Learning to Control Immersion in Interactive Soundscapes Generated by Brain-Computer Music Interfacing and Meditation

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ABSTRACT
This interdisciplinary, practice research develops a Brain-Computer Music Interface (BCMI) which reinforces brainwave patterns linked to meditative states of mind by giving auditory feedback. The proposed software employs the therapeutic benefits of neurofeedback, gaming, music and meditation in order to be effective in helping users understand consciousness. The software's effectiveness is investigated in training programmes and demonstrated in presentations and concerts with consumer-graded electroencephalography.

Keywords **-** brain-computer music interfacing, brainwave entrainment, consciousness, consumer EEG, generative music, immersion, interactive soundscapes, learning, meditation, neurofeedback, neurogaming, OpenBCI, SuperCollider

1 Introduction

This paper reports on the current state of my ongoing PhD research titled *Brain-Computer Music Interfacing with Meditation* at the Anglia Ruskin University, Cambridge[1]. It is an interdisciplinary practice research with technical and artistic methods and outcomes. It investigates disciplines of brain-computer interfacing (BCI), music, neurofeedback, neurogaming and meditation (psychology).

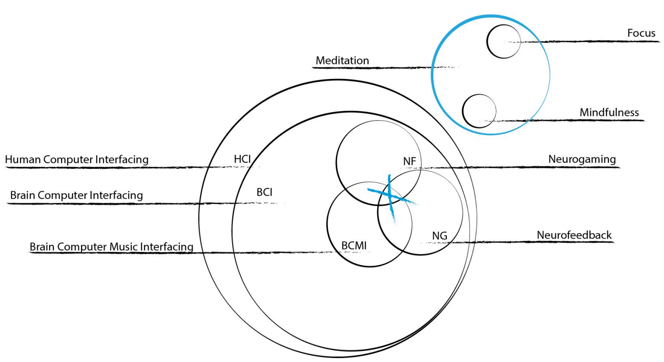

Fig. 1. Orientation.

The technical aspects of the research focus on developing software that composes generative soundscapes based on features extracted from real-time electroencephalography (EEG) i.e. brainwaves. The current state of the research uses an embedded micro-controller (OpenBCI) for EEG reading, and a programming language (SuperCollider) for EEG signal acquisition, signal processing and musification[2]. The artistic aspect of the research investigates 1) compositional methods that are believed to have consciousness changing functions and 2) how these functions can be used to create immersive generative soundscapes.

The interest in this research stems from personal experiences with music and altered states of consciousness and past interpretations of these experiences [2–7], with the intention of learning to control the focal point of my awareness with more precision. I trust that the main research outcome, the immersive and interactive audio neurogame will help others learn to control the focal point of their awareness as well, first with the BCMI and later without it as well.

The proposed soundscapes can be experienced in individual or public settings, e.g. at home with headphones or in musical performances. The main objective of the whole research is to provide an interactive tool for the users to measure and understand aspects of consciousness with meditation techniques in a musical context.

2 Orientation

BRAIN-COMPUTER MUSIC INTERFACING

BCI is a subfield of human-computer interaction. In BCI computers and machines can measure brain activity based on oxygen in the blood flow (MRI), magnetic (MEG) or electrical (EEG) fields. In an EEG reading, the electrical fields are measured with sensitive electrodes, then sent to the EEG hardware to be amplified. These amplified signals then are processed with analogue or digital signal processing on this hardware or later on the computer. These processes involve noise reduction, feature extraction and classification [8]. Finally, the classified features are mapped to control parameters, e.g. the movement of a robotic arm [9] or algorithms in computer-generated music [10].

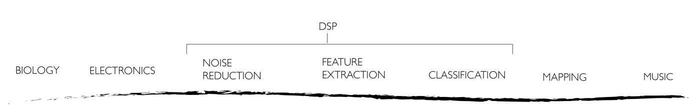

Fig. 2. Flow of information, from nerve to music in BCMI.

1. Archive at https://bcmi.khofstadter.info.
2. "The distinction between sonification and musification, both related forms of auditory display, is that in a musification, the data are not just auralized linearly, but instead, various constraints are created and applied in order to create a musical performance of the sonic data. [1]"

As technology evolves, music evolves. The early men drilled holes in bones to make flutes, today we merge ideas from *musique concrète* and *elektronische music* in a digital audio workstation on computers. To make electronic music we can use our fingers to type, move the mouse and twist knobs, however, we can also interact with computers via our physiological functions, e.g. heart rate or brainwaves. Some BCMI systems, including the one in my research, create a virtuous cycle where brainwaves and music are both an input and an output of each other, they interact.

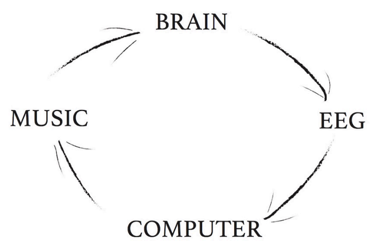

Fig. 3. Virtuous cycle, interaction in BCMI.

Whether a BCMI system focuses on improving lives [11] or on entertainment [12], it is important that it finds meaningful information in the brainwaves and designs an engaging musical system that responds to such information [1]. The response can be based on operant conditioning with positive and negative feedback (active control) or on machine learning, where the system is expected to learn and optimise the interaction between the user and the computer (passive control) [13]. Hybrid systems use both of these ideas. The current state of my research focuses on the use of operant conditioning, however, uses basic machine learning techniques as well. It is based on traditional neurofeedback training, with a focus on audio instead of visual feedback.

NEUROFEEDBACK

Neurofeedback is a special type of BCI bio-feedback promoting brain development in a variety of settings, from cognitive rehabilitation [14–16] to enhancement of performance in sport [17] and art [18]. While the use of biofeedback has been well documented in the arts, it is a promising interdisciplinary area to probe for therapeutic purposes located within music. Effective behavioural management has been demonstrated in numerous music theory [19, 20] as well as neurofeedback studies [21, 22], yet there has been little investigation in their combined therapeutic use. Existing neurofeedback software mainly focus on giving visual feedback and when there is sound, it is usually repetitious and un-stimulating [23], i.e. it neglects the wide-ranging capabilities of music [24].

MEDITATION

In a narrow sense, meditation is an ancient technique, that is considered to originate from shamanism in the Stone Age [25]. Since then in has evolved into a variety of different practices, linked for instance, to focusing on breathing [26], sex [27], repetitive mantras [28] or deep listening [29].

If meditation in its widest sense is a technique to help shift awareness, then everyone meditates sometimes. If you take deep breaths to calm yourself down, if on a cold winter morning you imagine being on a hot beach to warm yourself up [30], if you listen to upbeat music to cheer yourself up, you try to move aspects of your consciousness from one state to another.

To form a picture of a person's meditative state we can generate a frequency spectrum of the raw EEG signal with either digital filters or Fourier transform. Selected bandwidths are called brainwave rhythms: delta (0-4Hz), theta (4-8Hz), low alpha (8-12Hz), high alpha (12-16Hz), low beta (16-20Hz), mid beta (20-30Hz), high beta (30-35Hz) and gamma (35-45Hz). Delta rhythms are linked to sleep, theta to deep relaxation, trance and hypnosis, alpha to relaxed wakefulness and beta to alertness, stress or intense mental activity.

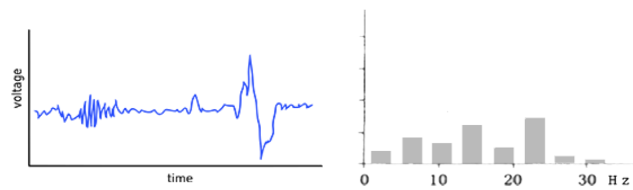

Fig. 4. Raw EEG signal and its frequency spectrum.

In traditional neurofeedback training, positive feedback is given when the user manages to increase or decrease the amplitude of specific brainwave rhythms.

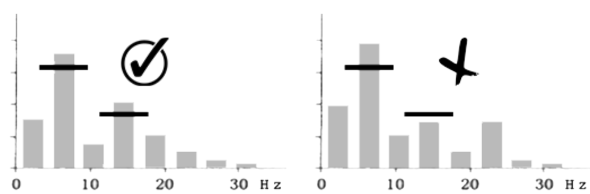

Fig. 5. A neurofeedback protocol that rewards when two objectives are met.

3 Experimental work

NEUROMEDITATION

Immersed in my BCMI's interactive soundscapes, the user is expected to understand various aspects of consciousness. The soundscapes are fundamentally audio games, where neurofeedback protocols determine when to embed positive or negative feedback in forms of musical expressions in the soundscapes. My next prototype employs two NeuroMeditation techniques: *focus* and *mindfulness* [31].

Fig. 6. In focus meditation (left) attention is paid to one object only, in mindfulness meditation (right) attention is not attached to any object specifically, rather the meditator is aware of all objects as they were one.

When training *focus* NeuroMeditation, positive feedback is given for increased mid beta (20-30Hz) or increased gamma (35-45Hz) at FZ and alpha (8-12Hz) at PZ. When training *mindfulness* NeuroMeditation, positive feedback is given for increased theta (4-8Hz) at FZ and gamma (35-50Hz) at PZ.[3]

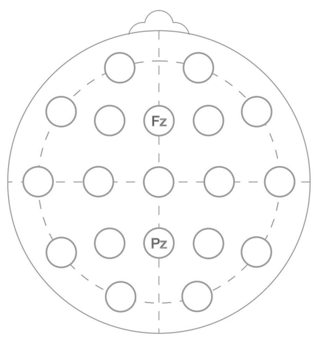

Fig. 7. Electrode locations of international 10-20 EEG system.

Each time a soundscape is played with the BCMI, it sounds slightly different. Firstly, as it interacts with new EEG data, secondly, as the sequence of musical events is triggered by chance operations. The in-determined nature of the soundscapes is to be utilised more often in *mindfulness* training than in *focus* training in order to increase immersion in a Cagian sense:

"Then the answers, instead of coming from my likes and dislikes, come from chance operations, and that has the effect of opening me to possibilities that I hadn't considered. Chance-determined answers will open my mind to the world around. [32]"

How brains respond to music depends on

1. the emotional significance of the circumstances where the music is listened to,
2. the mental state of the listener and
3. the cultural and musical background of the listener [33].

3. These NeuroMeditation protocols are designed for standard EEG. The NeuroMeditation Institute provides protocols for sLORETTA systems as well.

The BCMI addresses 1 and 2 by simply trusting the user's intent to gain experience, who therefore makes the necessary preparations in setting the desired circumstance and mental state. When a neurofeedback practitioner measures EEG, (s)he provides the appropriate 'set and setting' e.g. a sound-proof environment that is undisturbed for an hour. Condition 3 is addressed by investigating compositional methods that are considered to have a universal effect on brains, i.e. methods that affect people in similar ways despite their cultural and musical backgrounds.

RHYTHMIC ENTRAINMENT

Research suggests a relationship between tempo of music and physiological changes [34] and more specifically between tempo of music and brainwave rhythms [35–39]. This relationship is thought to be based on the principles of entrainment, which in related literature sometimes is referred to as frequency following response or synchronisation [40]. The first new soundscapes in my forthcoming prototype will investigate this relationship, the correlations between rate and complexity of rhythmic drumming and shifts of consciousness.

FURTHER SOUNDSCAPES

Other compositional methods that are considered to have a universal effect on brains are spatial sound [41], binaural beats [42], guided mediation [43] and extremely low frequency oscillations of bell sounds [44]. Investigating the literature of these methods and designing the soundscapes are beyond the scope of the current PhD and therefore will have to be scheduled for later. For better user experience it will also be necessary to develop a mobile application (Android, iOS).

4 Discussion

This paper briefly introduced my PhD research by highlighting the synergies between the disciplines involved and the next steps in the practical part. The main outcome of the research will be software experimenting with a new concept for NeuroMeditation. Disseminating the outcomes will be through demonstrations and concerts at events related to the mind and sound and further academic papers.

Notes

Is this research timely?

In 2013, the market intelligence *The Digital Brain Health Market 2012–2020* predicted "biometrics-aided meditation to become the next big thing in corporate and consumer wellness" [45], in 2017, a report on *Global Consumer EEG Device Market 2017-2021* [46] identified a huge growth in commercial applications for consumer EEGs, and today, we can see how interest has grown for research with consumer EEGs in the last 12 years (Fig.8).

2017/18	132
2016/17	128
2015/16	97
2014/15	76
2013/14	49
2012/13	32
2011/12	21
2010/11	6
2009/10	3
2008/09	2
2006/07	1

Fig. 8. Number of keyword searches "consumer+EEG" on Google Scholar.

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