Proceedings - 19th International Conference - IEEE/EMBS Oct. 30 - Nov. 2, 1997 Chicago, IL. USA

Morphological Variations in ECG During Music-Induced Change in Consciousness

G. C. Ray* Alexander Ya. Kaplan** E. Jovanov+

* Electrical Engineering Department, Indian Institute of Technology, Kanpur-208016, India

** Biological Department, Moscow State University, Russia

+ Institute 'Mihajlo Pupin', University of Belgrade, Yugoslavia

ABSTRACT

In these experiments, the state of mind was changed using music to a group of subjects susceptable to aesthetic appreciation, a phenomena alternatively known as musicogenic epilepsy. The change in EEG is characterized by large number of spikes, symtomatic to epilepsy, along with a change in the background EEG. The *fractal dimension* of EEG was found to reduce during epoch period. It was also noted that, morphological changes in ECG occur during some part of the epoch period. This change is characterized by the increase in height of the QRS complex and considrable reduction in the height of T-wave; indeed the latter gradually vanishes and appears again slowly. The heart rate variability (HRV) analysis of the epoch and nonepoch periods show increased height of the second peak ($0.05-0.15$ Hz) as well as higher ratio of the second to third peak ($0.18-0.45$ Hz) possibly suggesting mild sympathetic burst on the autonomic system (ANS). Pole-tracking algorithm, using linearization method, shows that the poles move considerably arround their initial positions during epoch period where as the movement of poles are very little during nonepoch.

Keywords: Musicogenic Epilepsy, Altered State of Consciousness, Heart Rate Variability (HRV), Pole-tracking, Morphological Change in ECG.

INTRODUCTION

Musicogenic epilepsy was first reported by Critchley [1]. Subsequently in the sixties, Servit *et al* [2] reviewed twenty cases where seizures were triggered by music; many of the reports indicated that the induced seizures were located in the temporal lobe and probably arose from foci in the auditory cortex. It is also interesting to note that musicogenic epilepsy, in some cases, has been found related to something devotional. Poskanzer *et al* [3] reported that only a discrete frequency band of church bell caused musicogenic epilepsy and Marsden *et al* [4] mentioned a patient whose grandmal seizures were initially provoked by certain types of classical orchestral and church music, and who could be induced to have a fit by Beethoven's Fifth Symphony. Most of the reports indicate that the induced seizures are located in the temporal lobe and probably arose from foci in the auditory cortex. However, in some recent study the impulses were found more widespresd towards frontal and parietal, but the occipital lobe was always free from it [5].

The present authors' emphasis on this topic is due to the fact that the altered state of consciousness and the consequent change in physiological parameters are rather easy to create in the laboratory and the results are experimentally repeatable.

EXPERIMENT AND THE RESULTS

During the experiment, the subjects reclined in a comfortable chair placed within a large Faraday cage (to minimize interference). Musics of their own choice were played and they concentrated on it with eyes closed. Lights were off and EEGs and the ECG were recorded in a multichannel TEAC MR-10 cassette recorder. Both classical and devotional musics were tried and the best result was obtained when the subjet was a soft-natured devotee and the music was devotional. The special emphasis required to enhance musicogenic epilepsy are described earlier [6]. In the EEGs, *epoch periods* were characterized by the presence of spikes and *nonepoch periods*, by its absence. The ECGs corresponding to the same periods (lead-II, recorded in the ninth channel) were also termed *epoch* and *nonepoch*. Both EEGs and ECGs were digitized by a $12-bit$ A-to-D converter with sampling period 5 ms.

Some of the waveshapes are shown in $Fig.1(a)$ to (h). Both (a) and (b) (EEG and ECG) correspond to nonepoch period whereas (c) and (d) for the epoch period. The change in EEG is characterized by the presence of spikes (all within 43 to 86 ms) in addition to the change in the background EEG (spikes are usually preceeded and followed by low magnitude slow frequency waves). These were obtained with other six subjects earlier [5]. In ECG, the height of QRS complex is increased more than 25% and the T-wave is considerably reduced.

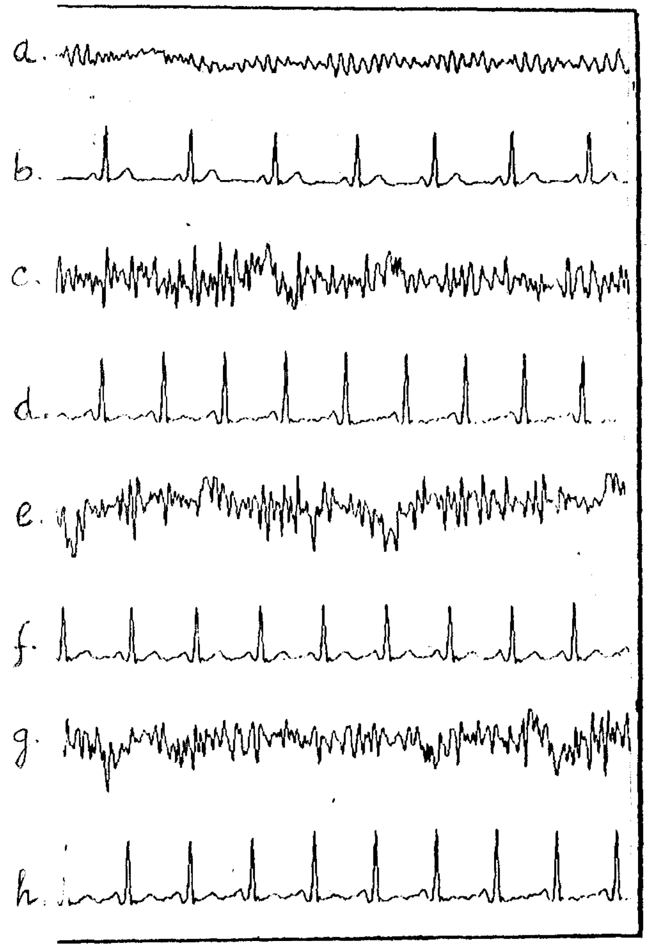

Fig.1 EEGs and ECGs during epoch and nonepoch periods (x-axis=5 seconds)

This type of change in ECG is seen when the duration of epoch in EEG exceeds more than a minute; also the duration of epoch in ECG remains for little time within the epoch of EEG. In the present example, the duration of epoch in ECG was about 7 *seconds*; the entire epoch in ECG is shown in *Fig*.2(*a*). In *Fig*.2(*b*), T-wave is gradually reduced in magnitude (enlarged view) and in 2(*c*) it appears gradually. When the duration of epoch in EEG is in the range of 5 to 15 seconds, there is little change in ECG except a little reduction in T-wave as is shown in *Fig*.1(*e*) and 1(*f*). In *Fig*.1(*h*) the gradual change in ECG is shown from almost near-normal to complete elimination of T-wave within epoch EEG.

Analysis of EEG

As it was reported earlier, both fractal dimension F_2 and r-parameter of EEG are reduced during epoch period [5-7].

Fractal Dimension: We assume that the system of interest (say the genesis of EEG) can be described by the interactions of m variables where m is large but unknown; also the exact nature of interactions among the variables are not known. In many cases a few trajectories (funtions of time) may be obtained from the system either by simulation or direct experimentation.

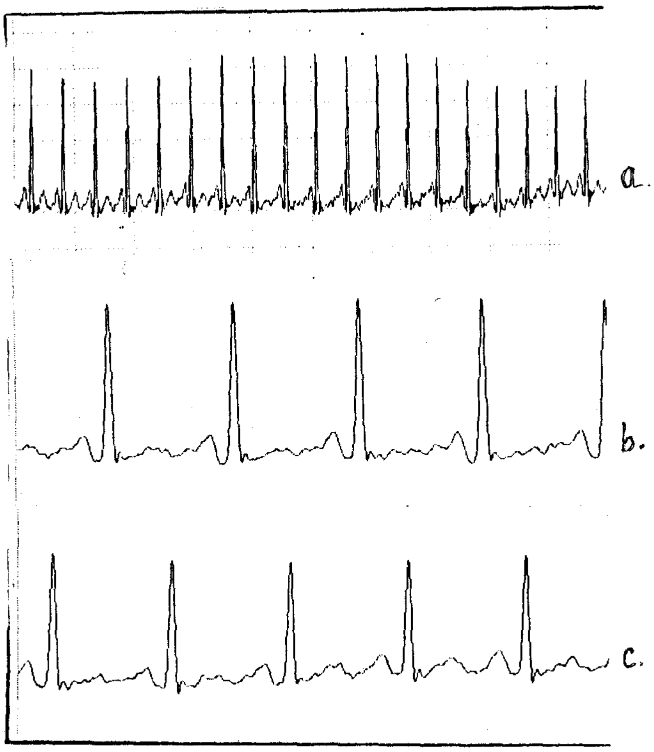

Fig.2 ECG in the epoch period
x-axis=10s in (a), but 2.5s in (b) and (c)

If the number of trajectory is at least one, it is assumed that it is influenced by all the m variables and also the entire set of unknown interactions have shaped it. With a single trajectory it may not be possible to decipher all the variables with its characteristic interaction, but chaos modelling provides some information about the system [8]. In a M-dimentional phase space a point $x_i(t)$ is represented as $x_i(t) = [x(t), x(t+\tau), x(t+2\tau), ..., x(t+(M-1)\tau]$ where τ is the sampling interval and $x(t)$ is the trajectory; similarly $x_j(t)$ may be represented by $[x(t+d), x(t+d+\tau), ..., x(t+d+(M-1)\tau)]$ where d is the delay. In brief the set of points $\{x_i(t)\}$ completely characterize the system. This set of points has been shown to have the same amount of information of multiple data streams comprising different variables if $M \geq 2m+1$. The point $x_i(t)$ (or simply x_i) moves around as the system evolves; it may approach a fixed point or limit cycle asymptotically in time as well as it may move randomly but lying confined within a chaotic attractor zone.

A count $Cm(r)$ may be obtained as [9]

$$Cm(r) = \lim_{N \to \infty} \frac{1}{N_{ref}} \sum_{i=1, j \neq i}^{N_{ref}} \theta[r - | x_i - x_j |] \quad (1)$$

where N = number of data points, N_{ref} = number of reference points and θ is the heavy-side function. The $lnCm(r)$ may be plotted as a function of $ln(r)$ and its slope gradually increases with the increasing embedding dimension M. The saturating value of the slope is the correlation dimension F_2.

The variation of F_2 with average and standard deviation during musicogenic epilepsy has been discussed elsewhere [6,7]. In the present waveshape of EEG, shown in *Fig*.1, it was reduced from 3.46 to 2.77 (from epoch to nonepoch).

r-Parameter : The logistic equation $\overline{y}_n = \overline{y}_{n-1} exp\{r(1 - \overline{y}_{n-1})\}$ where $0 <| \overline{y}_n |< 1.0$ is used here to find out the r-parameter [10]. Assume that the digitized EEG is represented by y_n, $n = 0, 1, ...N - 1$. Also the EEG is simulated using the logistic equation with r as a parameter and the summation of the square of the residuals are P_N. Basically the value of r is found out for minimum total error P_N.

This gives rise to several conditions: $\overline{y_0} \neq 0.5$, and

$$X_r = \sum_{n=1}^{N-1} e_n [\Pi_{i=1}^{n-1} exp\{r(1 - \overline{y}_i)\}(1 - r\overline{y}_i)] = 0 \quad (2)$$

and

$$rratio = (e_n / e_{n-1}) exp\{r(1 - \overline{y}_{n-1})\}(1 - r\overline{y}_{n-1}) \quad (3)$$

The value of r is found out from the last two equations [7]. It was found that, for the EEG of both epoch and nonepoch, r varied between 2.85993 to 2.86008, a very narrow range [10]. The r-parameter is calculated as $(r - 2.85990) \times 10^5$. In the present case it was reduced from 10.33 (nonepoch) to 7.00 (epoch).

Analysis of ECG

The ECG data of the duration of about 2.5 minutes were taken covering the epoch period of EEG. The R-R intervals were then taken (time intervals between successive QRS complexes). It is shown in *Fig*.3(a); it may be seen that the R-R intervals are gradually reducing, *ie*, heart rate is increasing except the two sudden peaks. In nonepoch period of the same duration, the R-R intervals remain more or less same *Fig*.3(b). These are mentioned here as heart rate variability (HRV) signal. HRV signals have been widely investigated since early 1970's for the assessment of autonomic functions [11,12] as well as for various pathologies like hypertension, diabetes and myocardial ischemia.

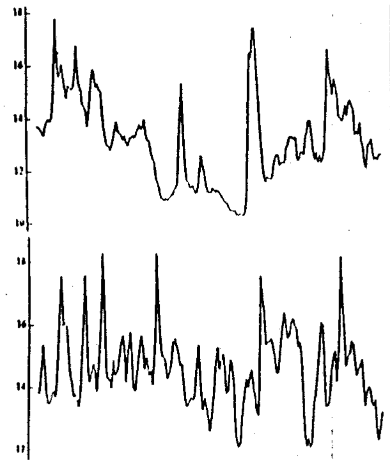

Fig.3 R-R intervals for the epoch (upper) and nonepoch (lower) periods of HRV signals

The frequency domain analysis of these signals show three main peaks. One is in the domain $0.18 - 0.45$ Hz and is synchronous with respiratory activity; this is generally accepted as a 'marker' of vagal tone [12].

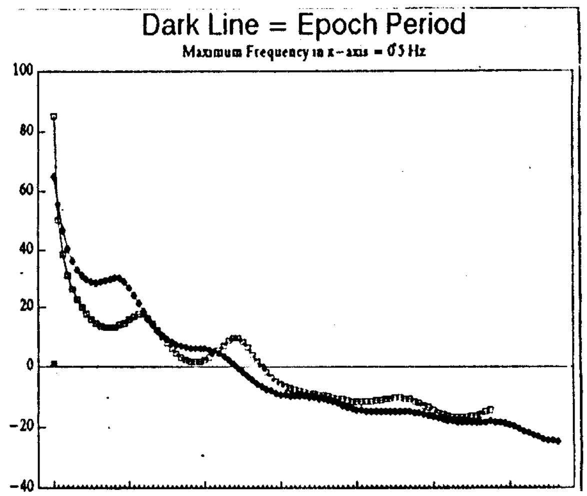

Fig.4 Spectrum of HRV signal: $x - axis$ is in Hz.

The second peak lies in the range $0.05 - 0.15$ Hz and the power in the peak increases in presence of increased sympathetic tone. The power in these two peaks and the ratio has been used as noninvasive measures of sympathovagal interactions [13]. The first peak lies below 0.04 Hz and is due to the thermoregulatory cycle.

HRV spectrum : The prediction coefficients (a_k, $k = 0, 1, ..p$) were obtained from the HRV signal using Levinson-Durbin algorithm following an all-pole model of order p. The spectrum was then calculated as $S(m) = G/(1 - \sum_{k=0}^{p} a_k e^{-j\omega mk}$, where G was the gain. The result is shown in $Fig - 4$ for both epoch and nonepoch periods. It shows a higher peak in the frequency range $0.05 - 0.15$ Hz for epoch period, *ie* a sympathetic burst on ANS.

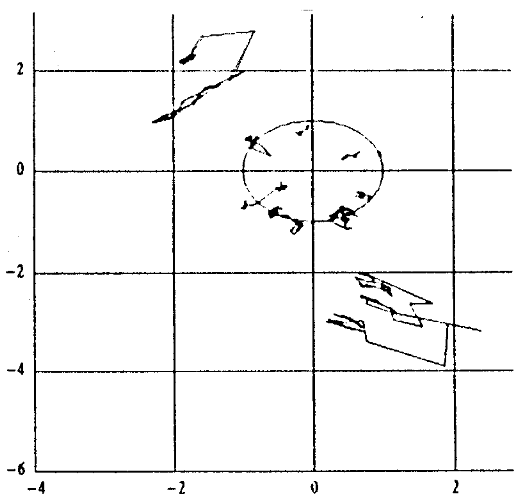

Fig.5 Movement of poles during epoch period

Pole-Tracking : Pole-tracking algorithm was carried out according to linearization method [13].

$$1.0 - \sum_{k=1}^{p} a_k z^{-k} = \Pi_{i=1}^{p}(z - z_i) \tag{4}$$

In the above equation, the denominator of the transfer function is represented by p poles. It is determined in the following way:

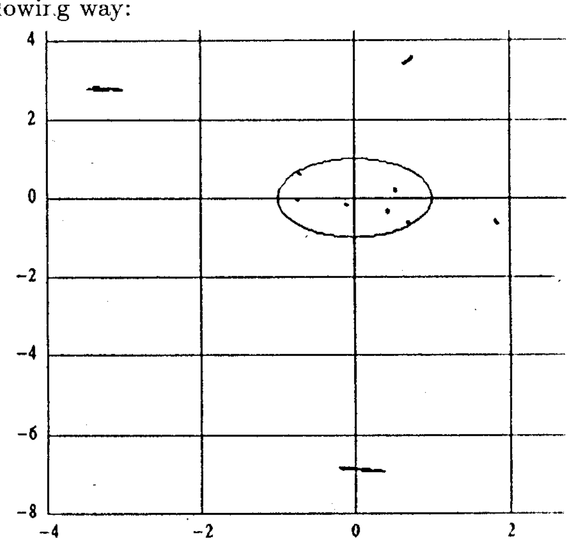

Fig.6 Movement of poles during nonepoch period

$$\frac{\delta z_i}{\delta a_k} = \frac{(z_i)^(p-k)}{\Pi_{l=1,l\neq i}^{p}(z_i - z_l)} \tag{5}$$

$$\Delta z_i = \sum_{k=1}^{p} \frac{\delta z_i}{\delta a_k} \Delta a_k \tag{6}$$

Initially small random complex values are choosen as poles. The first 32 values from HRV signal are considered as the first frame and its prediction coefficients (PCs) are obtained. The frame is then shifted right by one value and again PCs are calculated. The difference between the two gives $\Delta a_k, k = 1..p$. Using equation (5) and (6), the change in pole positions, $\Delta z_i, i = 1..p$, are obtained. The new pole-position is then calculated as $z_{i+1} = z_i + \Delta z_i$. In *Fig*.5, the movement of all poles during epoch period are shown. Out of ten poles, eight remain more or less confined within the unit circle; two remain outside. The pole positions and its movements are shown in *Fig*.6 for the nonepoch period.

It is seen that, movement of poles are very little during nonepoch period whereas it is considerably more in epoch period. The probable reason may be the sympathetic burst on ANS. Also poles outside the unit circle move more compared to those lying inside.

REFERENCS

[1] Critchley M, 'Musicogenic Epilepsy', *Brain*, vol.60, p.13, 1937.

[2] Servit Z *et al*, 'Reflex Influences in the Pathogenesis of Epilepsy in the light of Clinical Statistics', *Epilepsia*, vol.3, p.315, 1962.

[3] Poskanzar D C *et al*, 'Musicogenic Epilepsy Caused only by a Discrete Frequency Band of Church Bells', *Brain*, vol.85, p.77, 1962.

[4] *A Textbook of Epilepsy*, Laidlaw J & Richens A (eds). Churchill-Livingstone, p.108, 1982.

[5] Ray GC and Kaplan AY, 'Transcendent Signal and Its Possible Signature on Electroencephalogram' *Journal Inst. Engineers (India),* vol 74, March, pp.22-31, 1994.

[6] Ray GC, 17th Int. Conf. IEEE Engg. in Med. & Biol., Sept 20-23, Montréal, Canada, 1995.

[7] Ray G C, 'r-Parameter : A New Measure of Level of Consciousness', *Journal Inst. Engineers (India)*, Vol.76, p.7-12, September 1995.

[8] Parker S T and Chua L O, 'Chaos: A Tutorial for Engineers', Proceedings of IEEE, vol.75, no.8, pp.982-1008, 1987.

[9] Farmer J D *et al*, 'The Dimension of Chaotic Attractors', Physica, vol.7D, pp.153-180, 1983.

[10] May R M, 'Simple Mathematical Models With Very Complicated Dynamics', Nature, vol.261, June 10, pp.459-567, 1976.

[11] Hyndman B W *et al*, 'Spontaneous Rhythms in Physiological Control Systems', Nature, vol.233, pp.339-341, 1971.

[12] Billman G E *et al*, 'Dynamic Changes in Cardiac Vagal Tone as Measured by Time Series Analysis', Am. J. Physiol. vol.258, pp.H869-H902, 1990.

[13] Mainardi L T *et al*, IEEE Trans. Bio. Med. Engineering, vol.42, pp.250-259, March 1995.