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Review Article

A novel musical neurofeedback

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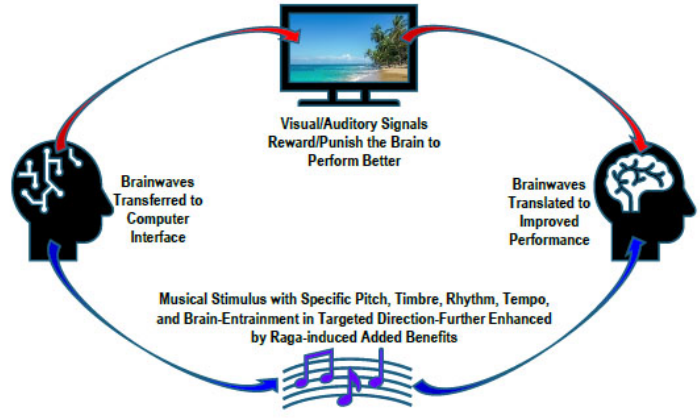
Abstract

A systematic analysis of Global Burden of Diseases (GBD) documented by the World Health Organization (WHO) now includes alarming prevalence of neurological diseases (NDs) as the foremost leading cause of death and disability worldwide. Given limited effectiveness of current symptomatic management of NDs, clinical implementation of alternative therapies is gaining increasing recognition as the viable option(s) for treating NDs. Neurofeedback, musical neurofeedback in particular, that utilizes music as a form of feedback, constitutes one of such alternatives. Musical stimulus with specific pitch, timbre, rhythm, and tempo is capable of entraining brainwaves in desired direction. These musical brain-entraining characteristics can be further magnified with the use of Indian Classical music (ICM) as the unique music stimulus. This brief review discusses added benefits of ICM/Raga neurofeedback in orchestrating comprehensive restoration of lost brain functions attributed to Raga's ability of activating Raga- specific emotions, neurotransmitters, and pertinent brain regions/pathways/networks.

Keywords: Indian classical music, Brain entrainment, Music genre, EEG, Raga, Dopamine, Emotional response

Abbreviations: AD: Alzheimer's Disease; ANS: Autonomic Nervous System; BCI: Brain-Computer Interface; Bpm: Beats Per Minute; EEG: Electroencephalogram; fMRI: Functional Magnetic Resonance Imaging; GBD: Global Burden of Diseases; ICM: Indian Classical Music; NDs: Neurological Diseases; NF: Neurofeedback; NIRS: Near-Infrared Spectroscopy; RF: Random Feedback; UWS: Unresponsive Wakeful Syndrome; WHO: World Health Organization

Graphical Abstract



Introduction

The increasing burden of neurological disorders afflicting ~3 billion people worldwide [1–4] and limited effectiveness of symptomatic therapy [5,6], prompted the emergence of alternative treatments in finding effective cure for neurological disorders (NDs) [7–9]. Neurofeedback (NF) constitutes one of such alternatives increasingly considered for treating NDs [10–13]. Neurofeedback is a type of biofeedback which refers to modifying bodily physiological functions [14]. A typical NF involves (a) An acquisition of patient's real-time brainwave map in the form of electroencephalogram (EEG), followed by (b) A feedback-EEG showing the existing abnormal brainwaves, followed by (c) A reward/punishment feedback showing the achievement level of NF training after "self-regulating" the brain activity in a desired direction [15,16].

Conventional Neurofeedback

Conventional neurofeedback is provided to patients by various brain-computer interface (BCI) modalities such as functional magnetic resonance imaging (fMRI), near-infrared spectroscopy (NIRS) or EEG [15,17] which can be achieved through visual, tactile or auditory stimulation [17,18]. Visual stimuli involve presentation of images, symbols or graphics with variations in color, shapes or movements which change in brightness or movement; tactile stimuli involve vibrations or touch; while auditory stimuli include presentations of sounds with variable pitch, volume; all visual, tactile or auditory stimuli increase/decrease indicating reward/punishment, in response to the success level of NF training [19]. Most NF systems use visual feedback system which is perceived to be more user-friendly, however, its implementation with "closed eye" medical conditions becomes limited [20]. On the other hand, auditory feedback, although not as user-friendly as visual NF, offers additional advantage of changing various parameters of sound [17,21]. Music constitutes one of the most powerful auditory NF due to its versatility [22,23].

Neurofeedback *per se* has been shown to impact clinical treatment of NDs due to its non-invasiveness [24] and its potential in modifying brain functions in a targeted manner [25,26]. Neurofeedback training was observed to rebalance theta brainwaves and sensomotor rhythm frequencies leading to improved memory and cognition with no effect on attention [27]. Neurofeedback treatment was effective in dementia subjects regardless of the type of dementia such as primary degenerative dementia, Alzheimer's disease (AD) related dementia, vascular dementia, depression or mild cognitive impairment [15,28]. Additional studies showed that neurofeedback training of alpha activity exerted a positive effect on working and episodic memory in healthy subjects [29] and improved cognitive functions and speech perception in elderly people with age-related hearing loss [30]. Thus, neurofeedback presents a potential non-invasive intervention for treating neurological disorders [31]. Despite all, the adversities associated with neurofeedback techniques make its clinical implementation somewhat questionable [20]. The most commonly practiced neurofeedback using visual cues such as computer games, cartoons and movies, are associated with fatigue and boredom due to prolonged therapy sessions [32], and auditory neurofeedback with monotonous sound stimulation is not perceived relaxing [17]. Moreover, it is expensive, time-consuming and benefits are not long-lasting [20].

Musical Neurofeedback

In contrast to such conventional NF [15], musical NF is perceived to be stress-free, enjoyable and more effective due to its likable versatility in genres, pitch, tempo, and emotional valence [17,21,33,34]. Moreover, brain's natural tendency of synchronizing brainwave frequencies to the external rhythmic stimuli of music, known as "Entrainment", makes musical NF a better choice [19,35–37]. In addition, music induces cognitive and sensory processes and emotions [38–41], via activation of autonomic nervous system [42–45] and brain networks [19,38,39], promising musical NF to be more effective than conventional NF [21,31,36].

Several reports have shown beneficial effects of musical NF intervention in health and disease(s) [31]. A double-blind placebo-controlled study indicated that eyes open alpha power music training in healthy gymnasts using their own favorite music improved sleep quality and mental abilities such as attention when compared to placebo controls exposed to random beta power training [46]. Ramirez *et al.* have shown that patients suffering from depression when subjected to listening to their own favorite music showed significantly lowered left alpha along with improved depression condition indicating that the integration of NF and receptive music therapy was beneficial [21]. A crossover study that examined whether music based NF would increase the power of alpha in healthy subjects compared to random feedback (RF) controls, showed that normalized alpha power was significantly higher in music-based NF than in control RF, revealing greater improvements in short-term memory and cognitive functions after musical NF [17]. Fedotchev *et al.* conducted a pilot study showed that compared to conventional NF, musical NF reduced stress sensations and induced positive shifts in mental and emotional status [33]. Keller *et al.* showed that in a small number of brain injured patients with unresponsive wakeful syndrome (UWS) with higher theta/beta ratio, when subjected to listen to their favorite music, dropped their elevated theta/beta ratio below the threshold, providing evidence that musical NF can be used in a state of UWS [47]. A preliminary musical NF study showed that relaxing music induced alpha waves and produced both short- and long-term soothing effects psychologically and physiologically [48]. Thus, compared to conventional NF, musical NF may be more promising [19].

Potential of Raga Music in Advancing Musical Neurofeedback

Indian Classical Music (Raga) is postulated to further enhance the effects of musical NF by virtue of its structural uniqueness, defined rhythmicity, circadian specificity [49–52], and activation of autonomic nervous system (ANS) that regulate sympathetic/parasympathetic functions [53–56].

Structural uniqueness of Raga includes defined arrangement of notes (Swara) in a particular ascending/descending order with a combination of "Shuddha" (Pure/Consonant/Major) or Komal (Flat/Minor) or Tivra (Sharp) Swaras (Notes) specified for a given Raga [49,57–61]. Predominance of Shuddha (Consonant/Major) Swaras makes the Raga "Happy/Cheerful" [49,58,62], that are known to modulate reward-driven music-memory consolidation [63,64] by activating dopaminergic system in music-evoked pleasure [65–67]. Whereas the predominance of Komal (Dissonant/Flat/Minor) Swaras makes the Raga progressively sentimental, promoting

relaxation, peace and tranquility [68,69]. Pleasurable music has been shown to induce alpha waves [70] and balance frontal alpha asymmetry in depression [71]. Relaxing music on the other hand, induces long-term psychological and physiological soothing effects, observed from the increase in alpha and theta brain waves [48].

Besides Swara composition, the defined rhythmicity of Raga adds to brain-entraining effects [50,60,72]. Brainwaves are the rhythmic patterns of brain activity which possess natural ability to synchronize with the rhythms of external origin-such as music [19,35–37]. Rhythm refers to the organized pattern of sounds/silence in music including tempo, beats per minute (bpm), meter [73,74]. The defined rhythmicity of Raga is conventionally presented in two to three different rhythmic modes consisting of an arhythmic mode called "Aalap", followed by a second mode called "Gat" with a faster tempo along with Raga-specific rhythmic cycles, followed by a third mode called "Tarana" with the fastest tempo of all and a specific rhythmic cycle, which may produce differential rhythmic stimulation [49,51,52,57,58,75]. The change in musical rhythmic patterns can alter the emotional content of music and the way it is perceived [76]. The perception of musical rhythm stimulates the release and circulation of dopamine throughout the brain leading to different types of cognitive and motor responses and experience of pleasure [72,77,78]. Music stimuli with different tempo can entrain differential EEGs [79] and produce varying emotional responses [80]. Yang and co-workers have documented that the slow (56 bpm), medium (106 bpm) and fast (156 bpm) tempi activated theta, alpha and beta/gamma brainwaves respectively, parallelly correlating with relaxation/soothing, pleasant and active/attentional emotional states respectively [80].

The Ragas influences the ANS-plexuses comprising of sympathetic/parasympathetic energy hubs called "Chakras" that regulate different physiological functions [54–56, 81]. There is one more aspect of Ragas, i.e. circadian (and also seasonal) specificity, that influences human health [82]. Human physiology exhibits ubiquitous circadian rhythmicity [83]. According to the Indian Ayurvedic medicine, bodily circadian rhythmic activity encompass three basic bio-natural elements with diurnal peak-times known as "Prakritis", i.e. "Kapha"(Water/Body- Fluids/Secretions/Inflammation-Edema) (6am/pm–10am/pm), "Pitta" (Fire/Metabolism) (10am/pm–2am/pm), and "Vata" (Air/Movement/Conduction/Transport) (2am/pm–6am/pm), governing body physiology [83,84], and gene expression, recognized as "Ayurgenomics" as one of the important components of P4 medicine [85,86]. Imbalance of any of these "Prakriti" doshas (dysfunction) can lead to the development of disease(s) [83,84], The Vata Prakriti dosha/imbalance is strongly implicated in the development of neurological diseases [85,87,88]. Circadian specificity of Raga is closely related to the bodily circadian "Prakritis" [89,90]. The Ragas designated to be performed/listened aligning with these "Prakriti" time slots (Kapha, Pitta, Vata) are postulated to regulate respective "Prakriti"-doshas [82,91,92]. Thus, such Raga- multiplicity can exert comprehensive benefits on brain/body physiology.

Conclusions

Indian Classical Music (Raga) can be exploited as an effective musical neurofeedback alternative attributed to its versatility of pitch, timbre, rhythm, and tempo entraining brainwaves in desired direction, and its extra-entraining comprehensive physiological effects exerted via induction of neurohormones, activation of pertinent emotive, cognitive and motor brain networks/pathways targeted at restoring normal brain functions in a circadian-specific manner [93] (**Figure 1**).

Author Contributions

All authors contributed equally.

Conflict of Interests

All authors declare no conflict of interests.

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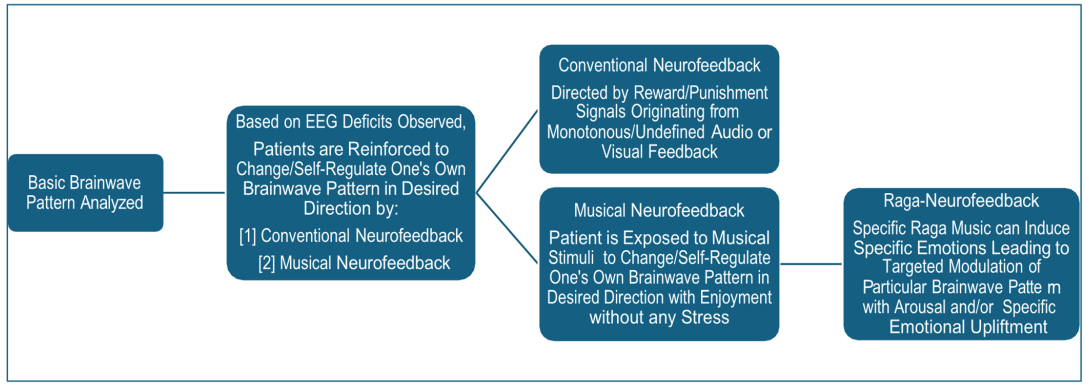

Figure 1. Raga Neurofeedback.

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