[22] Li Y, Sheng L, Li W, et al. Probucol attenuates atrial structural remodeling in prolonged pacing-induced atrial fibrillation in dogs. Biochem Biophys Res Commun 2009;381:198–203.
[23] Liu T, Li G. Probucol and succinobucol in atrial fibrillation: pros and cons. Int J Cardiol 2010;144:295–6.
[24] Vinten-Johansen J, Zhao ZQ, Nakamura M, et al. Nitric oxide and the vascular endothelium in myocardial ischemia–reperfusion injury. Ann N Y Acad Sci 1999;874:354–70.
[25] Kiziltepe U, Tunctan B, Eyileten ZB, et al. Efficiency of L-arginine enriched cardioplegia and non-cardioplegic reperfusion in ischemic hearts. Int J Cardiol 2004;97:93–100.
[26] Elahi MM, Worner M, Khan JS, Matata BM. Inspired nitric oxide and modulation of oxidative stress during cardiac surgery. Curr Drug Saf 2009 [Electronic publication ahead of print].
[27] Cavolli R, Kaya K, Aslan A, et al. Does sodium nitroprusside decrease the incidence of atrial fibrillation after myocardial revascularization? A pilot study. Circulation 2008;118:476–81.
[28] Perrone SV, Kaplinsky EJ. Calcium sensitizer agents: a new class of inotropic agents in the treatment of decompensated heart failure. Int J Cardiol 2005;103:248–55.
[29] Avgeropoulou C, Andreadou I, Markantonis-Kyroudis S, et al. The Ca2+-sensitizer levosimendan improves oxidative damage, BNP and pro-inflammatory cytokine levels in patients with advanced decompensated heart failure in comparison to dobutamine. Eur J Heart Fail 2005;7:882–7.
[30] Parissis JT, Andreadou I, Markantonis SL, et al. Effects of Levosimendan on circulating markers of oxidative and nitrosative stress in patients with advanced heart failure. Atherosclerosis 2007;195:e210–5.
[31] De Hert SG, Lorsomradee S, vanden Eede H, Cromheecke S, Van der Linden PJ. A randomized trial evaluating different modalities of levosimendan administration in cardiac surgery patients with myocardial dysfunction. J Cardiothorac Vasc Anesth 2008;22:699–705.
[32] Liu T, Li G, Xu G. Levosimendan may prevent postoperative atrial fibrillation through anti-inflammatory and antioxidant modulation. J Cardiothorac Vasc Anesth 2009;23:757–8.
[33] Selemidis S, Sobey CG, Wingler K, Schmidt HH, Drummond GR. NADPH oxidases in the vasculature: molecular features, roles in disease and pharmacological inhibition. Pharmacol Ther 2008;120:254–91.
[34] Dudley Jr SC, Hoch NE, McCann LA, et al. Atrial fibrillation increases production of superoxide by the left atrium and left atrial appendage: role of the NADPH and xanthine oxidases. Circulation 2005;112:1266–73.
[35] Kim YM, Guzik TJ, Zhang YH, et al. A myocardial Nox2 containing NAD(P)H oxidase contributes to oxidative stress in human atrial fibrillation. Circ Res 2005;97:629–36.
[36] Kim YM, Kattach H, Ratnatunga C, Pillai R, Channon KM, Casadei B. Association of atrial nicotinamide adenine dinucleotide phosphate oxidase activity with the development of atrial fibrillation after cardiac surgery. J Am Coll Cardiol 2008;51:68–74.
[37] Williams HC, Griendling KK. NADPH oxidase inhibitors: new antihypertensive agents? J Cardiovasc Pharmacol 2007;50:9–16.
[38] Sovari AA, Morita N, Karagueuzian HS. Apocynin: a potent NADPH oxidase inhibitor for the management of atrial fibrillation. Redox Rep 2008;13:242–5.
[39] Coats AJ. Ethical authorship and publishing. Int J Cardiol 2009;131:149–50.

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Heart rate dynamics in different levels of Zen meditation

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In this study we investigate the heart rate variability (HRV) during Zen meditation (Zazen), in order to study the system behavior in the absence of voluntary intention. The terms "focused attention" (FA) and "mindfullness" (MM) used throughout this paper are defined as follows: FA is the attention focused on the natural breathing process and is specially used by novice Zen practitioners. MM defines a no-pointed attention state where the mind passively observes the spontaneous experience, primarily as a means to recognize the nature of emotional and cognitive patterns [1]. On this basis we consider the definition for "meditation" in [2] limited to just one aspect of a broadest term.

Nineteen Soto-Zen meditation practitioners who have between 2 months and 20 years of experience (7 females and 12 males, mean age 43.78 ± 7.52 years), are represented in this study. None reported any cardiovascular disease and did not take any medication. They did not eat or take any stimulating drink in the last 2 and 24 h, respectively, before data recording. Informed written consent (in accordance with the Helsinki Declaration) was obtained from each subject.

RR interval data were collected by using Polar S810i (Polar Electro Oy, Kempele, Finland). The electrocardiogram and respiration signals (strain gauge) were recorded simultaneously using an I-330-C2+ monitor (J&J Engineering, Poulsbo, USA). The subjects adopted a cross-legged position, as they always do in Zazen, during the whole procedure. For the measures using Polar S810i, after a 10 min baseline recording Zazen was performed for 40 min. For the measures using the I-330-C2+, after 5 min baseline recording FA and MM were performed for 20 min each, in this order. Data were recorded 2–4 times in each subject during a month retreat in a Zen monastery. Total data was 57.

The spectral HRV measures were calculated by using the Fast Fourier transform (FFT) [3]. According to the Task Force [4], the power spectrum for short time series can be classified into 3 ranges as follows: (i) power in the very low frequency range (VLF), 0.003–0.04 Hz, (ii) power in the low frequency range (LF), 0.04–0.15 Hz, and (iii) power in the high frequency range (HF), 0.15–0.4 Hz. The series has been previously normalized by subtracting the mean and dividing by the standard deviation. This study also used the Continuous Wavelet Transform (CWT) [5], which decomposes a series into a time-scale domain (Appendix A).

We divided the normalized spectral density of each record into eight frequency bands and calculated the power of each by integrating

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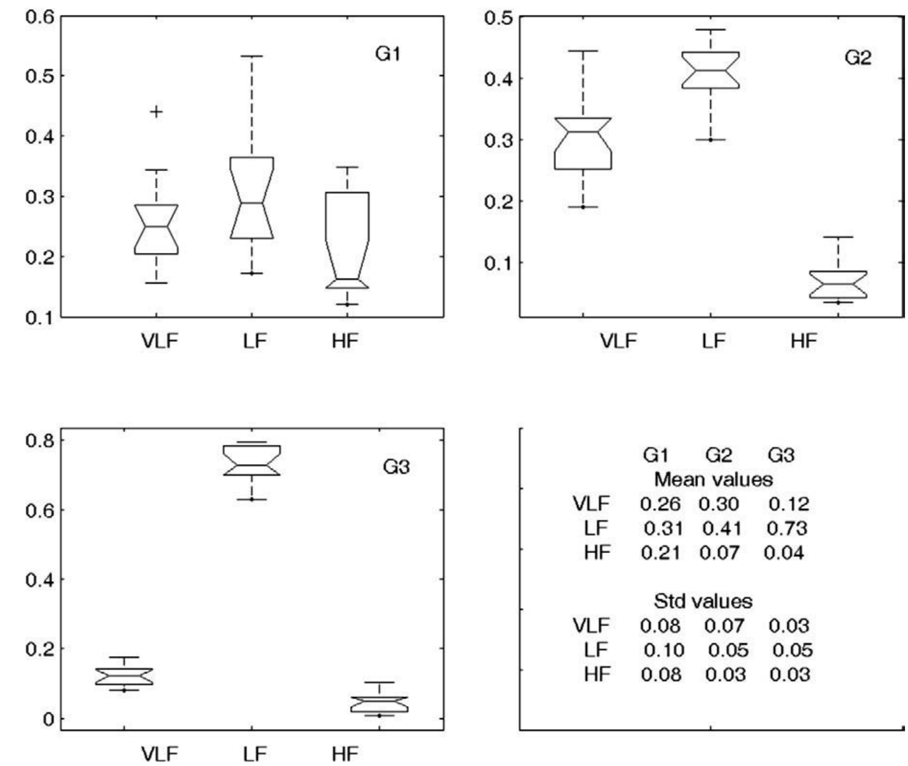

Fig. 1. Box-plots of the HRV normalized spectral density integrated in the three characteristic frequency ranges suggested by the Task Force, for the three groups**.** VLF (0.003–0.04 Hz), LF (0.04–0.15 Hz) and HF (0.15–0.4 Hz). Mean values and standard deviations are also shown. G1 ($n=5$; total data=15; mean meditation experience 4.5 ± 2.44 years) / G2 ($n=4$; total data=16; mean meditation experience 16 ± 3.65 years) / G3 ($n=6$; total data=18; mean meditation experience 13.66 ± 4.58 years).

the spectrum over the frequency bands. The central frequencies were selected using:

$$fn = \frac{dt}{2^n}$$

where $n=1,\dots,8$; and d*t* is the sample interval. Then, we performed a Principal Components Analysis (PCA) on this data set.

The PCA separated three different groups (Fig. 1). Novice practitioners with less than 1 year of practice present a resonant peak in the VLF or LF range and were not included in the PCA (Fig. 2).

Fig. 3 shows the FFT of HRV and breathing data for subjects S6 and S8 (G1) during MM and FA. Fig. 4 shows the same data for subjects S16 and S19 (G3). Note in Figs. 3 and 4 (subplots *a* and *b*) as it seems that

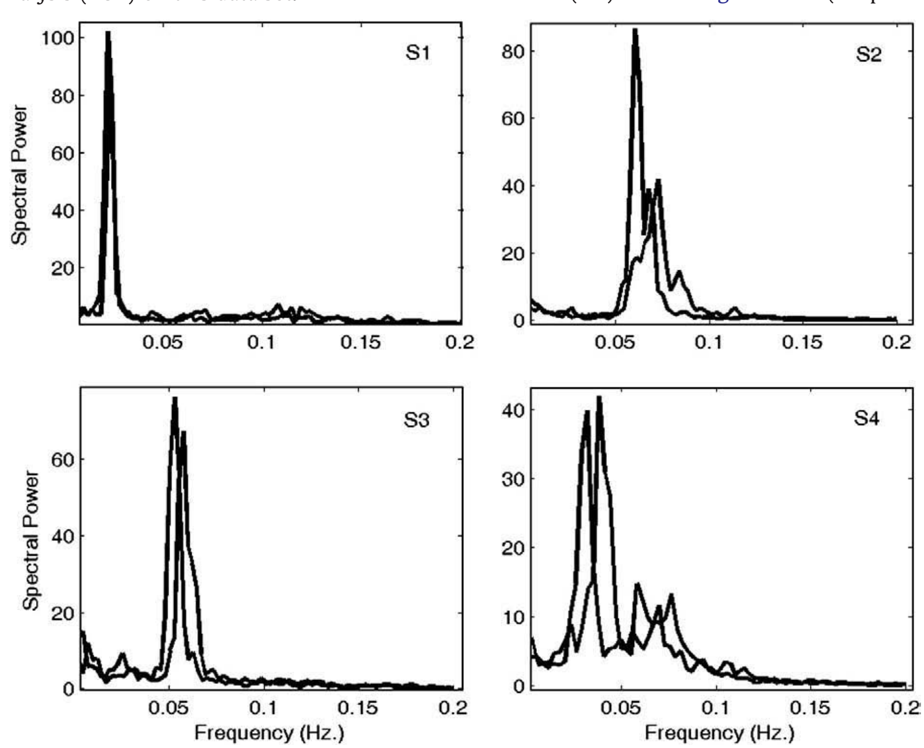

Fig. 2. Power spectrum of RR interval time series, in normalized units, for the novice subjects during Zazen. All plots present two meditations of each subject superposed.

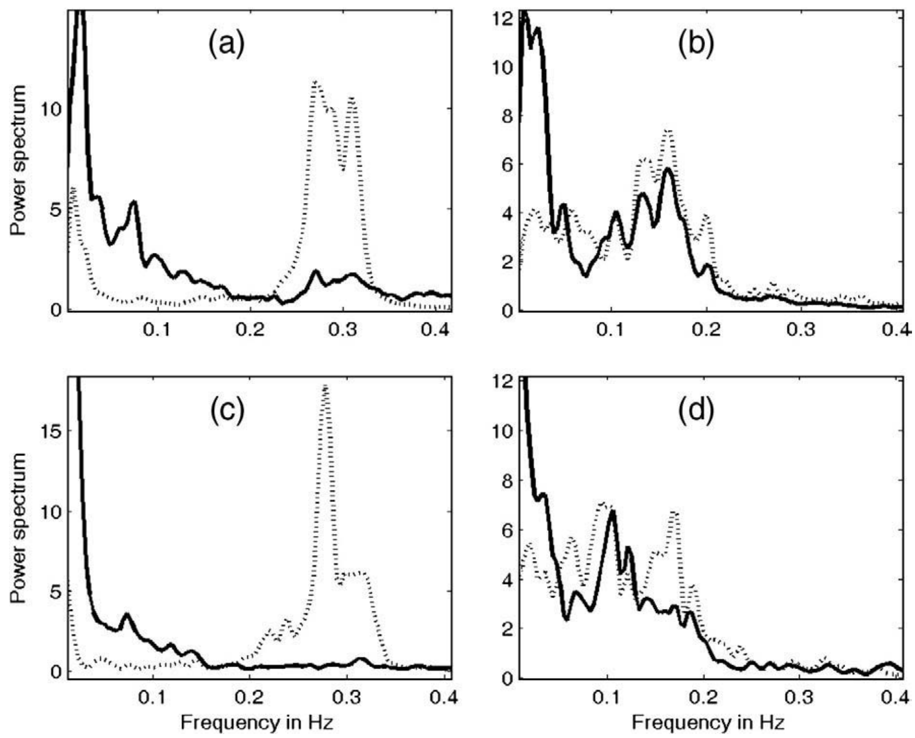

Fig. 3. Power spectrum of HRV (continuous line) and respiration (dashed line) time series, in normalized units, for subjects S6 and S8 (G1), during MM and FA. Subplots (a) and (b) represent S6 and S8, respectively, during MM. Subplots (c) and (d) represent S6 and S8, respectively, during FA. S6 and S8 practice Zen meditation since 3 and 5 years, respectively. For S6 the respiration modules only the typical RSA range, while for S8 the breathing also partially synchronizes with the LF oscillations. For S6 the RSA is decreased in FA (also see Table 1).

there is a tendency towards frequencies coupling as regards the number of years the subjects have meditated.

The temporal evolution of HRV and breathing for S16 during MM are represented in the CWT (Fig. 5). Fig. 6 shows the same data for the Zen master S19. Note the same pattern shown for S16 with two different phases in the meditation.

The presence of a resonant peak in the spectrum is characteristic among novices and experienced Zen meditators. It is in accordance with [6]. Nevertheless, the novices focus on and also silently count their respirations, which probably work as a rhythmic stimulus. Other authors also found that different rhythmical stimulations elicit high-amplitude oscillations in cardiovascular functions at resonant frequencies [7–9].

With expertise the need for voluntary attention efforts to attain concentration decreases and the practitioner gradually reduces the focus to a unique object [1]. This opening of the focus is characterized for the cardiac variability in the three frequency ranges and represents the prominent characteristic of G1. Less experienced practitioners in this group have a higher and more stable respiratory rhythm, while for oldest practitioners it oscillates more, probably due to the opening of the attention focus. The G2 presents much less power in the HF range compared with G1; however these subjects still have great power in the VLF range. According with previous results of advanced Zen meditators [6,10], the G3 presents almost all the HRV in the LF range; the different frequencies are coupled in this band, although there may be variations in frequency, especially in the second half of meditation. We believe that this more irregular pattern in the second half of Zazen, typical among long-term practitioners, could be related to an even less controlled state, when attention stability is well established and a higher deepness in the meditation can emerge.

We cannot establish a specific reason why long-term practitioners may present different results; however if we consider that there is a tendency towards a coupling between the HRV characteristic frequencies regarding the years of meditation practice, and also the previous works and the present results from the Zen master (S19), it is possible that the appearance of a resonant effect between long-term Zen meditators characterizes the pure state of mindfulness.

The decreased respiratory sinus arrhythmia found during FA, for S6, S16 and S19, may be related to a decreased parasympathetic outflow associated with the sustained attention [11], as well as to variations in the respiratory frequency and/or tidal volume induced by voluntary influences on breathing pattern [12].

In conclusion, we can distinguish four levels in Zen meditation. The evolution is coherent as regards the years of practice until a certain level. The specific patterns of HRV of each stage may reflect changes in the breathing pattern as in the parasympathetic outflow associated to the quality and focus of attention.

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Table 1
RSA/Respiration (Resp) quotient.

Subjects	*f* interval	Area RSA	Area resp	RSA/resp
S19 MM	0.05–0.1	0.8364	0.7529	1.1109
S19 FA	0.03–0.07	0.45	0.8775	0.5128
S16 MM	0.06–0.13	0.6331	0.5981	1.0585
S16 FA	0.12–0.17	0.4457	0.7039	0.6331
S8 MM	0.1–0.22	0.3927	0.5397	0.7276
S8 FA	0.075–0.22	0.4512	0.6096	0.7401
S6 MM	0.24–0.34	0.1288	0.7087	0.1817
S6 FA	0.24–0.34	0.0371	0.7408	0.0500

(f = frequency). These results may not be considered statistically significant, since just four subjects performed this procedure.

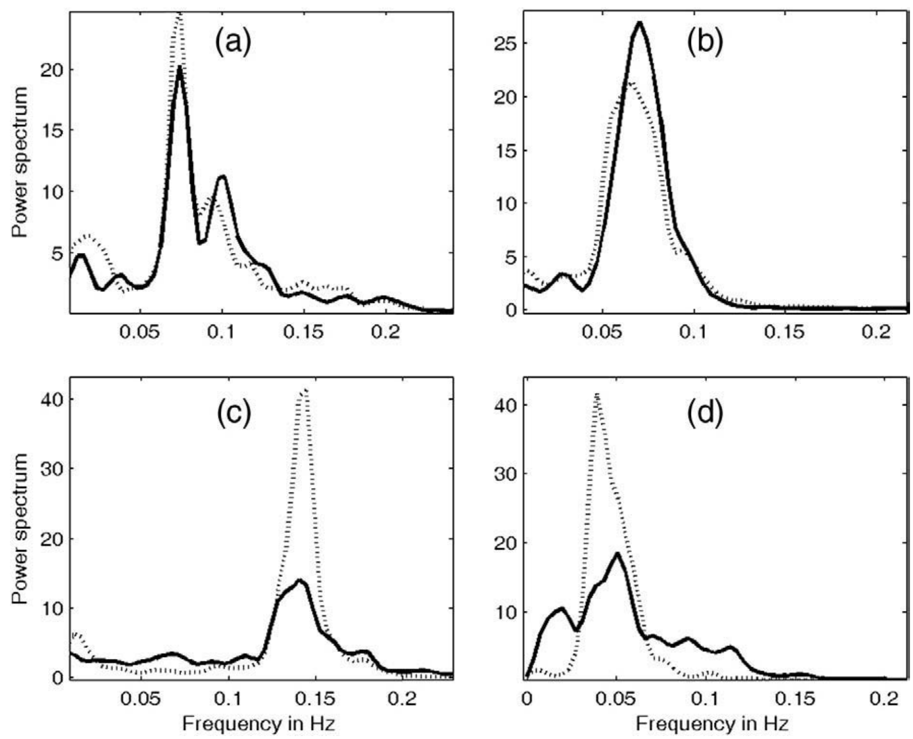

Fig. 4. Power spectrum of HRV (continuous line) and respiration (dashed line) time series, in normalized units, for subjects S16 and S19 (G3), during MM and FA. Subplots (a) and (b) represent S16 and S19, respectively, during MM. Subplots (c) and (d) represent S16 and S19, respectively, during FA. S16 and S19 practice Zen meditation since 11 and 20 years, respectively. S19 is a Zen master and presents an LF resonant peak. For both subjects the RSA is decreased and also shifts to other frequencies in FA (also see Table 1).

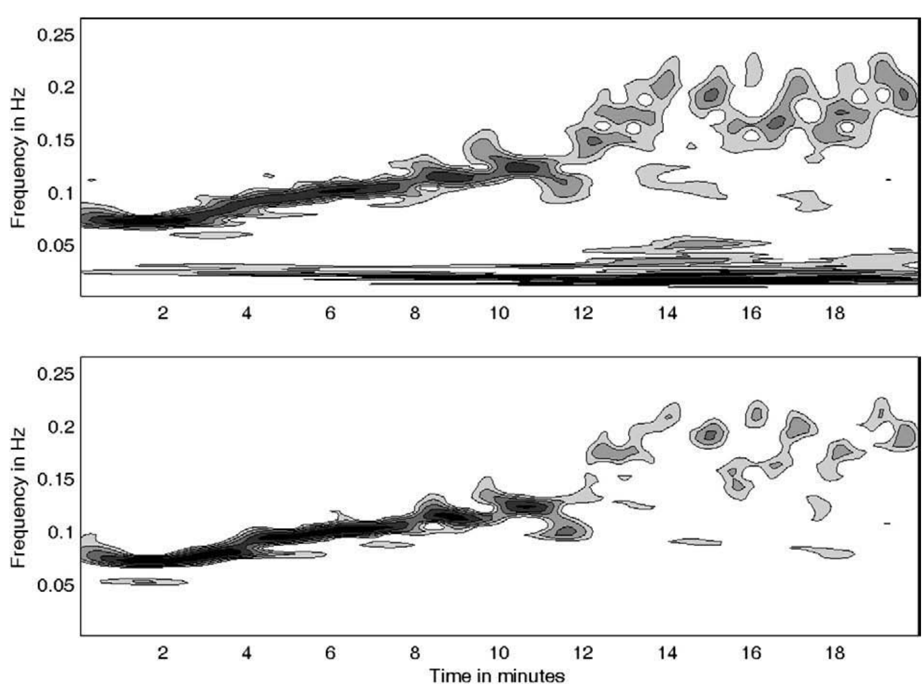

Fig. 5. Wavelet analysis (Morlet $\omega_0 = 20$) of HRV (top) and respiration (bottom) showing the temporal evolution of the frequencies for S16 during MM. The coefficient values (power) are shown in greyscale, where the darker areas represent the values with more power; lower values were excluded. Note as in the second half of meditation there is much more variation; and the disappearance of the resonant effect, although the RSA and the LF oscillations still coincides.

The time-scale or scalogram of a signal is the squared modulus of its wavelet transform: $|W(a, b)|^2$, and is an averaged power spectrum for all the scales or frequencies, similar to a smoothed Fourier, for each time. The scale a and localization parameters b assume continuous values, and the $|WT(a,b)|^2$ of a time series can be visually represented by an image or a field of isolines. In this work, the Morlet wavelet was

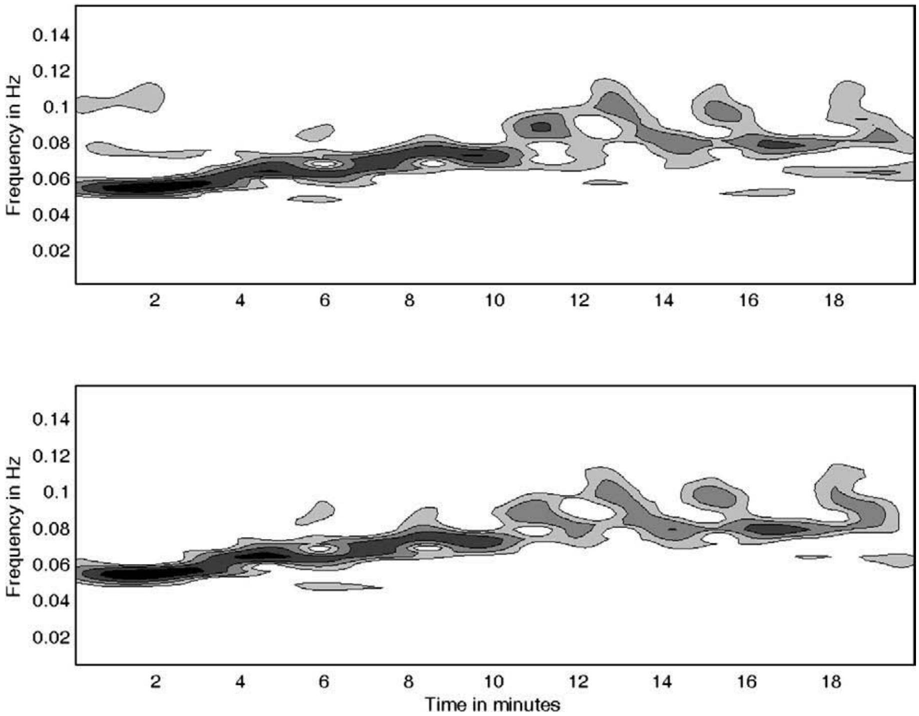

Fig. 6. Wavelet analysis (Morlet $\omega_0 = 20$) of HRV (top) and respiration (bottom) showing the temporal evolution of the frequencies for S19 during MM. The coefficient values (power) are shown in greyscale, where the darker areas represent the values with more power; lower values were excluded. Note as for this subject the breathing oscillates exclusively in the LF range and the resonant effect never disappears.

employed to analyse the temporal variation of the HRV. The Morlet wavelet is a modulated Gaussian function, which is well localised in time and frequency:

$$\psi_0(t) = \pi^{-1/4} e^{i\omega_0 t} e^{\frac{-1}{2}t^2}$$

where ω_0 is a dimensionless frequency which defines the number of cycles of the Morlet wavelet.

References

[1] Lutz A, Slagter HA, Dunne JD, Davidson RJ. Attention regulation and monitoring in meditation. Trends Cogn Sci 2008;12(4):163–9.
[2] Phongsuphap S, Pongsupap Y, Chandanamattha P, Lursinsap C. Changes in heart rate variability during concentration meditation. Int J Cardiol 2008;130 (3):481–4.
[3] Kamath MV, Fallen EL. Power spectral analysis of heart rate variability: a noninvasive signature of cardiac autonomic function. Crit Rev Biomed Eng 1993;21:245–311.
[4] Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology. Heart rate variability: standards of measurement, physiological interpretation, and clinical use. Eur Heart J 1996;17:354–81.
[5] Torrence C, Compo GP. A practical guide to wavelet analysis. Bull Am Met Soc 1998;79:61–78.
[6] Cysarz D, Büssing A. Cardiorespiratory synchronization during Zen meditation. Eur J Appl Physiol 2005;95(1):88–95.
[7] Bernardi L, Sleight P, Bandinelli G, et al. Effect of rosary prayer and yoga mantras on autonomic cardiovascular rhythms: comparative study. BMJ 2001;323:1446–9.
[8] Peng CK, Mietus JE, Liu Y, Khalsa G, Douglas PS, Benson H, Goldberg AL. Exaggerated heart rate oscillations during two meditation techniques. Int J Cardiol 1999;70:101–7.
[9] Vaschillo EG, Vaschillo B, Lehrer PM. Characteristics of resonance in heart rate variability stimulated by biofeedback. Appl Psychophysiol Biofeedback 2006;31 (2):129–42.
[10] Lehrer PM, Sasaki Y, Saito Y. Zazen and cardiac variability. Psychosom Med 1999;61:812–21.
[11] Porges SW. Cardiac vagal tone: a physiological index of stress. Neurosci Biobehav Rev 1995;19:225–33.
[12] Ritz T, Dahme B. Implementation and interpretation of respiratory sinus arrhythmia measures in psychosomatic medicine: practice against better evidence? Psychosom Med 2006;68:617–27.
[13] Coats AJ. Ethical authorship and publishing. Int J Cardiol 2009;131:149–50.

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