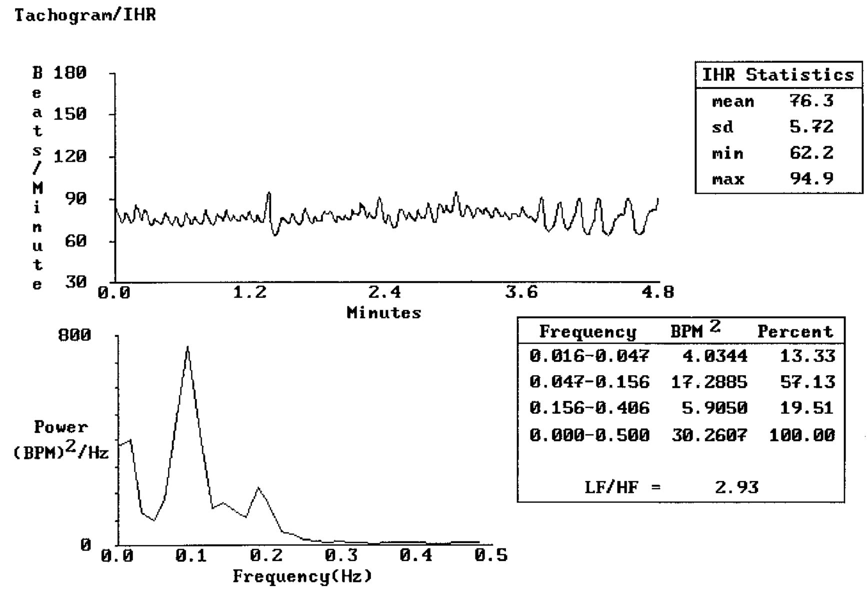

Fig. 1. HR and HR variability for a 32-year-old Zen nun during pre-Zazen rest. *Top*, HR. *Bottom*, Spectral power. BPM = beats/min; HF = high frequency; LF = low frequency; IHR = instantaneous heart rate.

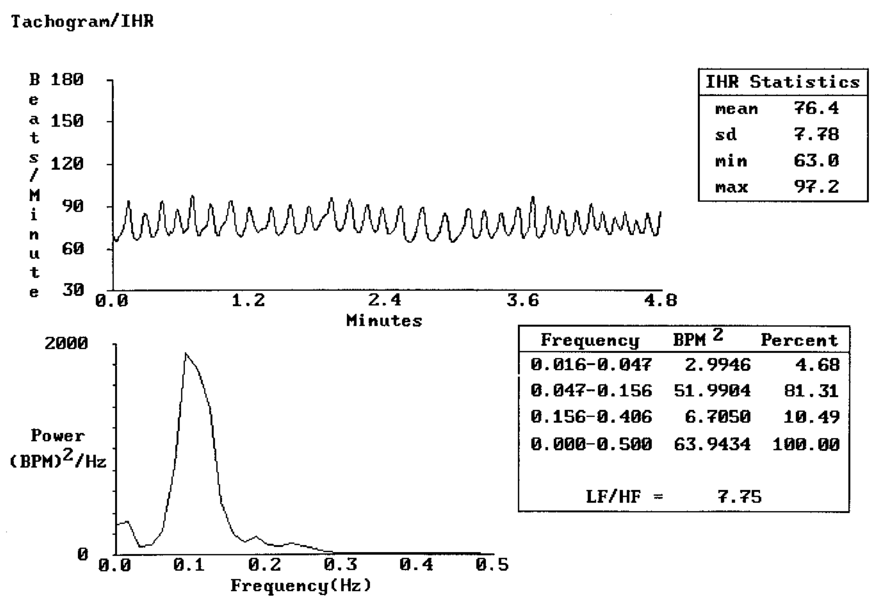

Fig. 2. HR and HR variability for a 32-year-old Zen nun during Zazen. *Top*, HR. *Bottom*, Spectral power. BPM = beats/min; HF = high frequency; LF = low frequency; IHR = instantaneous heart rate.

understood. Cardiac rhythm irregularities greatly increased during this period and occurred regularly and almost exclusively during inhalation (ie, during the cardioacceleratory phase) (Figure 4). In the analyses described above, we eliminated the effect of this arrhythmia by averaging the fast beats with the subsequent slow ones. This almost always smoothed the rhythms so that they seemed to reflect sinus rhythm and other known sources of oscillatory cardiac variability.

Also, the Rinzai practitioners universally reported that they felt warmer during Zen breathing despite, in some cases, practicing under near-freezing conditions. Indeed, upon coming to the testing session and finding the room at usual room temperature, one of the monks requested that the windows be opened so that the temperature of the room would approximate outdoor winter temperature, at which, he reported, he would be able to be more comfortable while doing Zazen.

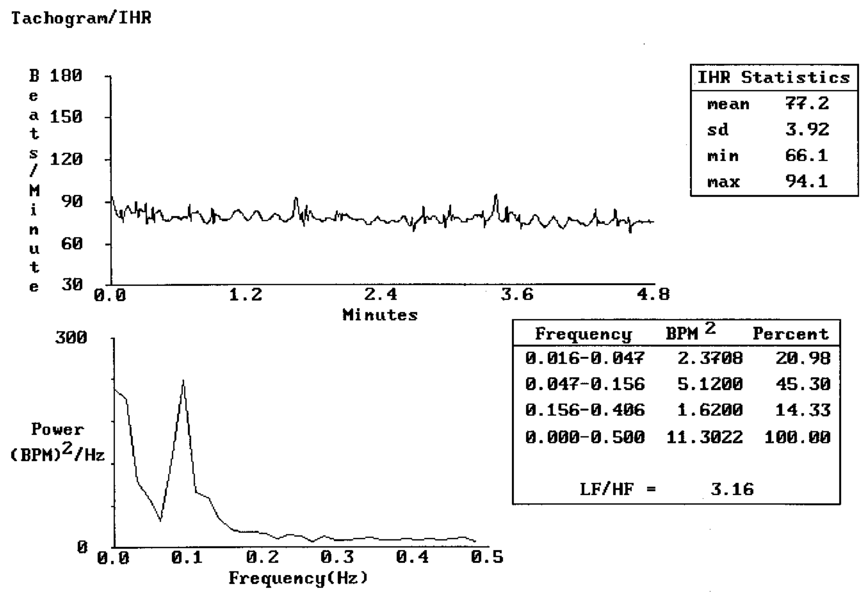

Fig. 3. HR variability for a 42-year-old Zen master (KS) during pre-Zazen rest. *Top*, HR. *Bottom*, Spectral power. BPM = beats/min; HF = high frequency; LF = low frequency; IHR = instantaneous heart rate.

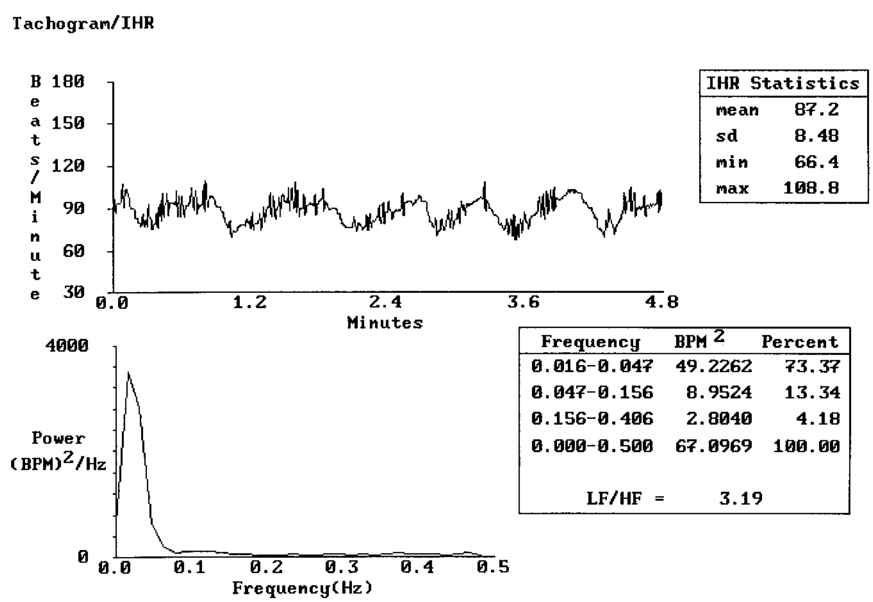

Fig. 4. Cardiac interbeat interval for Zen master (KS) during Zazen. *Top*, HR. *Bottom*, Spectral power. BPM = beats/min; HF = high frequency; LF = low frequency; IHR = instantaneous heart rate.

DISCUSSION

HR Oscillation, Respiration Rate, and Resonance Effects

These data confirm that Zazen breathing falls within the range of low- and very-low-frequency HR spectral bands and increases HR oscillations within these bands. During Zazen breathing, the majority of HR spectral power shifted to the low-frequency wave range. HR oscillation amplitudes increased within this range but decreased in the high-frequency range. This shift was accompanied by a large increase in amplitude of total band HR oscillations. Increases in the very-low-frequency band were noted where respiration slowed to within this frequency band. These data show that low breathing rates shift power of HR oscillations into low-frequency ranges not usually associated with respiratory influences on HR control.

As expected, practitioners of Rinzai Zen breathed more slowly and showed greater low-frequency wave amplitudes in HR. The attention to slow breathing seemed to have generalized from periods of explicit Zazen practice to periods of quiet sitting in this group. Rinzai monks pay particular attention to breathing slowly, and the demand characteristics of this study, in which we were testing a central aspect of their religious practice, may have added to this effect. This finding supports the theory that breathing within the low-frequency wave frequency range produces a shift to low-frequency wave dominance in HR oscillation frequencies.

These data are also consistent with Vaschillo's hypothesis that slow breathing at particular frequencies can produce resonance among various cardiochronotropic processes. Cardiac rhythm effects of respiratory activity seemed to resonate with processes involved in producing low-frequency waves, thus explaining the increase in oscillation amplitudes.

For subject KS, this shift occurred to the very-low-frequency wave band because of his extraordinarily slow rate of breathing. Kikuchi has similarly described cardiac variability in a man who breathed at approximately once/minute during Zazen, with large fluctuations in heart rate and blood pressure, in phase with his breathing (57).

Feelings of Warmth

The participants' experiences of warmth during Zazen suggest that the body's thermoregulatory system may have been affected by practice of this discipline. Subject KS, whose very-low-frequency wave amplitudes particularly increased, specifically remarked on his feelings of increased warmth during Zazen. Perhaps breathing at this very slow rate stimulated sympathetic reflexes that affect oscillations in HR within this very-low-frequency range. The meaning of these observations remains ambiguous, however, because we did not specifically examine thermoregulation, vascular tone, blood pressure, or any index of sympathetic activity. Although increases in HR occurred among some Rinzai subjects, these changes were small and not significant. Additional data are required on vascular and body temperature changes during Zazen and their possible relationship with increased sympathetic arousal and HR very-low-frequency wave activity. Previous observations of experienced Indian Yogis have similarly shown significant increases in body temperature during practice of yoga (58).

Irregular Heart Beats

The frequent irregularity in heart rhythm among experienced Rinzai monks was unexpected. Further investigation of raw electrocardiographic data is required to ascertain their source and with a larger sample to ascertain the regularity of this finding. It is possible that these irregularities represent some deleterious effects of Zen practice on the heart, although this could not be definitively established in the absence of a full-disclosure electrocardiogram. The low rate of heart disease and frequent occurrence of this HR pattern in this population suggests that the pattern may not reflect a pathological state. The fact that these beats tended to occur during the cardioacceleratory phase of large oscillatory swings in HR may reflect the effects of sudden withdrawal of vagal stimulation, which may modulate these irregular effects during high-amplitude stimulation of the heart by homeostatic regulatory processes (represented here by high-amplitude HR oscillations).

Implications for Understanding the Relationship Between Zazen and Cardiac Disease

The elevations in HR low-frequency waves among Zen monks may explain the apparently salutary effects of Zen on heart disease, although other factors also may play an important role (eg, an ordered lifestyle, vegetarian diet, and community support for those living in temples and monasteries). Elevated amplitudes of cardiac variability may reflect elevated baroreflex stimulation. This could, over time, lead to greater reflex efficiency through a training effect. The implications of frequent heart rhythm abnormalities among experienced Zen monks deserve further study.

Future Research

Future research may productively focus on the effects of very slow breathing among Zen practitioners, particularly those from the Rinzai tradition, which emphasizes this activity. Full cardiac evaluations among this population may help us determine the significance of the frequent irregular heart beats that may accompany long-term experience doing Zen. Similarly, assessment of vascular tone, blood pressure and body temperature, oxygen saturation, pCO_2, and catecholamine activity during Zazen would be necessary to explain the feelings of warmth experienced while practicing Zazen during very cold temperature conditions. Also, direct assessment of baroreflex gain in this population could determine whether, as suggested by increases in amplitude of HR low-frequency waves in this study, experience with Zazen increases the gain in homeostatic reflexes by which blood pressure and HR modulate each other.

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