# Chapter 21
# A Comparative Study on Three Different Types of Music Based on Same Indian Raga and Their Effects on Human Autonomic Nervous Systems

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**Abstract** Complex heart dynamics reflects activities of human non-autonomous system through Heart rate variability (HRV). Poincaré plot is one of the fascinating geometrical tools, which can properly describe the complex heart dynamics. In this chapter, the effect of music on HRV is studied by observing the geometric pattern of Poincaré plot. In this concern, Indian classical music based on Raga 'Malkaunsh' is selected in different forms, and HRV signals are collected from different persons. Then, we have identified the differences (if any) in the pattern of music in the three cases, where by pattern we understand dynamics, timber, rhythm and tonality. Next, by using Poincaré plot it is investigated whether the different types of music have different types of effects on HRV. The whole study has been carried out for both of Indian Raga music initiated and non-initiated (IRM and NIRM) persons.

**Keywords** Complex dynamics · Heart rate variability (HRV) · Psycho-acoustic music · Poincaré plot

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## 21.1 Introduction

Mind and body of the human being sometimes feel stressed due to lots of workload in the busy-world. Relaxation is a process by which human being can get relief from these stresses. Some organizations have already started designing many experiments by different tools for the purpose of getting feedback about physical and mental conditions of the subjects suffering from stress. One such useful tool is music. In this context, an essential question may arise—how does music affect human physiological condition and what are the important parameters needed to classify the pattern by which we can say that music has great importance to reduce stress. Various studies (Hong et al. 2004; Guétin et al. 2009; Wei et al. 2005; Yang et al. 1996; Orini et al. 2010) have been carried out to establish the role of music towards reduction of stress of mind. However, most of them are Phenomenology or statistical survey that is based only on human feedback, which comes from their intuition and feelings. Thus, different conclusions derived from such survey are prone to questions on accuracy. On the other hand, some scientific studies have also been carried out by different researchers. However, the results regarding the effect of music were found to be very much conflicting and confusing in relating to the exact circumstances and variables that affect the body's response to music, such as the type of music (Wei et al. 2005) and the subject's involvement in the music (Guétin et al. 2009). In some literature, it was found that music decreases the sympathetic nervous system (SNS) and increase parasympathetic nervous system (PNS) activity as measured by heart rate (HR), blood pressure (BP), and heart rate variability (HRV), indicating physiological relaxation (Guétin et al. 2009), while in some other literature it was found that music increases SNS activity and it also increases the HR in subjects who listened to some preferred music after exercise (Hong et al. 2004). In fact, two other factors—respiratory rhythm (Hong et al. 2004; Iwanaga et al. 2005) and gender (Hong et al. 2004) also affect the human physiological response to music.

Basically, music consists of some organized sounds and electrically it is like an impulse or signal. When it hits our brain, some information of impulses are selected, organized, and interpreted. This is called psycho-acoustic study. In this concern, some scientific parameters—dynamics, timber, rhythm and tonality play a vital role (Howard and Angus 2001). These measures are mainly based on time domain, frequency domain and time-frequency domain (Cook 1999). Dynamics measures degree of loudness, timber differentiates different sounds in music, rhythm defines how much calm a music may be and tonality classifies clarity of main key(s) of music. But whenever our mind organizes these sounds, our body is impressed due to some of them. In fact our hypothesis is that the effect of these sounds must reflect some of the physical signals of human body.

In this concern, HRV (Niskanen et al. 2004; Saul 1990) is such a non-invasive tool that can assess different heart conditions. Due to its non-invasive character HRV has become an attractive tool for using it in the study of human physiological response to different stimuli (Heitmann et al. 2011; Piskorski and Guzik 2011; Voss et al. 2012; Karmakar et al. 2013; Dong et al. 2014). HRV is the variation of time between two consecutive heartbeats. It is a useful tool to know the overall cardiac health and the status of the autonomic nervous system (ANS). There are two branches of the ANS—the sympathetic and the parasympathetic. The sympathetic branch increases heart rate and the parasympathetic branch decreases it. Thus at any instant, the observed HRV is an indicator of the dynamic interaction and balance between these two nervous systems. In the resting condition, both the sympathetic and parasympathetic systems are active with parasympathetic dominance. The balance between them is constantly changing to optimize the effect of all internal and external stimuli (Iwanaga et al. 2005). Although the effects of music on mind are mostly realized in brain through Central Nervous system (CNS), music also affects the conditions of heart through the dominance of Para-sympathetic nerves of Autonomic Nervous system (ANS). So it is no less important to study the effect of music through analysis of HRV data extracted from the corresponding ECG signals of the heart in the time domain, when we listen to music.

HRV is a time series whose elements are differences of successive time intervals of R-peaks appearing in ECG signal (Clifford et al. 2006). The geometry of Poincaré plot (Brennan et al. 2001) consists of those successive intervals and it conveys the information of condition of heart indirectly. Moreover, the axes of fitted ellipse on the aforesaid plot are used to quantify the Poincaré plot.

In Indian classical music, raga is realized by selection of notes and the sequence (s) of distribution of notes. Raga ‘Malkunsh’ is known for its special appeal to human feeling. It has got well prescribed notes for use and proper distribution of notes to follow.

In the present study, we consider samples of raga ‘Malkunsh’ of three varieties, one from classical vocal music, one from instrumental music (sitar recital) and the last one from Rabindra Sangeet (songs by universal poet Rabindranath Tagore). Our primary query is to know whether there is any difference in the pattern of music in the three cases, where by pattern we understand dynamics, timber, rhythm and tonality. These are determined through scientific musical analysis, which is mainly physical in nature. The secondary query is to see whether these types of music have positive impact on human autonomic nervous system (ANS) in the sense of dominance of parasympathetic nerves through Heart rate variability (HRV) signal. If so, then it is further investigated, whether the different types of music have different types of effect on ANS. This is studied through pattern of the long-term discrete dynamics of HRV signal, which means time independent phase space analysis of the HRV signals. The HRV data was taken from 20 subjects, of two groups—one conversant with rules of music and the other not conversant with the same. The music was of maximum 30 min duration in .wav/.mp3 format.

The whole chapter is subdivided into two parts. In the first part, patterns of instrumental music signal, classical vocal music signal and Rabindra sangeet are analyzed by dynamics, timber, rhythm and tonality respectively. In the last part, we first choose HRV-signals of persons under normal conditions and also when they were listening to the above types of music. Then we construct Poincaré plot for each of the HRV signals, quantify the Poincaré plots of those signals by using ‘ellipsoid fit’ and thereby establish the different effects of different music signals of same raga—‘Malkunsh’.

## 21.2 Data

### *21.2.1 Music Signals*

In Indian classical music, Malkunsh belongs to the “Bhairavi thaat” and its notes are Sa, komal Ga, shuddh Ma, komal Dha, and komal Ni. In Western classical notation, its notes can be denoted by: tonic, minor third, perfect fourth, minor sixth and minor seventh. Malkunsh is a serious, meditative raga, and is developed mostly in the lower octave (mandra saptak) and in a slow tempo (vilambit laya). Ornaments such as midh, gamak and andolan are used rather than ‘lighter’ ornaments such as murki and khatka.

For the purpose of the present study, the music signals of raga ‘Malkunsh’ are collected in three varieties, one from classical vocal music (music signal-1), one from instrument—sitar (music signal-2) and the last one from Rabindra Sangeet (music signal-3). The classical vocal music was performed by one of the legendary vocalists, the instrumental music was played by one of the legendary sitar player and Rabindra sangeet was also performed by an eminent Rabindra sangeet artist. Some portion of slow renditions (alap) has been taken in all the three cases. Sample size in all the three cases is taken as 100,000. All signals are converted into .wav format and .txt format by Adobe Audition for the purpose of analysis in MATLAB.

### *21.2.2 HRV Data*

As we think that the impact on the Indian Raga Music (IRM) initiated persons might be biased in some ways, we included persons with no previous exposure to Indian Raga Music (NIRM). This helped us in procuring relatively unbiased data.

All the signals are recorded under normal room temperature and least noisy environment. All signals are taken in ten minutes duration. Finally, recorded signals are processed by *MATLABR2010a* software using moving window integration of a digital filter and converted into HRV signals (Fig. 21.1).

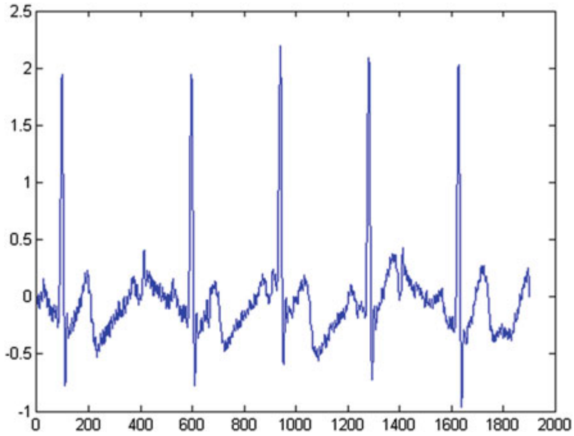


**Fig. 21.1** ECG signal

## 21.3 Methods

### *21.3.1 Time/Frequency/Time–Frequency Domain Based Analysis*

All measures related to this section are calculated in MATLAB software under an audio analysing toolbox. The followings are short preview of methodology of such measures.

a. **Dynamics**

The global energy of the signal can be computed simply by taking the average of the square of the amplitude, also called root-mean-square (RMS). With frame decomposition, we get energy curve. This energy curve can be used to get an assessment of the temporal distribution of energy, in order to see if it remains constant throughout the signal, or if some frames are more contrastive than others. One way to estimate this consists in computing the low energy rate, i.e. the percentage of frames showing less-than-average energy. This percentage is actually the degree of loudness or softness.

b. **Timbre**

In describing timbre, first, the audio sequence is loaded and then decomposed into successive frames, which are then converted into the spectral domain. In this process, we can recognize the key in a signal with respect to its corresponding time. Now by calculating slope of the corresponding curve how one key attack the next one, we can get attack slopes for every keys in a signal. In this way, timber can be defined by attack slope and this measure is able to differentiate two sounds from same instruments.

c. **Rhythm**

As pulsation is generally related to increase of energy only, the envelopes are differentiated, half-wave rectified, before being finally summed together again. This gives a precise description of the variation of energy produced by each note event from the different auditory channels. After this onset detection, the periodicity is estimated through autocorrelation. However, if the tempo varies throughout the piece, an autocorrelation of the whole sequence will not show clear periodicities. In such cases it is better to compute the autocorrelation for frame decomposition. This yields a periodogram that highlights the different periodicities. In order to focus on the periodicities that are more perceptible, the periodogram is filtered using a resonance curve (Toiviainen and Snyder 2003), after which the best tempos are estimated through peak picking, and the results are converted into beat per minutes. It is known as tempo of music.

d. **Tonality**

The spectrum is converted from the frequency domain to the pitch domain by applying a log-frequency transformation. The distribution of the energy along the pitches is called the chromagram. The chromagram is then wrapped, by fusing the pitches belonging to same pitch classes. The wrapped chromagram shows therefore a distribution of the energy with respect to the twelve possible pitch classes (Gomez 2006). Krumhansl and Schmuckler (Krumhansl 1990) proposed a method for estimating the tonality of a musical piece (or an extract thereof) by computing the cross-correlation of its pitch class distribution with the distribution associated to each possible tonality. The most prevalent tonality is considered to be the tonality candidate with highest correlation, or key strength. This method was originally designed for the analysis of symbolic representations of music but had been extended to audio analysis through an adaptation of the pitch class distribution to the chromagram representation (Gomez 2006). Key clarity is defined by key strength associated with the best key(s).

## *21.3.2 Poincaré Plot and Quantification*

a. **Poincaré plot**

Poincaré plot (Brennan et al. 2001) is a standard concept in analyzing a discrete signal. It gives a geometrical way of identifying the presence of nonlinear structures in a discrete signal. It is simply a phase space plot (Brennan et al. 2001) with unit lag which generally corresponds to the linear relationship among the data itself.

Let us consider a signal $\{x(k)\}_{k=1}^{N}$. Then, Poincaré plot (Brennan et al. 2001) is thus constructed by only plotting the points $(x(t), x(t+1)), t = 1, 2, \ldots, N-1$ in two dimensional space.

b. **Quantification by 'ellipsoid fit'**

After the construction of Poincaré plot (Brennan et al. 2001) of a signal, sometimes it can be seen that most of the points among $\{(x(t), x(t+1))\}, t = 1, 2, \ldots, N-1$ are roughly concentrated within an elliptical region. In this connection, the major axis and the minor axis of that ellipse has major role to cluster two types of Poincaré plots (Brennan et al. 2001) (constructed from two different signals of different subjects).

## 21.4 Evaluations

### *21.4.1 Time/Frequency/Time-Frequency Domain Based Analysis*

a. **Dynamics**

The percentage of window which contains lower energy of the signals is calculated from RMS energy. It is found that percentage of lower energy window is greatest for music signal-1and least for music signal-2. Thus, loudness of music signal-1 is greatest, the next one is music signal-3 and the minimum one is music signal-2 (Fig. 21.2).

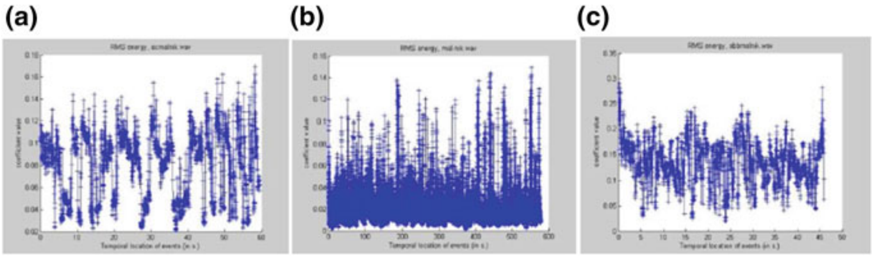


**Fig. 21.2** RMS energy of **a** music signal-1, **b** music signal-2, **c** music signal-3

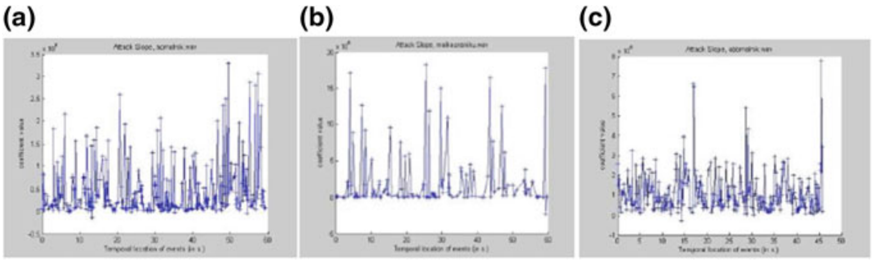


**Fig. 21.3** Attack slope of **a** music signal-1, **b** music signal-2, **c** music signal-3

b. **Timbre**

Figure 21.3 show how attack slopes changes in music signal-1, music signal-2 and music signal-3:

c. **Tonality**

Key clarity of the music signal-1, 2 and 3 are shown in Fig. 21.4.

From the parameters attack slopes and key clarity, it is found that pattern of three music signals are different in their attacking style and clarity of key(s).

d. **Rhythm**

Tempo of music signal-1, music signal-2 and music signal-3 are given by Fig. 21.5.

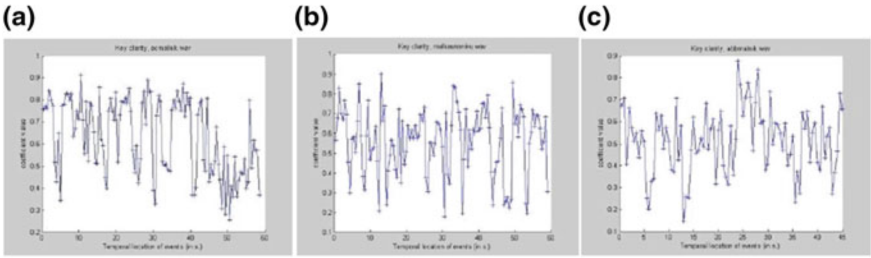


**Fig. 21.4** Key clarity of **a** music signal-1, **b** music signal-2, **c** music signal-3

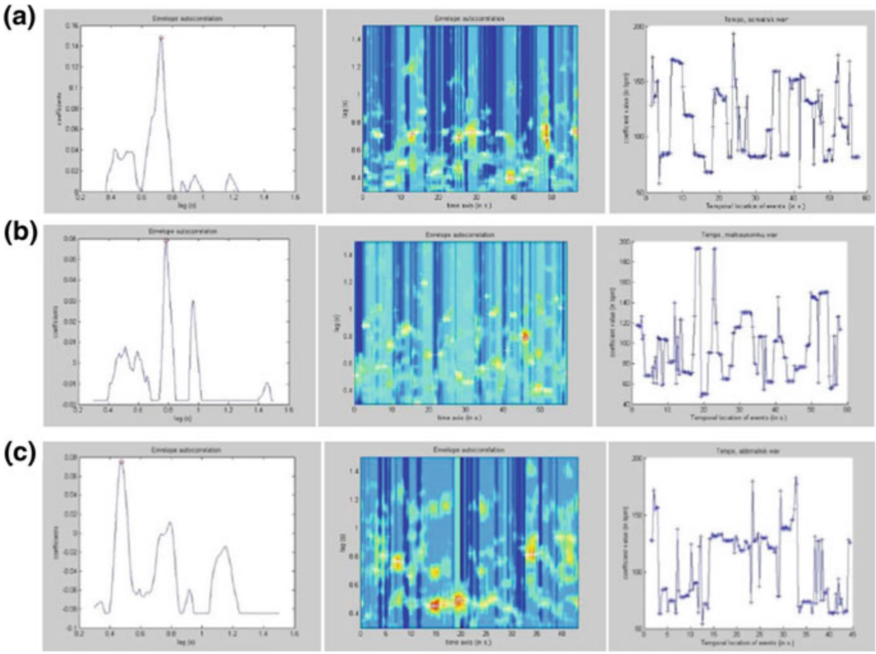


**Fig. 21.5** Tempo of **a** music signal-1, **b** music signal-2, **c** music signal-3

In fact, the lag, where first time autocorrelation meets maximum value is first found, then with the corresponding lag we calculate the time, where envelope autocorrelation attains its maximum and at the end, the bpm for that time is calculated. This is actually the value of tempo of the corresponding signal. It is found that the tempo of the music signal-1 is the largest, next comes the tempo of the music signal-3 and tempo of the music signal-2 is the least among all.

Tempo is the speed of the beat. A fast tempo in music gives a feeling of excitement and energy, whereas slow tempo gives a feeling of calm mood. Hence, music signal-2 is more in calm mood than music signal-1 and music signal-3. In fact, feeling of excitement and energy is greatest for music signal-1.

## *21.4.2 Poincaré Plots and Their Quantifications*

The Poincaré plots for each of the subjects (both IRM and NIRM subjects) for all the three types of music based on raga "Malkunsh" are constructed. Some of them are presented in Figs. 21.6 and 21.7.

Since the points in each of the Poincaré plots are concentrated about the line of identity, an ellipse with major axis as line of identity is fitted to the dense region of each of the plots. The area of the ellipse is taken as a quantification parameter. Interestingly, it is observed that the area of the fitted ellipse decreases in each cases (both IRM and NIRM initiated), when the subjects listen to Rabindra sangeet based

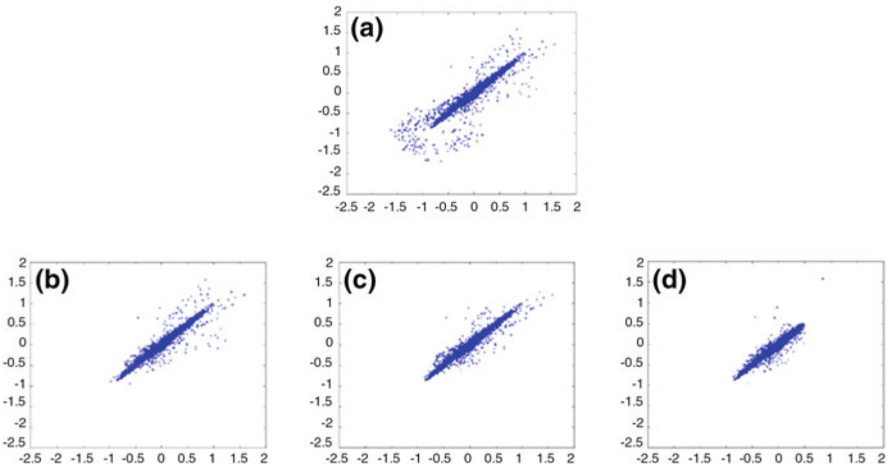


**Fig. 21.6** Poincare plots of IRM initiated normal healthy subjects **a** before listening to any music, **b** listening to Indian classical music, **c** listening to instrumental music, **d** listening to Rabindra sangeet

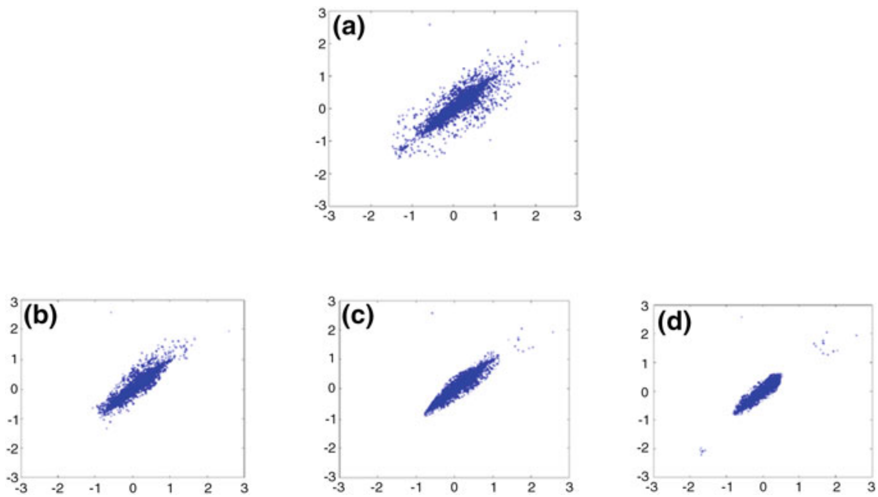


**Fig. 21.7** Poincare plots of NIRM initiated normal healthy subjects **a** before listening to any music, **b** listening to Indian classical music, **c** listening to instrumental music, **d** listening to Rabindra sangeet

on raga “Malkunsh”. However, a mixed trend is observed in the values of area for both IRM and NIRM initiated persons, when they listen to Indian Classical music based on the same raga. On the other hand, the value of the area decreases uniformly for IRM initiated persons but not uniformly form NIRM subjects, when they listen to Instrumental (Sitar) music based on raga “Malkunsh”.

## 21.5 Conclusion and Future Scopes

The study introduced in this chapter is new of its kind. Three different types of music based on the same raga have been selected and analyzed through its dynamics, timber, tonality and rhythm. Finally their effects on normal healthy subjects have also been investigated through Poincaré plot construction. Most interestingly, it is found that out of the three types of music based on raga “Malkunsh”, Rabindra sangeet has uniform effect on all of IRM and NIRM initiated persons. From the view point of time/frequency/time-frequency based analysis, all the three music are different in their attacking style and clarity of key(s), but loudness and calmness of Rabindra sangeet (music signal-3) is medium compared to the other two music of the same raga. Probably this is the reason for which the effect of Rabindra sangeet is uniform on normal healthy subjects, whether they are IRM initiated or not. Since the value of the quantifying parameter have decreased for all subjects, when they listen to Rabindra sangeet, it is expected that only Rabindra sangeet among the three different music based on raga “Malkunsh” has a strong positive effect in relieving stress from human being irrespective of the fact that they are IRM initiated or not. The future scopes of this article includes but not limited to the verification of the positive effect of Rabindra sangeet on human being, finding of a correlation between the psycho-acoustic measures and the degree of its effect on human being and also searching of some Indian classical ragas such that any type of music based on those ragas produce positive effect in relieving stress of the human-being.

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