

Anglia Ruskin University, Cambridge  
Creative Music Technology for Media

The development of software for auditory display incorporating principles of  
generative music and neuro-feedback training

*Krisztián Hofstädter*

*SID: 0610279/2*

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## Abstract

This project researches the use of electroencephalography (EEG) for artistic purposes as well as engages in the development of a prototype of an audio game that utilises Neuro-Feedback Training (NFT). In implementing this, I used real-time recorded brain-wave data for the creation of an auditory display consisting of generative music that may also have therapeutic purposes. Most commercially available NFT software uses visual feedback: the aim of this project is to design software in which audible feedback takes precedence.

I would like to point out that my primary motivation initially involved the interface between software and art (art defined in sonic terms with its main purpose on performance). However, as my research over the years has widened it has cognitively moved closer to music therapy.

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## **Introduction**

The motivation for this research is based both on personal experience in experimenting with different mental techniques to achieve more thoughtful states of consciousness as well as in my belief that my NFT software has practical value in therapeutic research with ADHD (Attention Deficit Hyperactive Disorder), learning difficulties and stress management.

In order to provide a theoretical background and a rationale for the development and use of the software in chapter **(I)** 'Literature review' I will thoroughly write about :

**(1)** information processing for attention allocation in the human brain with particular emphasis on the brain's reticular formation and on efficient learning.

Then, to introduce a possible solution for dealing with learning difficulties and stress, I will write about :

**(2)** mindfulness meditation with NFT as a tool for mental training in order to encourage better mental performance;

and

**(3)** sonification, where

I will introduce various inspirational sonic art projects using EEG data.

In chapter **(II)** 'Experimental Work'

I will write about the development of my software and its present and future uses .

Finally in chapter **(III)** 'Conclusion' I will summarize the work and my findings.

“And those who were seen dancing were thought to be insane by those who could not hear the music.”

Friedrich Nietzsche

## **(I.) Literature review**

### **1. Attention allocation**

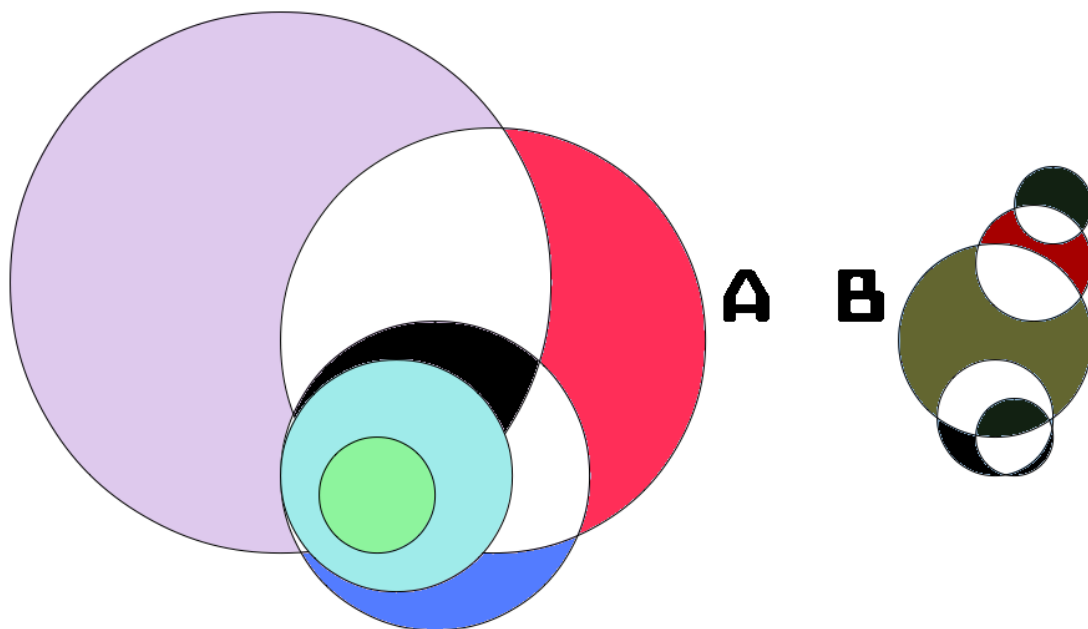
Attention is often defined as 'the cognitive process of selectively concentrating on one aspect of the environment while ignoring other things. Attention has also been referred to as the allocation of processing resources' (Anderson, 2004, p519). As the purpose of the developed software is designed to encourage a more focused control over *attention*, I will therefore, in what follows, explore the underlying psychological structures involved in *attention allocation*. The crucial terms here are *focusing* and *attention* which, in order to clarify in what essence they are intended to be used as follows.

*Focusing* is defined as the method used to consciously switch between different states of mind by an efficient filtering process in which certain thoughts in the mind are kept while others are ignored. In learning how to concentrate on or to ignore certain thoughts, mental or physical tasks can be carried out more effectively, while thoughtfulness be deepened and stress avoided (Austin, 2006, Csikszentmihalyi; 1992, Sheridan; 2006).

*Attention*: '... attention is the focusing of sensory, motor, and/or mental resources on aspects of the environment to acquire knowledge. Attention allocation is deciding what to focus those resources on, whether the decision making is conscious or subconscious, based on current task needs and the benefits and costs relative to what is known.' (Sheridan, 2006)<sup>i</sup>

When the mind is not focused on one allocated attention area - in other words, it is not concentrated on a single activity - the mental energy is split and allocated diffusely to various tasks. Therefore the full potential of *focusing* cannot be accessed. A term used in psychology to describe this phenomenon is 'divided attention', where attention is paid to a second task, or tasks, that do not serve the primary goal of an activity (Shinn-Cunningham, 2004).

Attention allocation can be pictured by breaking tasks down into sub-levels of micro- and macro-attention (Sheridan, 2006) which can be demonstrated with models of mathematical sets.



*Figure 1 - Sets of micro- and macro attention allocation: tasks and sub-tasks  
[ Set 'A' and 'B' represent a macro level (tasks) in relationship to the  
overlapping circles which represent micro levels (sub-tasks). ]*

The above diagram can demonstrate the aforementioned 'divided attention'. Set 'A' is considered to be the primary task to which attention should be paid and set

'B' is the task that is unnecessary.<sup>1</sup> If *crossing the street* is the goal, the task on a macro level to reach this goal is represented with set 'A'. Within this set, the overlapping circles represent subtasks that focus on specific allocated attention areas – for example, checking the colour of the traffic lights, the movement of vehicles and pedestrians, the assessment of risk and the engagement of motor skills such as walking. Set 'B' represents a mental task that is absolutely not necessary in the achievement of our aim, *crossing the street* - for instance *thinking idly about indulging in sexual intercourse*.

#### *Task identification for attention allocation*

In order to identify a task for attention allocation as being on a micro or on a macro level perspectives have to be considered: we have to examine from which vantage point we look at the task - that is to say, from the top down, or the bottom up, in a hierarchical system. The above example of *crossing the street* is macro as it was broken down into smaller subtasks, but when considering it as a component, say, of *going to the park*, it became micro, a subtask. However the discharge of a neuron is micro in relationship to a fluctuating EEG/brain wave-signal, but is macro when zooming into the cell and examining the rules of chemistry and physics. With mathematical terms, each set (task), is an element/member of a higher/larger set and vice versa.

#### *Task combination and divided attention*

In the early practice of psychology the *serial bottleneck* model was used to demonstrate how information is processed in the brain (Styles, 2006). This is the idea of a single channel filter that can only concentrate on one task but has a rapid switch to allow it to move its focal point towards selected allocation attention areas. A more recent concept is where the human operator has a pool of

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<sup>1</sup> Categorising tasks of serving or hindering the primary aim is beyond the scope of this essay. In this work, I consider mental noise - that is, unwanted mental activity – as being the main motor in set 'B', which can be unwanted, hindering, unreasonable, illogical or inessential.

processing resources (pre-attentive parallel processing) that can deal with many tasks simultaneously. When a processing unit in the pool demands more energy, others will be suppressed, unless the pool's performance is increased with extra energy (arousal, motivation). A basic routine for a task is:

- (1) to remember the goal,
- (2) to monitor and update the steps and
- (3) to update goal stages while running the routine (Styles, 2006, p.153).

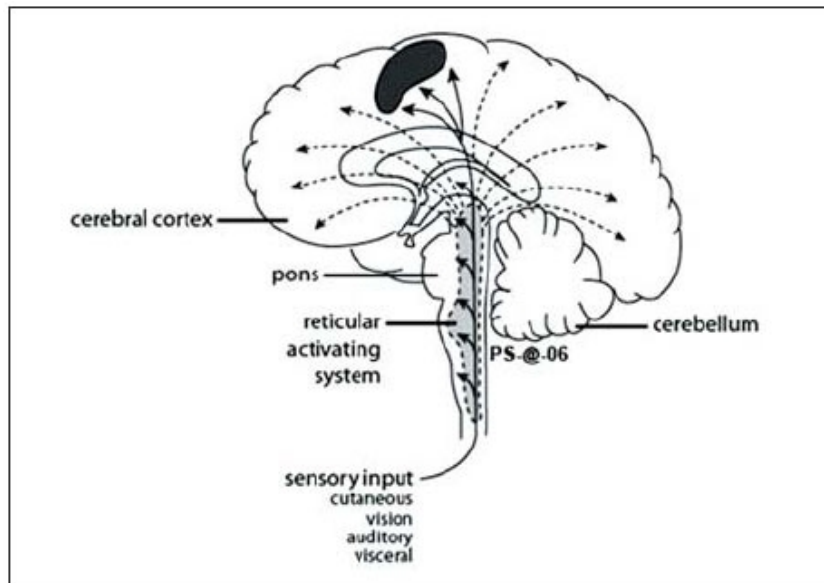
It is important to be able to deal with multiple tasks simultaneously if these subtasks, to which we allocate our attention to, all serve our goals and intentions. An apropos example would be the delivery of an outstanding essay in time (set 'A'). To achieve this, it is important to pay attention only to the required tasks and not to get distracted by mental noise or other seductive activities (set 'B'). With concentration and focus a disciplined mind will only allow attention to be allocated to the requisite areas. Divided attention interferes with learning and efficient information processing.

One of the key elements in learning is memory. In the mode of full attention, memory is stored more effectively than in the mode of divided attention. Why this should be, is not fully understood yet, but neuroscientists and psychologists regard the following as possible causes:

- (1) 'Deeper processing requires time to complete, and divided attention limits the time allotted to encoding',
- (2) 'consciousness and awareness is a necessary contributor to memory',
- (3) 'attention limits elaboration or organisation, both of which contribute to good memory.' (Baars & Gage, 2010, p.330).



## *The Reticular Activating System (RAS) – the attention centre of the brain*



*Figure 2 – the RAS*

To demonstrate how attention allocation is coordinated the work of the reticular formation of the brain stem needs to be explained<sup>2</sup>. This formation has axons to the mid-brain, fore-brain and the spinal cord. It is also called the The Reticular Activating System (RAS) as it regulates the levels of such activities as attention, sleep and arousal. It is a net, where the signals of the external and the internal world converge. Besides being responsible for sensory input to the cortex, it also maintains the muscle tone of 'antigravity muscles', assists in breathing, regulates the heartbeat and is involved in pain regulation, posture control and eye movements (Carpenter, 2003).

The general activity of the cerebral cortex is closely related to the level of consciousness. By stimulating the reticular formation, the level of consciousness can be altered (Brodal, 1998). Before looking at meditation<sup>3</sup> and at the importance of learning and practice in the acquisition of skills, we will first look

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<sup>2</sup> 'Binaural beats provide potential consciousness-altering information to the brain's reticular activating system. The reticular activating system in turn interprets and reacts to this information by stimulating the thalamus and cortex - thereby altering arousal states, attentional focus, and the level of awareness, i.e., the elements of consciousness itself' (Holmes, 1997). Binaural beats are planned to be used in the developed software.

<sup>3</sup> Defined as a mental training practice to help achieve desired states of mind.

at how the RAS activates the cortex.

To describe a 'well functionig brain' for peak performance, Collura (1997) highlights the work of the RAS in his model for EEG in action: EEG rhythms stimulated by the RAS are the 'push and pull' of the neuronal masses, that initiate cortical activity. Neuronal masses only oscillate if response requirements are met. One characteristic of the masses is 'resonant frequency'. This resonant frequency determines how the neuronal mass will move when stimulated, and it also determines the transformation of potential to kinetic energy.<sup>4</sup>

Collure writes:

'In terms of the brain, a relaxed, coherently firing neuronal pool will be more receptive to input than an agitated, busy brain preoccupied with a lot of high-frequency activity that will not let stimulation in. Note that the brain state corresponding to higher potential energy is more sensitive to differences in input, and is more able to distinguish subtle stimuli.'

The neuronal pool has more potential energy when the 'push and pull' of the RAS has more lower frequencies. More lower frequencies (alpha waves) create more potential energy and that means the brain is more receptive to input (learning) and can as well be more easily controlled.

Collura's thesis is that in order to develop an RAS that can efficiently deal with challenging circumstances **it is important to learn how to organise, plan and release corrective action**, rather than simply trying to solve a problem the hard way by putting more effort and energy in the system. The goal is the efficient transformation of energy not the introduction of extra energy.<sup>ii</sup>

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<sup>4</sup> The behaviour of this energy as well as how this fluctuating neuronal mass will respond to particular perturbations depends on balance between potential and kinetic energy. For further explanation of the RAS see 'collura-chaosoutoforder.pdf' in doc/reference\_material on attached DVD.

*Learning to produce lower frequency brain waves in order to learn more efficiently*

'When skills do not provide enough specification, attention is needed' (Styles, 2006, p198). When we do not know how to do something we have to learn and that usually entails practice. Investing time in study and practice requires discipline. The investment of time shall help the development of skills which lead to energy efficient mental or physical work.<sup>5</sup> A common distinction employed in within the field of psychological research is that there are two different modes used in the brain for information processing.

**(1)**     *Automatic control:*

This mode of processing is in charge, for instance, when any action is carried out without awareness – that is to say, when the actions are initiated without any conscious deliberation or when attention is drawn automatically to stimulus (Norman & Shallice, 1986 cited in Styles, 2006, p.183).

**(2)**     *Controlled control:*

This is processing is deliberate and conscious and requires more energy than the first mode. It can only deal with a limited amount of information at a time (Styles, 2006, p.183-184). When learning something new (writing, driving a car, learning a language, etc...) conscious control - 'controlled control' - is needed as there is no saved memory from which the mind is able to compile the processing task needed for 'automatic control'.

As stated earlier, each attention allocation task, is made up of sub-tasks. For instance, when learning how to drive a car, in order to become more proficient, we have to learn how to use the pedals, to change the gears and to use the wheel. As examples have shown (McLeod and Posner (1984), Schumacher et al.

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<sup>5</sup> Divided attention is not energy efficient. An energy efficient mind is capable of allocating only attention to the tasks which are considered to be useful in the achievement of the set goal.

(2001), and Shaffer (1975) cited in Styles, 2006, p.184) learning to combine such tasks is difficult and it demands even more attention if the mapping of the input and output systems are crossfaded. For example, in learning how to drive a car, the primary input system is the visual sense; while the primary output system is in the hands and feet. The eyes monitor what is happening inside and outside the car. The hands and feet have to be in control of various activities as well. In the beginning of learning each task has to be learnt individually, but later all tasks have to be forged into one complex whole.

The importance of such a process does not reside exclusively in learning each sub-task individually. It is equally crucial to develop a synergetic motion, the merging of elements into one in order to develop an efficiently functional task at a higher macro level where the right pathways for learning are activated in the brain. Learning a new skill is easier and more efficient, when the mind is coherently firing with a stable presence of alpha rhythms. In other words when the RAS produces more lower frequency waves to conduct the momentum of the neuronal mass, the pool of brain cells.

To support my research - which is to say that NFT with audio can help to achieve and develop desired states of mind for learning - the essay will continue by discussing a mental training technique called meditation.

## **2. Mindfulness Meditation and Neuro-Feedback Training**

As we have seen, in order to avoid having a busy brain, preoccupied with a lot of high-frequency activity, which will not let stimulation in and is therefore not capable of learning efficiently, the RAS has to generate more low frequency waves. For example, for efficient learning the RAS has to produce more alpha waves (8-14hz) to be able to store information in the subconscious mind and to avoid agitation (stress) it has to turn the volume down on the high beta waves (above 18hz). An effective method in achieve this is to practice meditation: for

instance mindfulness meditation, which is a mental training method that can help to develop a 'relaxed, coherently firing neuronal pool'.

Meditation is not about thinking. Indeed, we might even say that it is the opposite – which is to say it is *not thinking* in the sense of not thinking about attachments to outcomes. 'One basic approach to the Great Way is a calm, silent, no-thought style of attending to the present moment' (Austin, 2006, p.13). In my case the state of mind meditation helps to induce I, usually describe as waves breaking upon the shore. The motion of the waves depends on the depth of meditation being practised. The slower the waves the calmer the shore appears. In meditation, thought processes are more transparent and considered with more care. Labels such as good or bad disappear – the duality of the mind is liberated by a more comforting and gentle acceptance. A flow in which observations of the inner and the outer world both liberates and recharges.

Mindfulness, or other types of meditation can be practised not just sitting cross legged at home but can also be used in different spheres of life such as sports, education or in every day occupations.

Practitioners regard an awareness of the present moment as a key element in successful meditation. By conscious breathing, close attention on the to scenery and by detailed observation, the present moment can reveal itself as an aid in quietening the mind. The connection between the mind and the present moment can also be established by curiosity about ourselves. Ben Irvine, a young philosopher in Cambridge in his book 'Einstein & the Art of Mindful Cycling' expresses meditation as the following:

'Meditation, like charity, begins 'at home', since this is where we get distracted most easily. We get caught up in our thoughts, sensations and feelings, either trying to suppress or vent them or worrying about their origins and

consequences. Being mindful of ourselves in meditation helps us avoid struggles. Instead of judging our thoughts, sensations and feelings, we become curious about them. We simply witness them passing through the present moment like clouds in natural formations. In using one part of our minds to calmly observe another, we allow the contents of our inner lives to find their own balance, and we become more curious about the world outside (Irvine, 2012).'

Meditation is neither practised solely by hippies nor is it bound to a specific religion or culture. It is a well known mental training technique amongst artists, sportsmen, scientists and businessmen. Practising meditation, amongst other benefits, can help to improve self regulation and attention skills in several domains. It can also reduce the cortisol level - the so called stress hormone for which is a common reason for concentration problems. In other words meditation helps the processing of negative emotions under stress<sup>6</sup> (Austin, 2006, Brefczynski-Lewis, J. A. et al., 2007, Tang, Yi-Yuan et al., 2007, Jones and Bright, 2001, p.231, Engström, 2010).

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<sup>6</sup> 'In a recent "cross-cultural" development of note, EEG, fMRI, and PET studies of brain activity in the evocation of specific meditative states and positive feelings, such as compassion and devotion, in a highly trained long-term monastic practitioner (a Western Lama in the Tibetan tradition with a doctorate in molecular biology) have engaged the meditator not merely as subject but as a full collaborator in the design and interpretation of these investigations with his scientific counterparts, capitalizing as well on his highly developed ability to give a precise account of his mental activity during various practices. These investigations show a range of stable patterns of brain activity ("neural signatures of different mental states") that have never been observed in naive subjects, patterns that can be replicated by the subject at will, depending on his choice of meditative practice. Such studies have multiple implications for research in affective neuroscience, neuroplasticity, and our understanding of what might be possible through specific kinds of training regarding the ways we process and express emotion (Goleman, 2003). They assume practical relevance in light of brain changes reflecting enduring shifts in the processing of negative emotion under stress, which have been observed in novice meditators following training in MBSR in an 8- week worksite intervention' (Davidson, Kabat-Zinn, Schumacher, Rosenkranz, Muller, Santorelli, et al., in press)' (Kabat-Zinn, 2003).

## *Stress*

Stress, in general, is useful, as it can be powerfully motivational. For instance, it activates the brain in a way that enables us to work with deadlines and to make us more alert to life-threatening situations. Unfortunately, not being able to handle some stressful situations can have unfavourable outcomes. Therefore, it is important to understand how to cope with it. In stress situations, after an adrenalin surge in the body, the adrenal glands release cortisol into the blood stream.<sup>7</sup>Cortisol switches off all the functions in the body that are not essential for the purpose of flight - for example reproduction, digestion and thinking. Humans in social stress situations have the same reactions: a loss of appetite, but a craving for fast digestible sweet food; a loss of the sex drive, but the feeling of lethargy. Even more pronounced are the changes in behaviour caused by stress. People become monomaniacal, aggressive, depressed and subject to concomitant changes in their DNA.<sup>iii</sup>.

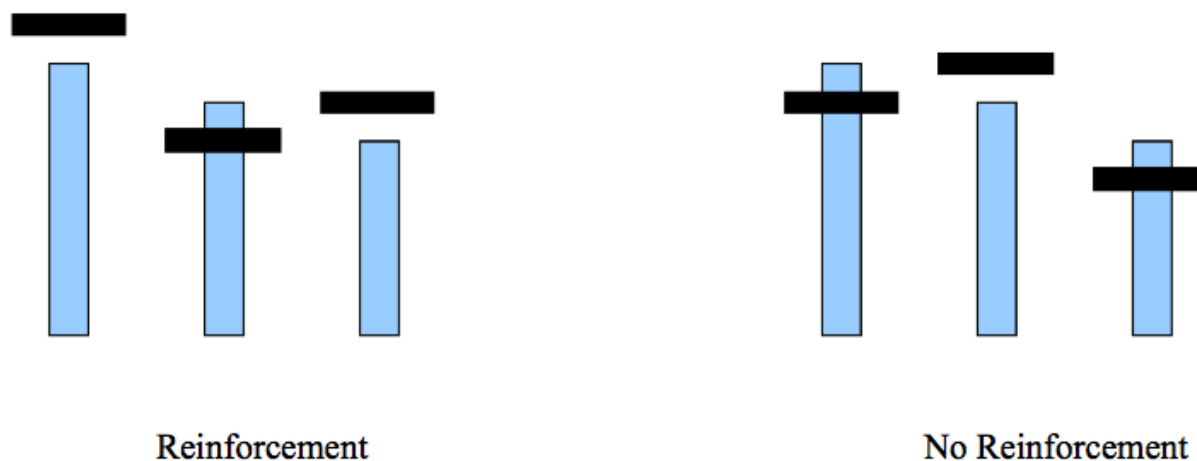
'Stress is often caused by negative self-talks' (Jones and Bright, 2001, p.228). Negative self-talk can be considered as set 'B' in our attention allocation figure (Figure 1). It is the non-productive task that hinders the mind in using energy efficiently. Negative self-talk is not only the cause of stress, but is a barrier in the development of self-confidence and the process of healing depression. As meditation in general is about calm alleviation of negative thoughts, it can help the RAS to be more efficient in generating lower frequency waves that allow more control over thought processes. Hasenkamp, (2011) in her study with fMRI scans on 'focused attention meditation', supports the proposition that 'People who train in this style of meditation cultivate their abilities to monitor cognitive processes related to attention and distraction'. In other words, by practising meditation a meditator is able to identify mind-wandering and quickly learns to allocate attention back on the chosen mental or material object. It is therefore, an excellent therapeutic method for those suffering from divided attention disorder

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<sup>7</sup> In the savannah, this hormone enables the zebra to focus exclusively on escaping the hungry lion (Mieras, 2010).

(DAD) or attention deficit hyperactivity disorder (ADHD).

### *Neuro-Feedback Training*



*Figure 3 - threshold (black) on the selected bandwidths*

Within my research practice I have been implementing various ways of using brainwaves (EEG) for creative purposes. The one I have found particularly interesting is Neuro-Feedback Training (NFT) - a type of biofeedback that helps to develop better control of central nervous system activity (Demos, 2005). In NFT the goal is to change an unhealthy (stressed, hyperactive, ... ) EEG pattern to a healthy one (focused, relaxed, ... ) by training the brain to be able to change amplitudes of selected frequency bandwidths.<sup>8</sup> The usual procedure is to have thresholds for bandwidths that need to have a stronger amplitude (micro volts) or a weaker amplitude. Most NFT systems implement mainly visual feedback (as a reward) when the inhibited filters sense signals above or below the thresholds. “Most graphics tend to be boring and repetitive... there are only a few systems which can hold the clients attention unless they are highly motivated” (Demos, 2005). Today, in 2013, this is different. The reward systems of recent NFT

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<sup>8</sup> Figure 3 demonstrates an example in NFT a BETA/SMR (sensorimotor: 12-15) training. This training includes only one reward filter combined with two inhibit filters. (Norton, 2005).



software have become more advanced, however only when it comes to the visuals (appendix 2).

### 3. Sonification

Since the first EEG experimentation in electronic music, Alvin Lucier's 'Music for Solo Performer' in 1965, there have been many sonic art projects involving brainwaves, especially since cheaper hardware like the IBVA, Neurosky and the Emotive are readily available for experimentations. Besides the pioneering Brain Computer Interfacing (BCI) works using sound of prof. Eduardo R. Miranda at Plymouth University and Dr. Mick Grierson at Goldsmith College, London (Hofstädter, 2009) here is a list of stimulating work:

#### *Fragmentation - a brainwave controlled performance*<sup>9</sup>

Alberto Novello a.k.a. JesterN is a scientist, a composer and a sound and video artist. The performance aims to expose the brain status of an actor in a sonic metaphor with the use of the audio programming environment SuperCollider and the Emotive hardware. As a skilled programmer he is able to avoid using the supplied algorithms that claim to provide reliable levels of meditation, relaxation, attention, etc... . By using the 'Signal class' in SuperCollider, Alberto can easily utilise FFT to access spectral information of the raw signal in order to map magnitudes of bandwidths (brain-wave rhythms like alpha or beta) to properties of sounds (pitch, loudness, length, ...) <sup>10</sup>. According to him, the 'fuzzy' algorithms provided by Emotive cannot be used efficiently as they do not output data that can be trusted. As the sonic part of this work is entirely developed in SuperCollider and that it employs DSP, which I want to incorporate in my further research, as well as the fact that Alberto is both approachable and supportive, *Fragmentation* has been very inspiring to me.

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<sup>9</sup> Fragementation performance: <https://vimeo.com/45238025>.

<sup>10</sup> Fast Furier Transformation (FFT) is the most used Digital Signal Processing (DSP) in NFT. An easy comparison is a visual equalizer on a music player, where the volume of lower and higher frequencies are in movement.

### *Sitting.Breathing.Beating.[Not]Thinking<sup>11</sup>*

This project by Adam Overton has been developed under the supervision of David Roseboom, who is a pioneer in the use of neurofeedback in music. The project's parsing of EEG data and its mapping to noise sounds has been established in SuperCollider software. The performance in 2004 was delivered in seven days, an hour each day at noon by sitting cross-legged, meditating in a park. This interactive sound software uses not only EEG, but amongst others, breath count and pulse count with real time mapping to certain parameters of prerecorded sound-files. It is one of the few EEG projects where both the software and the hardware were developed by the artist.

### *Global Mind Project*

This Australian project focuses on the mapping of EEG to still images and audio-visual artwork and features performance artists like Stelarc (performance artist interested in cybernetics), Dominico de Clario (visual art, sound installations) and Jill Orr (performance installations). The performance is planned as well as improvised, 'allowing the artists to both shape each phase of the event according to their own creative processes as well as responding to the presence of others. Jill Orr's performance draws on theatrical practices of mesmerism and early hypnosis; Stelarc examines the cyborg being, through the adoption of a virtual reality persona; and Dominico de Clario offers a musical and meditative performance via a mind controlled piano.'<sup>12</sup> Emotive's wireless system is used here as well.

This vast project is a luxurious example of the use of EEG in interdisciplinary art where the entertainment in both, the visual and sonic medium is absorbing.

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11 *Sitting.Breathing.[Not]Thinking*: <http://plus1plus1plus.org/meditations/sBBNt>

12 <http://www.globalmindproject.com/events/>

### *Brain Study of Julian Klein*

This installation uses the neural activity of five different regions in the brain recorded live from five performers simultaneously. The aim of the experiment is to sonify communication between the brains by stimulating them with auditive and visual feedback generated from the activities of measured brains. 'They listen to their own brain activity and are able to influence the auditive perception of other players by their brain status. This network communication is organized as a model of the stimuli processes within the brain: every brain plays the role of a definite functional part of the brain.' For a fuller experience of the inner sound of the brain, the audience can listen to the performance with headphones as well. 'By the use of psychoacoustic phenomena, the stereo sound of the headphones is transformed into a virtual three-dimensional acoustic space, ...'<sup>13</sup> where the activity of the selected brain areas are positioned exactly where the listener's corresponding brain part is situated as well.

This project uniquely demonstrates that it is possible to have a musically entertaining as well as scientifically stimulating outcome with live recorded EEG data.

### *SubConch<sup>14</sup>*

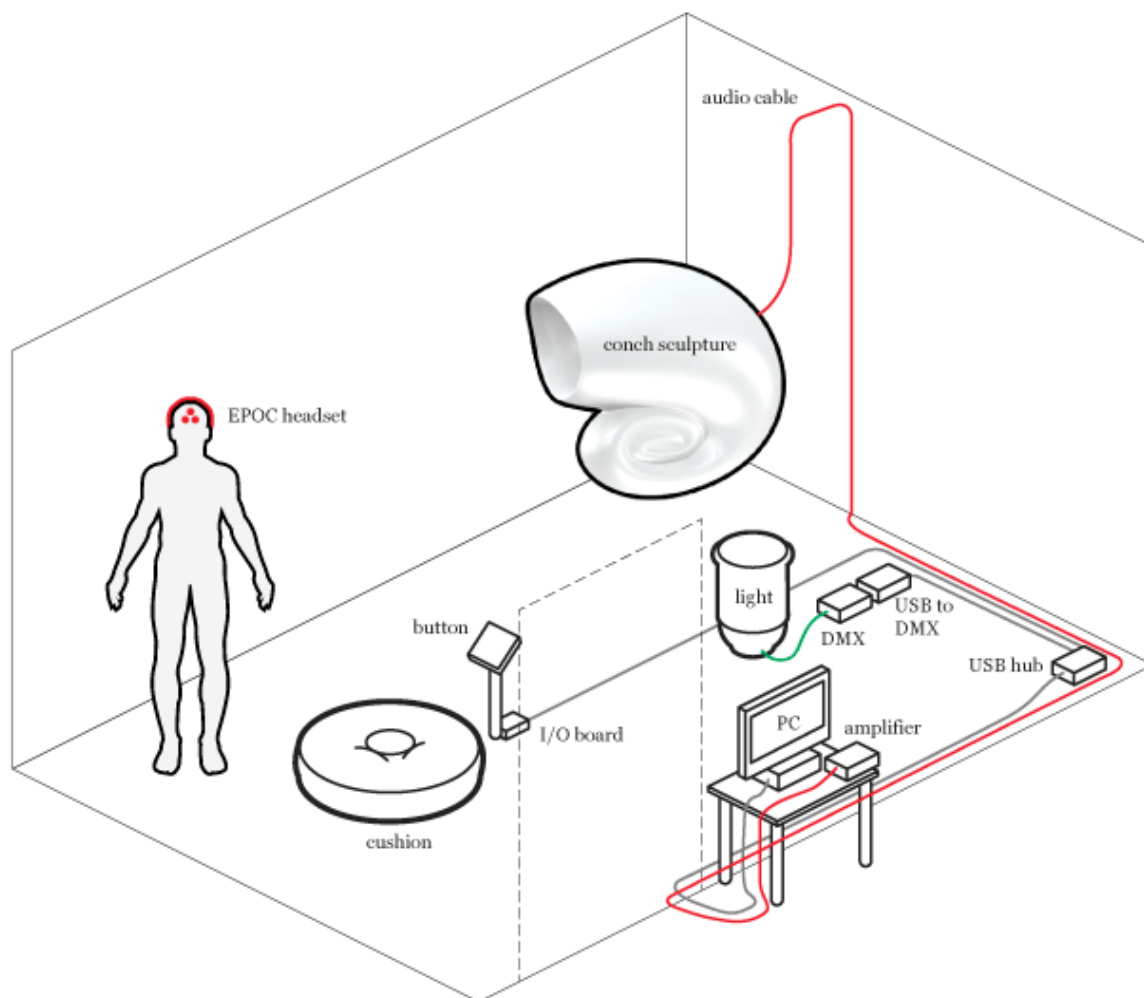
This smaller scale project is an example of an elegant approach to the use of EEG in a gallery environment. The installation uses the Emotive system with a custom designed software and artefact, called the 'conch', hanging from the ceiling. This project convincingly shows implications of the Emotive system's vast potential.<sup>15</sup>

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13 Julian Klein's website: <http://www.julianklein.de/>

14 SubConch: <http://www.subconch.net> – Recently exhibited in Oslo.

15 Instead of 1 channel, like with Neurosky, Emotive has 16 channels, therefore more and different types of brainactivities are accessible for creative purposes.



*Figure 4 – SubConch Installation*

### *DECONcert1*

A concert played by the minds of the audience. As with 'SubConch' the brains activities of the audience/participants whose brain activities are used to create a sonic environment. At the performance, in Toronto in 2003, the EEG signals of 48 people were averaged, cleaned and then fed into a system that looked for alpha brain rhythm synchronicity. 'The soundscape being generated generates a response from the participants, and the collective response from the group of participants is sensed by the computer, which then alters the music based upon this response.'<sup>16</sup> The participants received not only a constant auditive response but also a visual feedback, a waveform of each individual's brain wave signal on

<sup>16</sup> DeConcert: [http://www.eyetap.org/about\\_us/people/fungja/regen.html](http://www.eyetap.org/about_us/people/fungja/regen.html)

a projector. *DECONcert1* is an interesting approach to sonify synchronised minds.

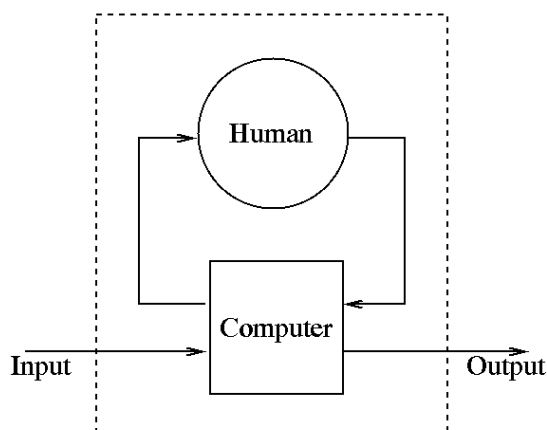


Figure 4 – *DECONcert1* loop

*Brainwave Beats in Collin's Lab (MAKE Magazin)*<sup>17</sup> and *Chanter*<sup>18</sup>

Both Neurosky projects present simple mapping systems using brainwaves to alter music. *Brainwave Beats* uses Processing software to send MIDI signals to an Ableton sequencer. The four brainwave rhythms, theta, alpha, beta and gamma, control percussive sounds in a drum kit sequence. To change the overall sound, the parameters of the special effects are altered by the 'attention' and 'meditation' levels, the eSenses<sup>19</sup>. *Chanter* is a software that people can download for £5 from the Neurosky application store. It is the only commercial software in the online Neurosky store that has a more sophisticated auditive feedback than a visual one. These software for Neurosky motivate me in my research because of their popularity, *Chanter*, despite it's simplicity, mainly because of its presence as a commercial NFT software on the Neurosky website.

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17 MAKE Magazin link: <http://blog.makezine.com/2011/05/05/collins-lab-brainwave-beats/>

18 Chanter on Neurosky application store: <http://store.Neurosky.com/products/chanter>

19 eSenses are the 'meditation' and 'attention' signals, which are calculated in the Neurosky micro-chip and then sent via bluetooth to the computer.

## (II.) Experimental Work

Under the supervision of Dr Tom Hall and Dr Richard Hoadley Human Computer Interaction (HCI) has been the focus of my recent research. In the last few years, as demonstrated in the Contemporary Music Review (Miranda, Overy, 2009), the use of EEG in music has significantly increased. Similarly, as with some aforementioned EEG projects, my research also uses brain wave rhythms to obtain an efficient sonic response to particular changes in the monitored brain-hemispheres. However, my software differs as follows: With the use of NFT principles and the care to deliver an absorbing sonic experience, besides its adaptability for performance, **the project aims to establish new means in music therapy** for attention deficit disorders (ADD, ADHD) and stress and pain management. **The outcome of this research is the development of a new approach in the creation of musical expressions for NFT.**

When I engage with art, work, pleasure or with any area of life, I am aware of a dual process:

1) cognitive thinking and a state of mind that I associate with Mihaly Csikszentmihalyi's

2) *flow* experience<sup>iv</sup>. There is a difference in terms of (1) the mental analysis of the experience (cognitive thinking) and (2) the process of the experiencing itself (*flow*). The balance between how much I am absorbed in cognitive thinking (interpreting the experience) and in *flow* (being deeply engaged in the experience without thinking) depends mainly on my ability to change focal points of attention allocation in the mind.

The eSense signals used in the project are the 'attention' and the 'meditation' levels of the participant's EEG. When I started working on the project I hoped that these two signals would represent my involvement in the two aforementioned states of mind, *attention* representing cognitive thinking and

*meditation* representing the *flow* experience. In the early stages of the project I focused primarily on maturing the code structure and reliability of the software without considering the practicalities of its application to the actual act of focusing being more attentive and meditation more relaxation. As I only later have found out that these eSense signals were more difficult to control, and therefore not easy to use with my software, I had to reconsider how to incorporate them into the system.

Although Neurosky's eSense signals, *attention* and *meditation* derive from secret algorithmic formulas, the company has, nevertheless, confirmed<sup>20</sup> that beta waves are the main motor for attention and alpha for meditation. *Delta* (0 - 4Hz), *Theta* (4 - 8 Hz), *Alpha* (8 – 13 Hz) and *Beta* (13 – 30 Hz) are the bands of EEG activity. *Delta* rhythms are associated with sleep; *Theta* with drowsiness, trance, deep relaxation or meditation and hypnosis; *Alpha* with relaxed wakefulness and *Beta* with alertness, intense mental activity or stress (Miranda, 2006). It is a common misunderstanding that certain states of minds are entirely monopolised by one type of brain rhythm.<sup>21</sup> As the brain can produce high beta and alpha waves at the same time, measuring high *attention* and high *meditation* levels simultaneously with Neurosky is not rare. The result of this finding has been that the reward system of the developed software in SuperCollider has had to be emended by extensions. How the eSenses are used and how the tree main parts of the software (sequencer, gui, rewardsystem), are thoroughly explained in the video demonstrations<sup>22</sup>.

Many of Neurosky's applications and some NFT software incorporate gaming aspects and I decided to do the same. The NFT part (reward system) of my

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20 Alpha and beta in eSense: [http://www.linkedin.com/groups/OK-so-heres-question-lots-3572341.S.131701475?qid=b61134ff-4657-4bc3-8529-5ceb83fb7d0a&trk=group\\_items\\_see\\_more-0-b-ttl](http://www.linkedin.com/groups/OK-so-heres-question-lots-3572341.S.131701475?qid=b61134ff-4657-4bc3-8529-5ceb83fb7d0a&trk=group_items_see_more-0-b-ttl)

21 'Going down into alpha' does not mean that doing meditation or a similar mental training filters out all frequencies below the range of 8-14hz, but that these frequencies will be the subject of amplification while others, like beta or theta can be subdued. In other words, the RAS will generate more frequencies in the alpha bandwidth than in others.

22 See attached DVD.

software does not only reward the user with new sounds when reaching a threshold with the eSenses, but by having more difficult challenges in further levels it shall maintain engaging.

The levels are called islets. Each islet has its own challenge that has to be completed in order to move to the next islet. Islets are the levels within an island. At the moment in the game there is only one island that can be considered as having similarities with a 'campaign' in a common computer game. By using the same instruments with similar musical expressions on an island, completing all islets shall provide the experience of having created a rich generative composition.<sup>23</sup> The prototype on the DVD has 4 islets on 1 island.

The software and thorough video demonstrations of its structure and use can be found on the attached DVD.

Future plans for the research and software development are:

1. the refinement of sound synthesis (SynthDefs) and the advancement of code for stability and reliability;
2. the extension of the software with audio busses enabling better control over unwanted frequencies when mixing to the main output;
3. an extension for a wider sound experience by adding 'music concrete' to the sequencer. Further functions/task will trigger and manipulate prerecorded sounds samples;
4. the extension of both, MIDI as output (triggering sounds in an analogue synth) as well as input (reading midi files in the sequencer);
5. the building of connections with the main EEG hardware companies to acquire information from their hardware's data transferring/parsing in order to broaden the compatibility of the developed software<sup>24</sup>;

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<sup>23</sup> A simple computer game called 'flow' has been very inspiration when making plans on how a visual feature for software shall look like. As an earlier work of mine with SuperCollider software was to create an alternative sound-design for this game a copy of this project will be provided on the DVD (\_doc/flow\_game).

Original version can be found here: <http://interactive.usc.edu/projects/cloud/flowing/>

<sup>24</sup> A recently developed device with great potential: <http://www.neuroelectrics.com/>



6. the investigation of 'using both music as an input stimulus as well as in using the musical output of the brain to help facilitate the desired training (Miller, 2011)';
7. the investigation of the effects of binaural beats<sup>25</sup>, harmonics, repetitive-monotonous- and droning sounds and minimalist music have on the brain;
8. the furthering of my knowledge in digital signal processing in SuperCollider for accessing and transforming EEG signal into meaningful data;
9. the building of standalone software for various platforms (OSX, Windows, Android...) that also features a sequencer GUI. This would allow users to create their own soundscapes for the NFT software;

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25 Binaural beats are used to stimulate the brain in order to change states of mind. I have been using them for meditation with positive outcomes.

'Finally, we must consider the pathways within the brain that transmit the binaural beats to the cortex for processing. The reticular activating system (RAS), a large net-like region in the brain stem, plays a major role in filtering sensory input and focusing attention and awareness and is strongly involved in the cortical processing of binaural beats. Studies indicate that the binaural signals are processed in the RAS. (Homes, 1997)'

## Conclusion

There are some indications that therapeutic benefits are to be derived from using NFT, for those suffering from anxiety and depression (Graham, 1999). Although many years of research with ADHD children and other research groups (focusing on enhancing cognitive and artistic performance) have shown that NFT does not always work, there is enough evidence to demonstrate that it can be used successfully. Biofeedback practitioners consider this non-invasive, non-drug alternative treatment a valuable tool and, in connection with music therapy, an area where research is needed (Miller, 2011). As mentioned earlier in this essay, my software is a new approach in NFT. With SuperCollider as its engine and development environment, it has vast and untapped potential in the field of music therapy as well as in sonic art<sup>26</sup>.

As more and more EEG devices have become accessible for general consumers, the market for BCI is expanding. A market intelligence predicting *Digital Brain Health* for 2012 -2020, amongst others, reports the following:

- 'Biometrics-aided meditation will become the next big thing in corporate and consumer wellness.'
- 'Insomnia and depression will be first-line treated with computerized Cognitive Behavioral Therapy in at least two national health services.'
- 'At least one major insurer will launch an educational campaign to help adults proactively take charge of their own “brain fitness” navigating emerging research and digital brain health tools.'<sup>27</sup>

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<sup>26</sup> However, the research as a whole is driven by the desire to develop a more sophisticated sound environment for the investigation of NFT for therapeutic purposes, it is the nature of such research that it will contain aesthetic components - for example, compositions and installations, live electronics, sonic art (installation, HCI) and algorithmic compositions.

<sup>27</sup> A summary of the research: <http://www.sharpbrains.com/market-report/> (last accessed 20/02/2013)

The outcome of this report has been encouraging the further development of the software and is giving hope in the finding of a scholarship for further academic studies (PhD) or financial gain from merchandising the product<sup>28</sup>.

This research to me is a journey with insights on my mental health and ability. Although, I widen my holistic and esoteric literacy on a daily basis, seeing is believing. To see, and now, to hear to changing of the states of mind from one state to another, I consider as success.

... unfortunately I still spend more time interpreting the experience than experiencing it...

The more we talk to ourselves, i.e. the more we analyse, the less we engage in the experience. It is Zen philosophy that says: to be more objective one has to drop the self. However, as good things take time, it is my opinion, that we should not become overly trapped in the duality between cognitive thinking and *flow*. So, while it is acceptable to effect some analysis while experiencing a deeper state of mind, such as the flow, it is useful to have the ability to keep calm when cognitive thinking takes over the mind.

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<sup>28</sup> The means of selling the product due the SuperCollider's GNU licence will have to be investigated.

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## **Further reading:**

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## Appendix 1)

SC posts of relevance to this research:

[http://new-supercollider-mailing-lists-forums-use-these.2681727.n2.nabble.com/template/NamlServlet.jtp?macro=user\\_nodes&user=63490](http://new-supercollider-mailing-lists-forums-use-these.2681727.n2.nabble.com/template/NamlServlet.jtp?macro=user_nodes&user=63490)

## Appendix 2)

List of NFT software (updated on 1 February 2013)

source: [http://en.wikipedia.org/wiki/Comparison\\_of\\_neurofeedback\\_software](http://en.wikipedia.org/wiki/Comparison_of_neurofeedback_software)

Software	Type	Version	Operating systems	Developer	License
<a href="#">BioGraph Infniti</a>	Neurofeedback/Biofeedback	6.0	Windows XP & Vista & 7	Thought Technology Ltd, Dr. Hal Myers	Proprietary
<a href="#">BioEra</a>	Biofeedback: visual designer	2.0	Windows, Android	PROATECH LLC	Proprietary
<a href="#">BioExplorer</a>	Neurofeedback	1.5	Windows	Cyberrevolution, Larry Janow	Proprietary
<a href="#">BioTrace+</a>	Neurofeedback & Biofeedback	V2009	Windows XP & Vista & 7	Mind Media Netherlands	Proprietary
<a href="#">Brainathlon</a>	Game	?	Java	Amy Palke	Open source
<a href="#">BrainBay</a>	Neurofeedback: MIDI, particle display	?	Windows	Chris Veigl and Jeremy Wilkerson	GPL
<a href="#">BrainMaster</a>	Neurofeedback	v2010	Windows XP & Vista & Windows 7	BrainMaster Technologies, Inc.	Proprietary
<a href="#">BWView</a>	Brainwave viewer	1.0.5	Linux, Windows	Jim Peters	GPL
<a href="#">Cygnet</a>	Neurofeedback	1.1	Windows XP & Vista & 7	EEG Info, Inc	Proprietary
<a href="#">Dual Drive Pro</a>	Biofeedback GSR & Temp	3.0	Windows XP & Vista	Somatic Vision Inc.	Proprietary
<a href="#">eBio</a>	Neurofeedback & Analysis	1.0	Windows XP & Vista & 7	Gottfried Arens, Physicist	Proprietary
<a href="#">EEGer</a>	Neurofeedback & Analysis	4.2.2	Windows	EEG Software LLC	Proprietary
<a href="#">ElectricGuru</a>	Neurofeedback	0.4	Windows	Rob Sacks	Open source
<a href="#">MindReflector</a>	Neurofeedback	1.1	Windows XP, Vista, & Windows 7	MindReflector Technologies, LLC	Proprietary
<a href="#">NeuroOptimal</a>	Neurofeedback	2.0	Windows Vista & Windows 7	Valdeane W. Brown, Ph.D.	Proprietary
<a href="#">Mind WorkStation</a>	Neurofeedback, Biofeedback, and EEG-Driven Entertainment	1.3	Windows	Transparent Corporation	Proprietary
<a href="#">NeuroServer</a>	Raw EEG to TCP/IP + EDF converter	0.7.4	Linux, Windows	[Ruof Cilibrasi]	GPL
<a href="#">SmartMind</a>	Neurofeedback	v2010	Windows XP & Vista & Windows 7	BrainTrain, Inc.	Proprietary
<a href="#">OpenVIBE</a>	BCI, Visual Designer, Analysis, Neurofeedback	0.10.1	Linux, Windows	INRIA	GPL



## Endnote

i 'I will start by suggesting that attention is the focusing of sensory, motor, and/or mental resources on aspects of the environment to acquire knowledge. Attention allocation is deciding what to focus those resources on, whether the decision making is conscious or subconscious, based on current task needs and the benefits and costs relative to what is know. (Sheridan, 2006, p.16)

ii Efficiency is defined as USEFUL OUTPUT ENERGY divided by TOTAL INPUT ENERGY. It has a maximum value of 1(100% efficient).

Imagine a child on a swing in the playground. Eventually the swing will stop unless a "push" is given by another person (external energy input). If the push is given at the same frequency and phase as the natural swing frequency, then the maximum energy is transferred, I.e. the external input energy is used most efficiently. If the push is given at a different frequency from the natural swing frequency then some of the input energy from the push is wasted as it attempts to change the natural swing frequency as energy is wasted the system is less efficient.

iii By switching genes on and off and by releasing enzymes and protein into the cell nucleus, stress makes parts of the DNA indecipherable. Scientists at the Southwestern Medical Center, Texas, found that stressed mice switched off genes that are responsible for the production of BDNF (brain-derived neurotrophic factor) in the brain. BDNF is essential for the neurons to survive. In average, one third less of the BDNF was produced and that had serious effects on certain parts of the cortex: damaged memory, smell, less motivation for activity. Less BDNF worsens serotonin sensitivity which means that mice – as well as humans – become depressed and their social relationships decline (Mieras, 2010, p.184).

iv Flow experience: A state of mind of joy, creativity and the process of total involvement with life (Csikszentmihalyi, 1992).

'Music, which is organised auditory information, helps organise the mind that attends to it, and therefore reduces psychic entropy, or the disorder we experience when random information interferes with goals. Listening to music wards off boredom and anxiety and when seriously attended to, it can induce flow experiences (Csikszentmihalyi, 1992).'

'Because attention determines what will or will not appear in consciousness, and because it is also required to make any other mental events – such as remembering, thinking, feeling, and making decisions – happen, it is useful to think of it as psychic energy. Attention is like energy in that without it no work can be done, and in doing work it is dissipated. We create ourselves by how we invest this energy. Memories, thoughts, and feelings are all shaped by how we use it. And it is an energy under our control, to do with as we please; hence, attention is our most important tool in the task of improving the quality of experience (Csikszentmihalyi, 1992, p.33 - Anatomy of consciousness).'