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Study on Brain Dynamics by Non Linear Analysis of Music Induced EEG Signals

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HIGHLIGHTS

- EEG data with music induced stimuli.
- Non linear analysis of alpha, theta and gamma brain rhythms using DFA technique.
- Retention of memory corresponding to alpha frequency range.

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ABSTRACT

Music has been proven to be a valuable tool for the understanding of human cognition, human emotion, and their underlying brain mechanisms. The objective of this study is to analyze the effect of Hindustani music on brain activity during normal relaxing conditions using electroencephalography (EEG). Ten male healthy subjects without special musical education participated in the study. EEG signals were acquired at the frontal (F3/F4) lobes of the brain while listening to music at three experimental conditions (rest, with music and without music). Frequency analysis was done for the alpha, theta and gamma brain rhythms. The finding shows that arousal based activities were enhanced while listening to Hindustani music of contrasting emotions (romantic/sorrow) for all the subjects in case of alpha frequency bands while no significant changes were observed in gamma and theta frequency ranges. It has been observed that when the music stimulus is removed, arousal activities as evident from alpha brain rhythms remain for some time, showing residual arousal. This is analogous to the conventional 'Hysteresis' loop where the system retains some 'memory' of the former state. This is corroborated in the non linear analysis (Detrended Fluctuation Analysis) of the alpha rhythms as manifested in values of fractal dimension. After an input of music conveying contrast emotions, withdrawal of music shows more retention as evidenced by the values of fractal dimension.

1. Introduction

Music is a continuous stream of transient auditory events that people perceive and respond to in an affective manner [1]. Music is dynamic and changes over time [2]. Depending on the way sound waves are pronounced and heard, they have an impact on the way the neurological system (brain and nerve) works in the human body. Neurological studies have

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identified that music is a valuable tool for evaluating the brain system [3]. It is observed that while listening to music, different parts of the brain are involved in processing music; these include the auditory cortex, frontal cortex and the motor cortex [4]. Exposure to music regularly enhances a number of cognitive functions such as painting and language abilities in children [5–9]. Western classical music is based on harmonic relations between notes, while Hindustani music (HM) is based on melodic mode (raga) structures within rhythmic cycles. Hence, these two forms of music may demand qualitatively different cognitive engagements.

Each type of music has its own frequency, which can either resonate or be in conflict with the body's rhythms (heart rate). Studying EEG dynamics typically relies on the calculation of temporal and/or spectral dynamics from signals recorded directly from the scalp. Due to volume conduction, EEG data recorded at the scalp are linear mixtures of electrical potentials projected from multiple distinct cortical domains and non-brain artifacts arising from eye blinking, lateral eye movement, muscle tension, etc. [10]. Each frequency band of the EEG rhythm relates to specific functions of the brain. EEG rhythms are classified into five basic types: (i) delta (δ) 0.5–4 Hz, (ii) Theta (θ) 4–8 Hz, (iii) alpha (α) 8–13 Hz, (iv) beta (β) 13–30 Hz and (v) gamma (γ) 30–50 Hz.

It has been observed that pleasant music produces a decrease in the alpha power at the left frontal lobe and unpleasant music produces decrease in the alpha power at the right frontal lobe [11–13]. Also, activity in the alpha frequency band has been found to be negatively related to the activity of the cortex, such that larger alpha frequency values are related to lower activity in the cortical areas of the brain, while lower alpha frequencies are associated with higher activity in the cortical areas [14,15]. Davidson [14] have shown that disgust cause less alpha frequency in the right frontal region than happiness while, happiness cause less alpha power in the left frontal region. Frontal midline (Fm) theta has been mostly related to heightened mental effort and sustained attention during various functions. The Fm theta power was positively correlated not only with scores of internalized attention but also with subjective scores of the pleasantness of the emotional experience. Furthermore, two studies on the relationship between Fm theta and anxiety reported negative correlations between Fm theta during mental tasks and anxiety measures [15,16]. It has also been shown that pleasant music would elicit an increase of Fm theta power [17]. Recent researches have demonstrated that the modulation of gamma band activity (GBA) in time windows between 200 and 400 ms following the onset of a stimulus is associated with perception of coherent visual objects [18], and may be a signature of active memory. GBA has also been found sensitive to emotional vs. non emotional stimuli and more specifically it was related to the arousal effect: GBA was enhanced in response to aversive or highly arousing stimuli compared to neutral picture [19]. While listening to music, degrees of the gamma band synchrony over distributed cortical areas were found to be significantly higher in musicians than non musicians [20,21]. Another study reports higher order inter-frequency phase synchrony between delta oscillations in anterior and gamma oscillations in posterior region for musicians. Also, consistent left hemispheric dominance, in terms of the strength of phase synchrony, was observed in musicians while listening to music, whereas right hemispheric dominance was observed in non-musicians [22]. The gamma band EEG distributed over different areas of brain while listening to music can be represented by a universal scaling which is reduced during resting condition as well as when listening to texts [23]. Specifically, Ref. [24] have found that gamma activity increases after subjects had been made aware of the stimulus. So, we envisaged to study the response of gamma band in emotion elicited by Hindustani music stimuli.

Selecting the right type of music is thus important because the EEG spectral power depends on the intensity and style of music [25]. It has been reported that the psychological and physiological health of individuals can be improved by music therapy [26].

In this paper, we wanted to test whether hysteresis-like effects are present in brain response to emotional musical stimuli. To test our prediction, we used a protocol which reveals the time duration for which the neuronal activation persists even after the removal of the musical stimuli. Works in perceptual hysteresis show that the content of one's perception at time t depends on the recent history of the perceptual system [27]. In the visual domain, Sacharin et al. [28] showed that when subjects are presented with certain facial emotional expressions evolving over time from a particular emotion to another, they persist in perceiving the original emotion. Whether the hysteresis effect is present in the case of neurons triggered by musical stimuli has not yet received the attention of cognitive neuroscientists. Hysteresis is usually investigated using designs comprising of "ascending" and "descending" sequences, that is, sequences ordered in terms of a certain physical parameter [29]. In this case we used a positive emotional clip as an ascending sequence while another clip conveying negative emotion consisted of the descending one. In the middle, "no music" or rest conditions comprised of the neutral states which we considered as the baseline or the threshold value. In case of music induced emotions, it would be interesting to know which emotions stay longer in the human brain and whether it has any relationship to the type and genre of music. We attempt here the study with Hindustani music utilizing a rigorous non-linear approach as elaborated later.

In our study, we used a scaling analysis technique called Detrended Fluctuation Analysis (DFA) to analyze the long range temporal correlations (LRTC) of the observed fluctuations in EEG. In the realm of complex cognition, scaling analysis technique was used to confirm the presence of universality and scale invariance in spontaneous EEG signals [30]. In stochastic processes, chaos theory and time series analysis, DFA is a method for determining the statistical self-affinity of a signal. It is useful for analyzing time series that appear to be long-memory processes (diverging correlation time, e.g. power-law decaying autocorrelation function) or 1/f noise. The obtained exponent is similar to the Hurst exponent, except that DFA may also be applied to signals whose underlying statistics (such as mean and variance) or dynamics are non-stationary (changing with time). DFA method was applied in Ref. [31] to show that scale-free long-range correlation properties of the brain electrical activity are modulated by a task of complex visual perception, and further, such modulations also occur during the mental