Acceleration Change Index for Heart Rate Variability Analysis

Wajid Aziz, Rahat Abbas, Muhammad Arif

Department of Computer and Information Sciences

Pakistan Institute of Engineering and Applied Sciences (PIEAS)

Post office Nilore, 45650 Islamabad, Pakistan.

Fax No. 051-9223727

Emails: kh_wajid@yahoo.com, rahat_abbas@yahoo.com, marif@pieas.edu.pk

Abstract

Acceleration change index (ACI) is a fast and robust marker for analysis of heart rate variability (HRV) dynamics. This index characterizes the sign of difference of time series and theoretical study relates it to autocorrelation function of the time series. HRV time series contains information on the neural modulation of cardiovascular system by autonomic nervous system. Considerable attention has been focused on the potential health benefits of a variety of meditative, relaxation techniques and their possible effects on autonomic nervous system. We applied ACI to analyse heart rate time series from two groups of healthy young adults before and during two well known forms of mediation. We also explored ACI for RR-interval time series of young and elderly subjects watching Fantasia movie and healthy young adults during exercise. It was observed that ACI was almost constant for mediation state and varied for the pre-mediation state. ACI increased during the exercise and was lower for young subjects as compared with the elderly subjects.

Keywords

HRV Analysis, Mediation techniques, exercise stress, and acceleration change index, variation of ACI with age.

1-   Introduction

The human heart is controlled by a series of electrical discharges from specific localized nodes within the myocardium (cardiac muscle). These discharges propagate through the cardiac muscle and stimulate contractions in a coordinated manner in order to pump deoxygenated blood via lungs and back to the vascular
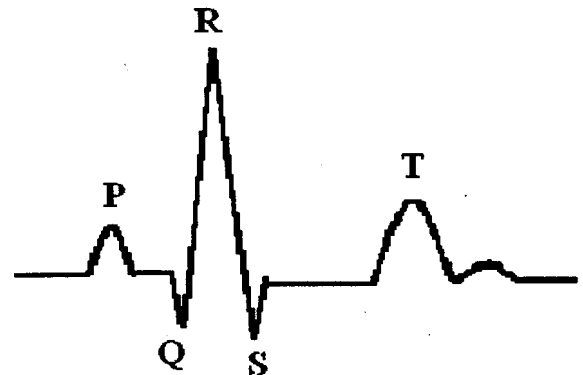
Figure 1: Morphology of PQRS complex of normal subject

system. The physical action of the heart is therefore induced by a local periodic oscillation. As a result of this stimulation, a change of potential of 1mv can be measured during the cardiac cycle between two surface electrodes attached to the patient upper torso. The signal is called electrocardiogram (ECG).

An Electrocardiogram (ECG) is a record of the origin and propagation of the electric potential throughout cardiac muscle. It is considered as a representative signal of the cardiac physiology, useful in diagnosing cardiac disorders. A single normal cycle of ECG represents successive atrial depolarization/ re-polarization and ventricular depolarization/re-polarization which occurs with beat. These can be approximately associated with the peaks and troughs of the ECG waveform labeled as P, Q, R, S and T in Figure 1.

Extracting useful clinical information from real noisy ECG, requires reliable signal processing techniques [10]. These include R-peak detection [12], QT interval detection [17], heart rate and respiration rate

from the ECG [14,15]. The RR-interval is the time between successive R-peaks, the inverse of this time interval gives the instantaneous heart rate. A series of RR-intervals is known as a RR tachogram. Analysis of variations in the instantaneous heart rate time series using beat-to-beat RR tachogram is known as heart rate variability analysis [1, 10].

The easiest way to demonstrate the effects of autonomic modulation on the heart is to monitor the function of the sino-atrial node, i.e. changes in the heart rate. The increased sympathetic stimulation increases heart rate and decreases variability of heart rate [7]. Heart rate variability analysis by time-domain (statistical and geometrical indices) and frequency domain (spectral indices) methods are widely used non-invasive methods for evaluating cardiac autonomic activity. The usefulness of these HRV indices depends on their specificity and sensitivity, their robustness in the presence of artefacts and time required for their computation. On one hand the spectral indices need more computing time than statistical indices. On the other hand statistical indices have less sensitivity and specificity to several cardiovascular diseases. All the power spectral indices and some statistical indices that need the estimation of the variance of the signal are prone to fail in the presence of artefacts. Despite of their pitfalls these indices are still used in clinical research. Nowadays, indices for the characterization of the dynamics and complexity of heart rate variability time series have arisen [3] with promising results. Nevertheless, these indices need more computer resources and are difficult for the physicians to understand.

Ashkenazy et al [4] used the sign of the differences of the RR time series as an intermediate time series in their scaling analysis of RR time series. They applied the detrended fluctuation analysis method in order to obtain the scaling exponents of the sign series. Instead of this approach, Gonzalez et al [5] proposed acceleration change index (ACI), which characterizes the heart rate variability dynamics. This index is related to the autocorrelation function (ACF) of the time series. This is robust fast index, easy for the physician to understand, which characterizes the sign of the differences of time series.

There has been much interest in heart rate dynamics during a variety of physiological and pathological states. In addition, considerable attention has been focused on the potential health benefits of a variety of meditative, relaxation techniques and their possible effects on neuroautonomic function. Surprisingly, however, there is little information regarding the effects of mediation on the beat-to-beat heart rate dynamics as an indirect assay of autonomic regulation [6,8,9]. The aim of the work is to study two meditative techniques by applying ACI index and sought to determine 1) whether there are any distinctive heart rate dynamics during these practices and 2) whether such meditative states induce a quiescent (less variable) or active (more variable) pattern of autonomic response. The effect of exercise on the ACI index and its variation for young and elderly subjects is also explored during this work.

1.   Acceleration Change Index

Acceleration change index (ACI) arises from the quantification of the transformation of the tachogram involving linear and nonlinear operations. Following procedure was adapted to obtain ACI.

1.   Given a filtered time series RR. The differentiated time series (DRR) is obtained as:

$$DRR(n) = RR(n+1) - RR(n) \qquad (1)$$

$$n \in [1, N-1]$$

Where RR(n) is the RR interval from beat n to beat n+1, and N is the total number of RR-intervals.

2.   The $SDRR$ time series is the sign of the DRR series. Accordingly, its elements are either 1 (if $DRR \geq 0$) or 0 (if $DRR < 0$). If $SDRR(n) = 1$, the heart rhythm decelerates between beats n and $n + 1$. Conversely, $SDRR(n) = 0$ implies an acceleration between beats n and $n+1$.

3.   Starting from $n = 1$ to $n = N - 1$, we generate the sign change (SC) series as

$$SC(j) = n \qquad (2)$$

if $SDRR(n) \neq SDRR(n-1)$, $j \in [1, M+1]$

where $M + 1$ is the number of sign changes. $SC(j) = n$ implies that $RR(n)$ is the jth local maximum or minimum of the tachogram. On the other hand, there are $M + 1$ local maxima and minima.

The DSC is defined as the differentiation of SC to obtain the distance (in beats) between successive changes of sign of the DRR time series:

$$DSC(j) = SC(j+1) - SC(j)$$
(3)

The acceleration change index (ACI) is defined as:

$$ACI = \frac{k}{M}$$
(4)

where k is the number of times DSC time series equal 1 and M is the total number of samples of DSC time series. The ACI is equal to the number of times that a local maximum is followed immediately by a local minimum (or vice versa) divided by the total number of local maxima and minima. Figure 2, shows the graphical representation how ACI was computed.

2. Relationship of ACI with ACF

Equation (4) does not reflect its relationship with the dynamics of the signal. If we analyse the local behavior of three consecutive samples of SDRR (a series of '1' or '0'), k only increases when the sequence {0,1,0} or {1,0,1}

(a)

(b)

(c)

(d)

(e)
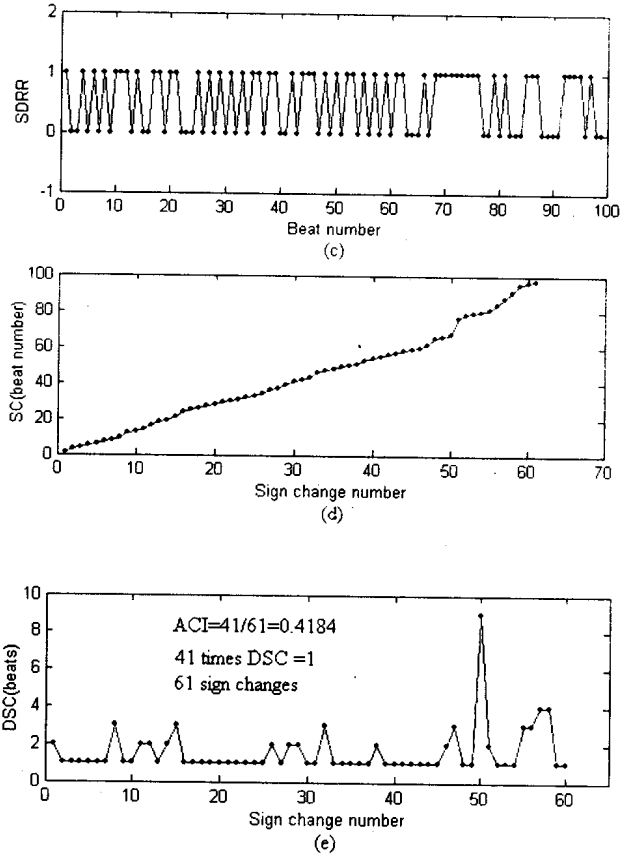
Figure 2: (a) RR-interval time series (RR) (b) Differentiated time series (DRR) (c) Sign of DRR (SDRR) (d) Position (in beats) of the sign changes (SC) and (e) Distance between successive sign changes (DSC).

and M increase when the sequence {0,1} or {1,0} is present. Then ACI can be calculated as:

$$ACI = \frac{\sum_{i=3}^{N} \frac{1}{2} \left(\begin{array}{c} |SDRR(i) - SDRR(i-1)| + \\ |SDRR(i-1) - SDRR(i-2)| + \\ |SDRR(i) - SDRR(i-2)| \end{array} \right)}{\sum_{j=2}^{N} |SDRR(j) - SDRR(j-1)|}$$
(5)

Let Sk is a bimodal random variable that is '1' when samples separated by a lag k have different signs and '0' when they have same signs. Let sk is realization of Sk. Then sk = $|X_i - X_{i+k}|$=1, when samples i and i+k have different signs and sk = $|X_i - X_{i+k}|$=0, when they have same signs, where Xi is the sign of the time series at sample i.

Barentt et al [4] have demonstrated that (for monotonic transformations, additions and products of
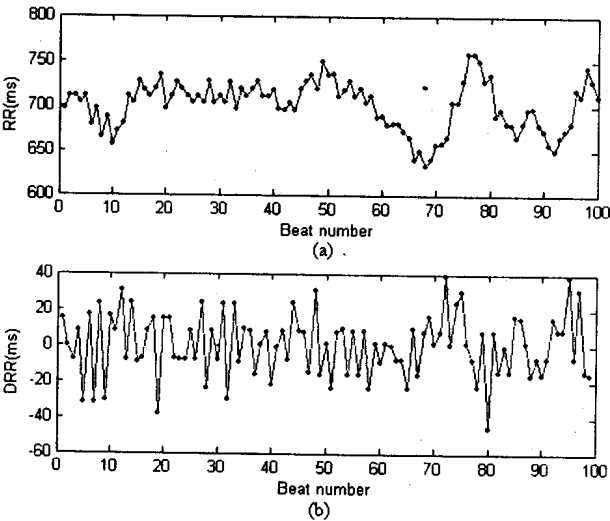
This study tries to find the effect of mediation on the ACI. We studied two mediation techniques namely, Chi mediation and Yoga mediation and compared pre-mediation and mediation states. In addition to this, we also compared three non-mediating control groups with Chi mediation group.

In case of Chi mediation (500samples), the pre-mediation ACI is (0.65±0.12) and mediation ACI is (0.64±0.10). No significant difference was observed between the results of pre-mediation and mediation state (p=0.37). The ACI for the Yoga pre-mediation state is (0.51±0.13) and for mediation state is (0.66±0.04). When comparing pre-mediation and mediation state, the test showed no significant difference (p=0.076).

We also compared Chi mediation group with three healthy non-mediating control groups(i) A spontaneous breathing during sleep, (ii) Metronomic breathing group during sleep and (iii) Elite athlete group in their pre-raced period during sleep.

The ACI for the spontaneous breathing is (0.56±0.2) and for chi mediation is (0.65±0.07). No significant difference was observed between the results of chi mediation and spontaneous breathing group (p=0.12). The ACI for metronomic breathing group is (0.4±0.15) and for the mediation group is (0.65±0.07). When comparing chi mediation with metronomic breathing group, a significant difference was observed (p=0.001). The ACI of elite athletes is (0.54±0.14) and for mediation group it is (0.65±0.07). Significant differences were observed in elite athlete group and mediation group (p=0.05).

It was also observed that ACI remained almost constant during mediation as compared to pre-mediation or with three non-mediation groups.

Variation of ACI with Age:

ACI was calculated for 10 young (21-34) and 10 old (68-85) subjects. The ACI for young subjects is (0.48±0.1) and for old subjects ACI is (0.59± 0.06). Thus elderly subjects have large ACI than young subjects. The paired student t-test showed a significant difference (p=0.03) between young and elderly subjects.

Effect of Exercise on ACI:

We applied ACI to RR-interval time series of exercise data set and studied effect of the duration of exercise on the ACI. We made two studies. 1) for fixed time intervals 2) for whole duration. In both cases we observed that ACI increases during and with the increase in the duration of the exercise. The increase of ACI with exercise can be explained by the increase in the sympathetic and vagal tones.

Matlab 6.1 [19] was used for simulating these results.

6.   Conclusion:

ACI is a fast and robust index that reflects the dynamics of the RR-interval time series and is related to autocorrelation function of the time series. We applied   ACI to analyse heart rate time series from two groups of healthy young adults before and during two well known forms of mediation and compare them with three non-mediating control groups. We also explored ACI for RR-interval time series of young and elderly subjects watching Fantasia movie and healthy young adults during exercise.

It was observed that during mediation state the ACI remained almost constant as compared non-mediating state. On comparing mediation group with three healthy non-mediating control groups, the t-test showed significant differences (p<0.001) for metronomic group. When comparing young and old subject, the ACI is lower for young for young subjects than in elderly subjects. The ACI increases during exercise and with duration of the exercise.

In this preliminary study ACI has shown some promising results. Nevertheless, an epidemiological study must be performed in order to assess the discriminant value of the index.

Table 1: Comparison of ACI in Chi mediation and yoga mediation group

Group	State	ACI
Chi Mediation Group	Pre-Mediation	0.65 ±0.12
	Mediation	0.64 ± 0.10

Yoga Mediation Group	Pre-Mediation	0.51 ± 0.13
	Mediation	0.66 ± 0.04

Table 2: Comparison of ACI in Chi mediation and control breathing groups.

Chi Mediation	Spontaneous Breathing	Metronomic Breathing	Elite Athletes
0.65±0.07	0.56±0.2	0.4±0.15	0.54±0.14

Table 3: Comparison of ACI for young and elderly subjects.

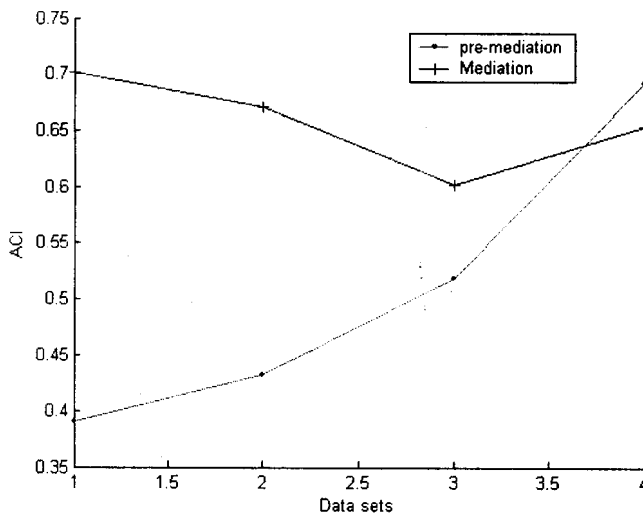| Young Subjects	Elderly Subjects
0.48±0.1	0.59± 0.06
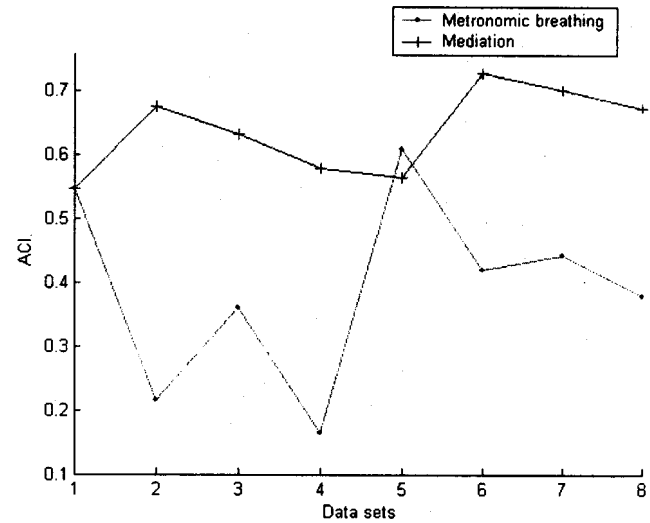
Figure 5: ACI for chi mediation and metronomic breathing.
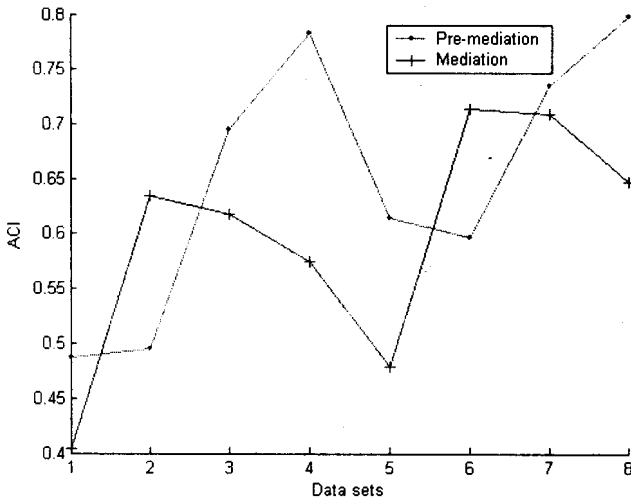
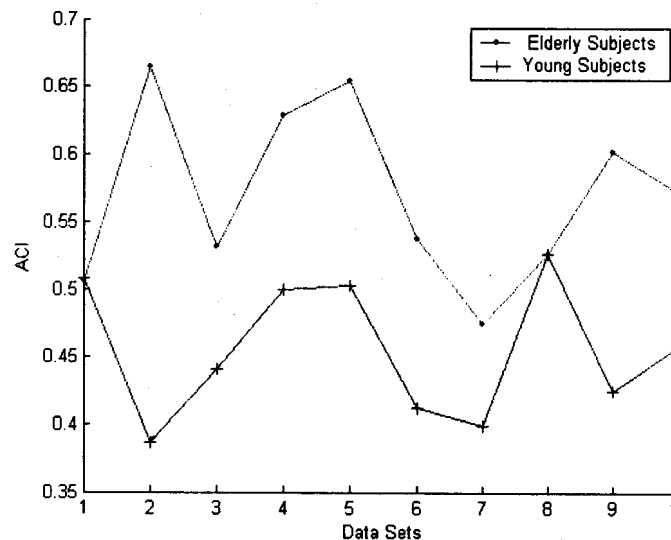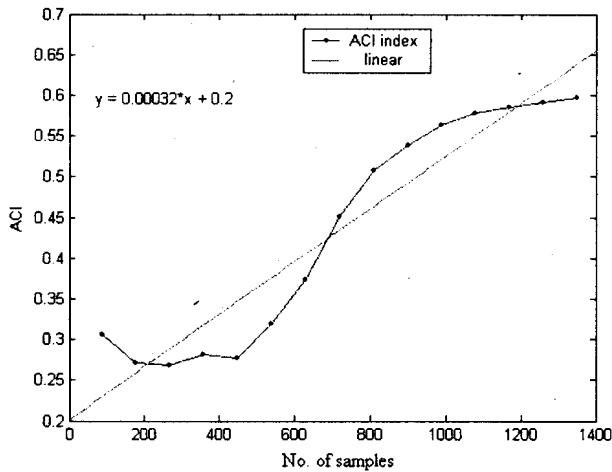**Figure 3**: ACI for Chi mediation
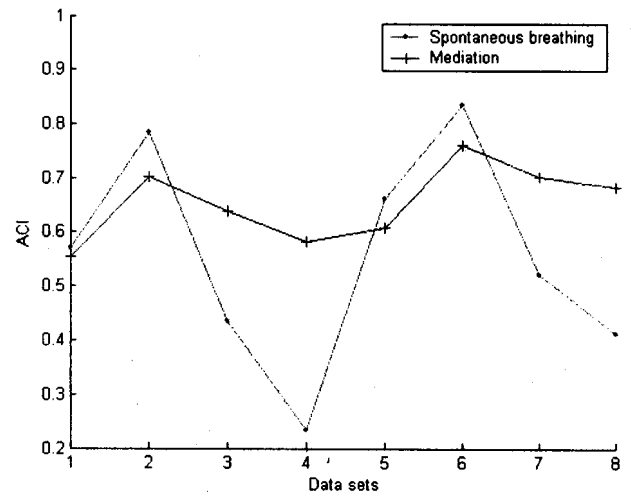
Figure 6: ACI for chi mediation and spontaneous breathing.

Figure 4: ACI for Yoga mediation

Figure 7: ACI for young and old subjects

Figure 8: ACI during exercise

References:

1. D.T. Chandra, D.B. Yeates and L.B. Wong (2003). "Heart Rate Variability Analysis — Current and Future Trends,", business briefing healthcare.

2. Task Force of European Society of Cardiology, the North American Society of Pacing, Electro-physiology (1996). "Heart rate variability standards of measurement, physiological interpretation, and clinical use" Eur Heart J. 17 354-81.

3. Barentt and Kendem B 1998 " Zero-crocessing rates of mixtures and products of Guassian process IEEE Trans. Inf. Theory 44 1672-7.

4. Ashkenazy Y, Ivanov PCh, Havlin S, Peng C K Yamamoto Y, Goldberger A L and Stanley H E 2000 "Decomposition" of heartbeat time series: scaling analysis of the sign sequence proc, compt. Cardiol.27 139-42.

5. M A Garcia-Gonzalez, J Rames-Castro and Fernandez-Chimeno (August 2003) "A new index for the analysis of heart rate variability dynamics: characteriza-tion and application.

6. C.K. Peng, Joseph E. Mietus Yanhi Liu, Gurucharan Khalsa, Pamela H. Douglas Herbert Benson, Ary L Goldberger "Exaggerated Heart Rate Oscillations During Two Mediation Techniques".

7. Asterios P. Deligiannis Laboratory of Sports Medicine, Department of Physical Education and sports Science, Aristotle University of Thessaloniki, Greece "The effect fo Exercise Training on Cardiac Autonomic Nervous Activity.

8. Corby JC, Roth WT, Zarcone VP Jr, Kopell BS. "Psycho-physiological correlates of the practice of Tantric Yoga mediation. Arch Gen Psychiatry 1978; 35:571-577.

9. Sakakibara M, Takuchi S, Hayano J. " Effect of relaxation training on cardiac parasympathetic tone. Phychophysiology 1994;31:223-228.

10. Malik M, Camm AJ. Heart Rate variability. Armonk NY: Futura publishing, 1995.

11. http://www.physionet.org/physiobank/data base/Fantasia.

12. J. Pan and W.J. Tompkins, (1985)" A real time QRS detection algorithm" IEEE Tran. Biomed. Eng., vol. BME-32, pp.220-236.

13. D.T. Kaplan, "Simultaneous QRS detection and feature extraction using simple matched filter basis function " computers in cardiology. Los Alamitos, CA: IEEE comput. Soc press 1991, pp.503-506.

14. G.B. Moody, R.G. Mark, M.A. Zoccola, and S. Mantero, "Derivation of respiratory signals from multi-lead ECGs" in compu. Cardial., 1985, vol.12 pp.113-116.

15. G.B. Moody, R.G. Mark, M.A Bump, J.S. Weinstein A.D. Berman, J.E. Mietus, an dL.A Goldberger , " Clinical validation of the ECG derived respiration (EDR) technique," comput. Cardial., vol. 13, pp . 507-510, 1986.

16. "Analysis of Heart Rate Dynamics By Methods Derived from Nonlinear Mathematics Clinical applicability and

prognostic significance," Ph.D. thesis by Timo Makikllio University of Oulu 1998.

17. P. Davey, " A new physiological method for heart rate correction of the QT interval, in Heart 1999, vol. 82, pp.183-186.

18. https://petrus.upc.es/~wwwdib/people/ GARCIA_MA//databasemain.htm.

19. http://www.mathworks.com.

20. http://www.physionet.org/physiobank/ database/meditation/data.