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ACOUSTICAL COMPLEXITY DEPENDENT RESPONSE OF PLANT TO MUSIC STIMULI – A NEW APPROACH

Dipak Ghosh[1], Mousumi Das[2] and Sankha Sanyal[3]

Dipak Ghosh[1], Sir CV Raman Centre for Physics and Music, Jadavpur University, Raja SMS Road, Kolkata-700032, India.email:deegee111@gmail.com

Mousumi Das[2],Dept. of Zoology, Sammilani Mahavidyalaya, Baghajatin, E.M. ByPass, Kolkata-700094, India.email:mousumidas21@gmail.com

Sankha Sanyal[3], Sir CV Raman Centre for Physics and Music, Jadavpur University, Raja SMS Road, Kolkata-700032, India .email: ssanyal.sanyal2@gmail.com

***Corresponding author Email: mousumidas21@gmail.com**

ABSTRACT
The effect of musical sound in plant system is still neglected in biophysics research. Firstly, this work is intended to show the effect of the musical sound on growth of gram bean (Cicer arietinum) plants. Four different types of musical sound with different acoustical complexities were selected as audio signal during the growth period of Cicer arietinum plants. Keeping the same environmental conditions plants were taken in separate pots and were stimulated with different kinds of music, namely Natural music, Indian Classical music, Contemporary music and Epic horror music while one group was kept in silence as the control group. Difference in height of plants was monitored for a regular basis till 336 hours, because after that no significant change was seen in height of the plants. Statistically very significant differences have been noted in average increase of stem length of different music treated plants and untreated plants up to 336 hours (P<0.001). Plants exposed to Indian Classical music showed the maximum elongation of shoot length. Our second objective is to show a correlation between the responses of plant (in terms of shoot length) with acoustical complexity (Hurst exponent) in perspective of chaos based analysis of music signal. For this four clips of 3 min each are taken in a way that they convey a variety of moods. The result shows the increase of shoot length depends on Hurst exponent of music stimuli. Finally we can say that the absence of strong long range correlation in the acoustic feature of music sample may lead to higher response of plant so far as plant growth is concerned.
KEYWORDS: *Acoustical complexity, Hurst exponent, music stimuli, plant growth.*

INTRODUCTION

It is well known from the work of Sir Jagadis Chandra Bose (1902 and 1926), an Indian plant physiologist and physicist, that plants react to the attitude with which they were nurtured and plants are sensitive to factors in the external environment, such as light, cold, heat, and noise. If plants respond to the ways it is nurtured and have several sensory perceptions, then how do they respond to sound waves and the vibrations created by musical sounds? After pioneering work of Sir J. C. Bose, very little research has been conducted on how music effects plant growth. Ponniah and Singh (1955) were two of the pioneers in this kind of work. As a source of music they play violin pieces to plants and observe the plant growth. Hicks (1993) shows that the music treated plants sprouted faster and were greener with thicker stems than the silent plants. Creath and Schwartz (2004)shows musical sound plays an important role on the number of seeds sprouted to untreated control. Ramaswamy and Chivukula (2014) uses music as stimulation for improving *Rosa chinensis* flower production.

The physics of music is as interesting because of its aesthetic beauty as well as its ability to convey a variety of moods through its rendition. Music signals show a chaotic, self-similar (Fractal), and generally, non-linear behaviour. Therefore, the analysis of music using linear and deterministic frameworks seems not to be useful. According to Voss and Clarke (1975), Kumar and Mullic(1996) and Sengupta *et al*., (2001and2010)non-linear dynamical modelling clearly indicates the relevance of non-deterministic or chaotic approaches in understanding the speech or music signals. Fractal analysis is a good technique to obtain the power exponent that defines the scale invariant structure of the whole signals.

Fractal analysis of audio signals was first performed by Voss and Clarke (1975). Music time series signals are non-stationary in nature and the methods like Detrended Fluctuation Analysis (DFA) which are known for its robustness against non-stationarity is very useful. DFA was first used by Peng*et al.* (1994) to determine the long range correlations present in

DNA nucleotides. The utility of using this technique is that we can classify the genre of musical stimuli with the help of a single DFA scaling exponent 'α' which gives an estimate of the amount of long-range correlations present in the time series data.

OBJECTIVE

The primary objective of the present study is to see the effect of the different kind of musical stimuli on growth of gram (***Cicer arietinum***) plants. Our second objective is to show a correlation between the responses of plant (in terms of shoot length) with acoustical complexity (Hurst exponent) in perspective of chaos based analysis of music signal.

MATERIALS AND METHODS

Experiments on plant

For our experiment, gram (***Cicer arietinum***) has been used, because gram is widely consumed in India and due to its relatively short life cycle, it helps to do more repetitive experiments during the whole study. To understand the effects of musical sound on growth of plants, four different types of music were used to ***Cicer arietinum*** plants as audio signal during the growth period. For this experiment 100 ***Cicer arietinum*** fully germinated seeds with root and shoot portion pierced out from seed coat were taken and potted at equal depth of 2/3th inch inside the soil. All the pots were of similar size with equal amount of mud. Plants were taken in five separate pots taking 20 plants in each group and four were subjected to one of the following types of music- Natural music, Indian Classical music, Contemporary music and Epic horror music, and one group were kept in silence as the control group. The duration and time of music exposure was 3 hours in the early morning between 5:30-8:30 AM and 2 hours in the evening between 4:30-6:30 PM for a period of 336 hours. The environmental conditions were same for all the set of plants. The pieces of music and volume of the pieces remain constant throughout the whole experiment period. The height of plants was recorded with the help of a measuring scale in every 48 hours for regular basis till 336 hours, because after that the optimum growth of the plants occurred and no significant change was seen in plants. The experiments were repeated five times.

Correlation study

The second experiment was on correlation study between plant growth and acoustical complexity. Four audio clips of 3 min each were taken in a way that they convey a variety of moods. All clips were used as arousal stimuli. All the signals are digitized at the rate of 22050 samples/sec 16 bit format. Each three minutes signal is divided into three equal segments of 60 seconds each. This was done to see the change of complexity in each time window for each clip.

DFA for a time series say {t1; t2; t3:::::: t n} can be computed by following:

Another series T as [T (1); T (2); T (3)......T (N)],

$T(k)=\sum_{i=1}^{k}(t_i - t_{mean})$. t_{mean} denotes mean of the points in the series t.

The series T is under interest. Series T is sliced into threads of length N. Each thread must contain this same number of element which is N. For each of the N element thread, a line is fit which signifies the trend in the thread. The fit is called T n (k).The detrending is $[T(k) - T_n(k)]^2$ which helps in calculation of RMS fluctuation.

F (N) = $\sqrt[2]{\frac{1}{n}\sum_{k=1}^{n}[T(k) - T_n(k)]^2}$ is called root mean square fluctuation.

F (n)$\propto n^{\alpha}$, α is expressed as the slope of logarithmic plot of log [F(n)] versus log(n).

Obtained α is the DFA value of a signal. It is called the DFA scaling exponent or the conventional Hurst Exponent (H) and it quantifies self-similarity and correlation properties of time series. As it suggests, a time series having has higher DFA scaling exponent is a symbolic quantification of presence of long range correlation. DFA quantifies complexity of using fractal property.

The scaling exponent α denotes the following:

α< 0.5 anti-correlated

α= 0.5 white noise

α> 0.5 positive autocorrelation

α=1 1/f noise

α=1.5 Brownian noise

The DFA exponent is the measure of long range temporal correlation (LRTC) present in a music signal.

RESULTS

Effect of music on plant growth

The height of plants (shoot length) was recorded in every 48 hours for regular basis till 336 hours. The data helps to distinguish differences between shoot lengths of gram seedlings subjected to different kinds of music verses control after different time intervals like 48,96,144,192,240,288 and 336 hours. Each includes nature of music stimuli, variation of shoot length in cm. with time in hours for all 20 samples. Figure1 shows the average increase in shoot length of gram plants measured after distinct hours with different types of music treatments along with control. It is clear from the above figure that the average increases of shoot length in gram plants were highest in Indian Classical music treated plants, followed by Contemporary music, Natural music and Epic horror music till 336 hours. Interestingly throughout the whole experiments the average increase in shoot length of all untreated plants were much lower in compare to the music treated plants except Epic horror music stimulated plants, which showed lower growth rate than control group up to 144hours but after that suddenly the situation reversed. The maximum average increase of shoot lengths was noted after 96 hours with 2.64 times higher increase in Indian Classical music stimulated plants, 1. 93 times higher in Natural music and 1.56 times higher in Contemporary music treated plants as compared to control group. Throughout the whole experiments the Indian Classical music stimulated plants showed the highest rate of increasing trend in shoot length. Statistically very high significant differences were noted in average increase of shoot length between each music treated and untreated group of plants ($P<0.001$)after 48,96,144,192,240,288 and 336 hours of time intervals.

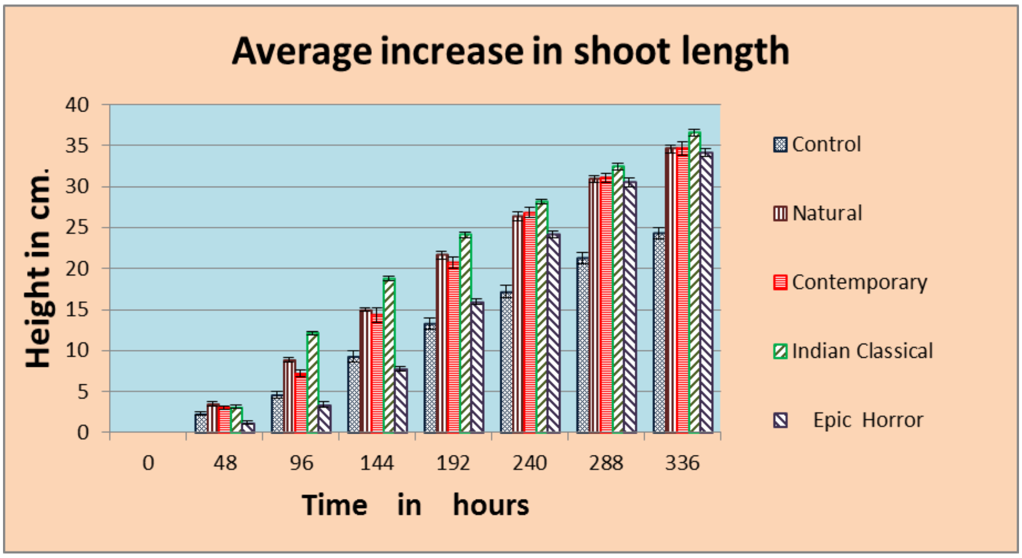

Figure – 1: Graph showing average increase in shoot length of control and four different music treated plants with time (Vertical bars represent means ± SD).

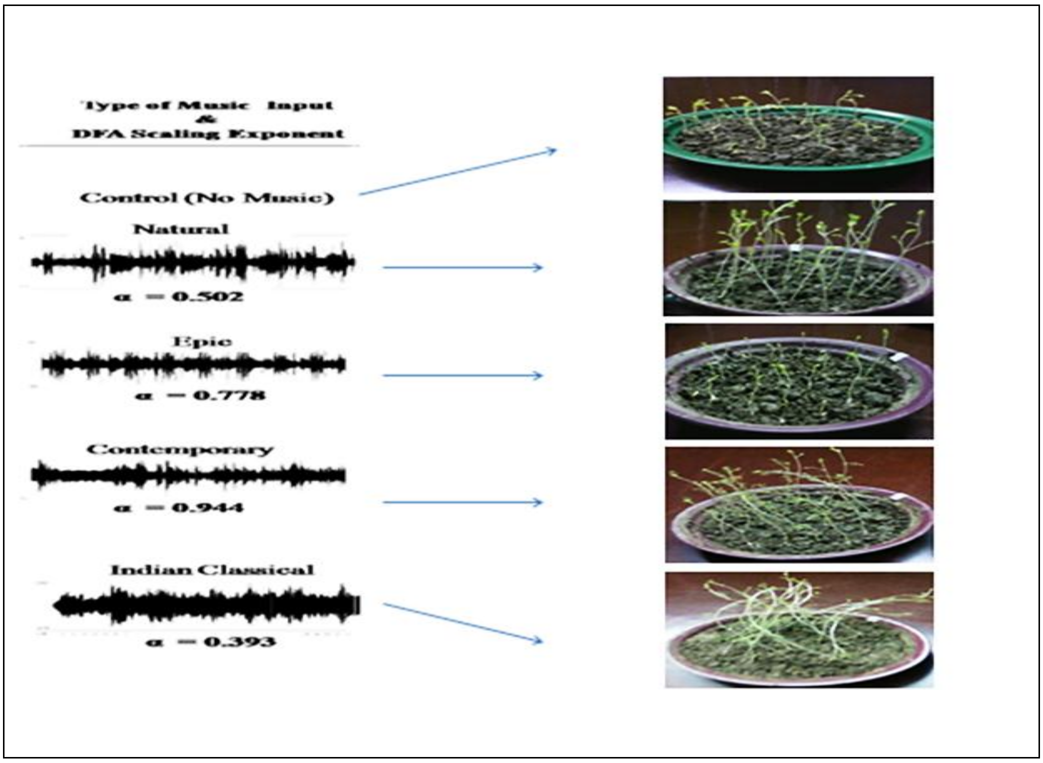

Figure – 2: DFA scaling Exponent of different music input and corresponding growth response of plants.

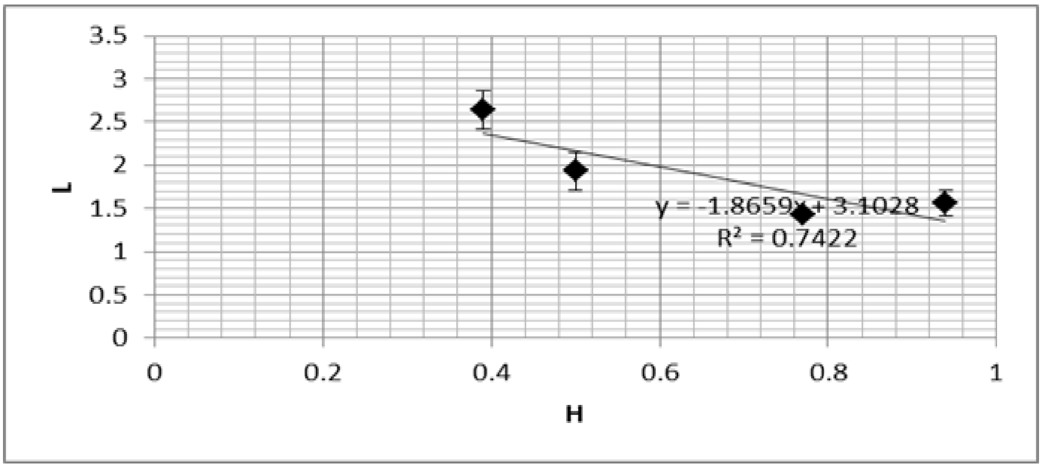

Figure -3: Graph showing correlation between Hurst Exponents of four different kinds of music with maximum increase of shoot lengths of four different music stimulated plants in comparison to control (Vertical bars represent means ± SD).

Table - 1: Variation of DFA scaling exponent for the different parts of 4 clips

	Clip 1(α) Contemporary music	R^2	Clip 2(α) Natural music	R^2	Clip 3(α) Indian Classical music	R^2	Clip 4(α) Epic Horror Music	R^2
Part 1	1.01	0.004	0.494	0.011	0.264	0.007	0.764	0.006
Part 2	0.960	0.007	0.515	0.026	0.336	0.002	0.812	0.002
Part 3	0.863	0.002	0.498	0.061	0.388	0.005	0.758	0.003
Average	0.944		0.502		0.393		0.778	
SD	0.074		0.011		0.062		0.029	

Table -2: Values of Hurst Exponents of four different kinds of music along with maximum increase of shoot length of four different music stimulated plants in comparison to control

Music stimuli	Hurst Exponent	Maximum increase of shoot length in comparison to control (In times)
Indian Classical	0.39	2.64
Natural	0.50	1.93
Contemporary	0.94	1.56
Epic Horror	0.77	1.43

DFA scaling Exponent of different music input and growth response of plants

DFA was applied on the extracted amplitude envelopes on a moving window basis with a window size of 60s taking an overlap of 50% between the windows. A single scaling exponent α was obtained corresponding to each window of 60 seconds. The table1 shows the variation of Hurst Exponents for the four different clips used in our study along with the R^2 values and also the averaged Hurst Exponent for each clip. It is clear from the table that each genre of music has its very specific pattern of scaling or self-similarity which leads to a complete distinctive pattern in their DFA scaling exponent. Herein lays the originality of that musical clip, each of which creates a completely different mood and ambiance very distinctive from the other, the basics of which are hidden in the complex waveform possessed by each. The clip used for Contemporary experiment has the highest order of self- similarity while the Indian Classical clip has the lowest degree of self- similarity. The clip with Natural sound and the Epic clip have LRTC which lies somewhere in between the two. This significant variation in the scaling pattern causes distinct differences in the perception of the living organisms that are made to listen to these clips. Figure 2 shows the DFA scaling Exponent of different music input and corresponding growth response of plants. The table 2 shows the value of the parameter (H) for four different kinds of music sample used as input and the corresponding maximum increase in shoot length of plants (in times)in comparison to control. We finally attempt to detect the degree of response of plants (in terms of growth of shoot length) with different types of music conventionally labelled as Indian Classical, Contemporary, Natural, Epic horror and acoustically characterized by a non-linear parameter (the implication of which have been elaborated earlier).The figure 3 (H/L) shows how the increase of shoot length L depends on Hurst exponent of music stimuli difficult speak for itself. This dependence is predominantly linear and since the value of H (as detailed earlier) decides whether this acoustics time series is of long range correlated one is characterize by the value of H. One may conclude that the absence of strong long range correlation in the acoustic feature of music sample may lead to higher response of plant so far as growth is concerned. In short, this experiment for the first time attempts to find a clue in terms of chaos based analysis of the acoustic sample. The response pattern of plants may provide a guideline for further research for proper understanding in detail the response of plant to music from a deeper scientific footing.

CONCLUSION

From the above experiments and from their results we can say that definitely music plays an important role in the growth of gram plants. Plants can distinguish between different kinds of music and responses accordingly. In one word, the presence or absence of strong long range correlation in the acoustic feature of music sample may lead to lower or higher response of plants so far as growth is concerned.

DISCUSSION

The domain of response of plant to music stimuli is still unexplored. Although evidences have been accumulated in favour of not only significant growth of plant with plant stimuli but also music specific growth is not rare. It is possible in light of recent developments in plant physiology as well as acoustical pinning of music stimuli, to explore the dynamics of plant growth from a scientific prospective. We present here a serious attempt to ascertain quantitatively in one hand a contribution of the music of different variety taking statistically significant number of samples, controls, as well as with unaltered environmental parameters, so that one can correlate the response with an acoustical parameter determined from a nonlinear chaos based signal processing methodology. It will not be irrelevant to mention that no serious attempt has been reported by physicist and botanist till date. This paper is essentially a report of our findings of rigorous experiments, considering all aspects elaborating above. This work provides first time some meaningful findings to be taken seriously for proper understanding about the impact of complex signal (music) on another complex system (plant).

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