BEYOND PERCEPTION

Reinvention of the Mindmachine

Christopher Pietsch & Luis Grass

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Bachelor's thesis for the degree of *Bachelor of Arts*.

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PRACTICE

ABSTRACT

In the last thirty years, there has been an explosion in brain research, so that today, with the latest neuroscientific discoveries, it is possible to approach existential topics that have been the exclusive domain of human science for centuries. One is now able to image the ze- rebral anatomy and localize it using a variety of imaging techniques. These technologies make it possible to directly observe which brain areas are involved in a variety of perceptual, executive, and cognitive tasks. With scientific progress comes the opening of technology in the non-scientific realm, as well as the development of Brain Computer Interfaces (BCI) methods and applications. Inexpensive and widely accessible EEG devices lower the inhibition threshold and simplify the creative use of brainwave readout.

Based on this development, the following work shows how proven stimulation techniques can be used to open a communication channel for self-exploration. For this purpose, with the help of a portable EEG headset, the own brain activity is used as a source for changing an audiovisual stimulation. Thus, the passive consumption of mind maps can be transformed into an interactive experience.

ABOUT THIS WORK

Since we started to study the visualization and ma- nipulation of brainwaves through audiovisual stimulation in 2011 in the course "Messing with our Minds" at the FH Potsdam under the direction of Willy Sengewald, we have developed our project
"Brainstatesharing" continuously developed, built on festivals and gained important experience in the process.
The title "Beyond Perception" is the logical consequence of our project development and now refers to the individual process of perception of the emerging inner images, which are made with closed eyes during the application of our mindmachines. The generated perception is not only the subjective result of the process of perception, but it is based on neurophysiological processes. We want to investigate and understand the unconscious and emotional processes involved. The scientific discussion will help us to define factors for the refinement of the audiovisual stimulation and to test them in experiments. to evaluate. We want to trans- form the passive consumption of mindmachines into an interactive experience. In combination with a portable EEG headset, the own brain activity can serve as a source for changing the stimulation.

In addition, it is essential for our new development of the Mindmachine to find out how brainwaves can be translated into audiovisual stimulation. To get to the bottom of these questions we will first give an insight into the current race to decode the brain and give a feeling for the rapid progress of technology in neuroscience, neuroengineering and BCI. We will shed light on the trends in neurotech and highlight its cultural shift to open up technologies.

In order to understand how we can measure brain activity and which frequency bands are particularly suitable for our concern, EEG basics will be explained. Subsequently, we will give an overview of the different techniques of brain stimulation with a focus on audio-visual stimulation, explaining the basics and functioning of the mind machine. Furthermore, with regard to the reinvention of the mind machine, its history of development will be pointed out and visual as well as auditory stimulation will be considered historically.
In the following, the practical part of the paper describes our common process from the first prototype, the installation at the Lange Nacht der Wis- senschatten, as well as the field studies and experiences at festivals in the following three years. Finally, an outlook on our imaginable practical work is given, describing approaches and ideas how we can redevelop the functionality of the Mindmachine by implementing new hardware and how we can gain new knowledge by conducting different experiments.

For us as interface designers, this topic is particularly exciting because brain-computer interfaces (BCIs) touch on a variety of interdisciplinary areas. In our design, a new BCI is to be made tangible through experience. With the help of this work we want to design a communication channel to our own brain in a creative way, which opens the access to self-exploration.

T H E V E R -M E S S I O N O F T H E G E H I R N S

How do billions of neurons organize themselves into a functioning whole? Neuroscientists are trying to use high-tech tools such as nanotechnology, optics, and genetics to measure brain processes in order to create high-resolution maps of the brain on the one hand and to listen to individual cells or manipulate them in such a way that they reveal their function on the other. The following chapter provides an insight into the research and the progress relevant to our work.

Fig. 1
Axons and dendrites in a cortical cleft, the modular subunit of the Neocortex of mammals.

MISSION GEHIRN

For about 30 years, scientists have been working to establish a direct link between the brain and a computer in order to open a communication channel to exchange information with the outside world in a non-muscular way, so far with only moderate success.[1]

The research field of neurotechnology received new impetus in 2013 through a multi-billion dollar funding program by the EU (Human Brain Project[2]), the USA ([BRAIN3]) and China ([Brainetome4]).

"The decoding of the brain is the great intellectual challenge of the 21st century!"[5] This is how Bill Newsome, neurobiologist at Stanford University School Medicine, describes this promising field. The goal of these large-scale projects is to map the entire network of the human brain in order to simulate all brain processes in large-scale computers. Since the exact simu- lation of a single neuron has failed so far, the high financial expenditure is criticized by some researchers and the success is questioned, . However, over the years, technological progress has provided neuroscientists with ever new high-tech [tools6] with which the brain can be measured and stimulated in an unprecedented level of detail. The statement of Konrad Kording from Northwestern University in Chicago: "In a half a minute, the human brain produces about as much data as the Hubble Space Telescope in its entire lifetime "[7] shows that the human brain has an inner complexity equal to that of the universe, and that decoding it requires incredible effort.

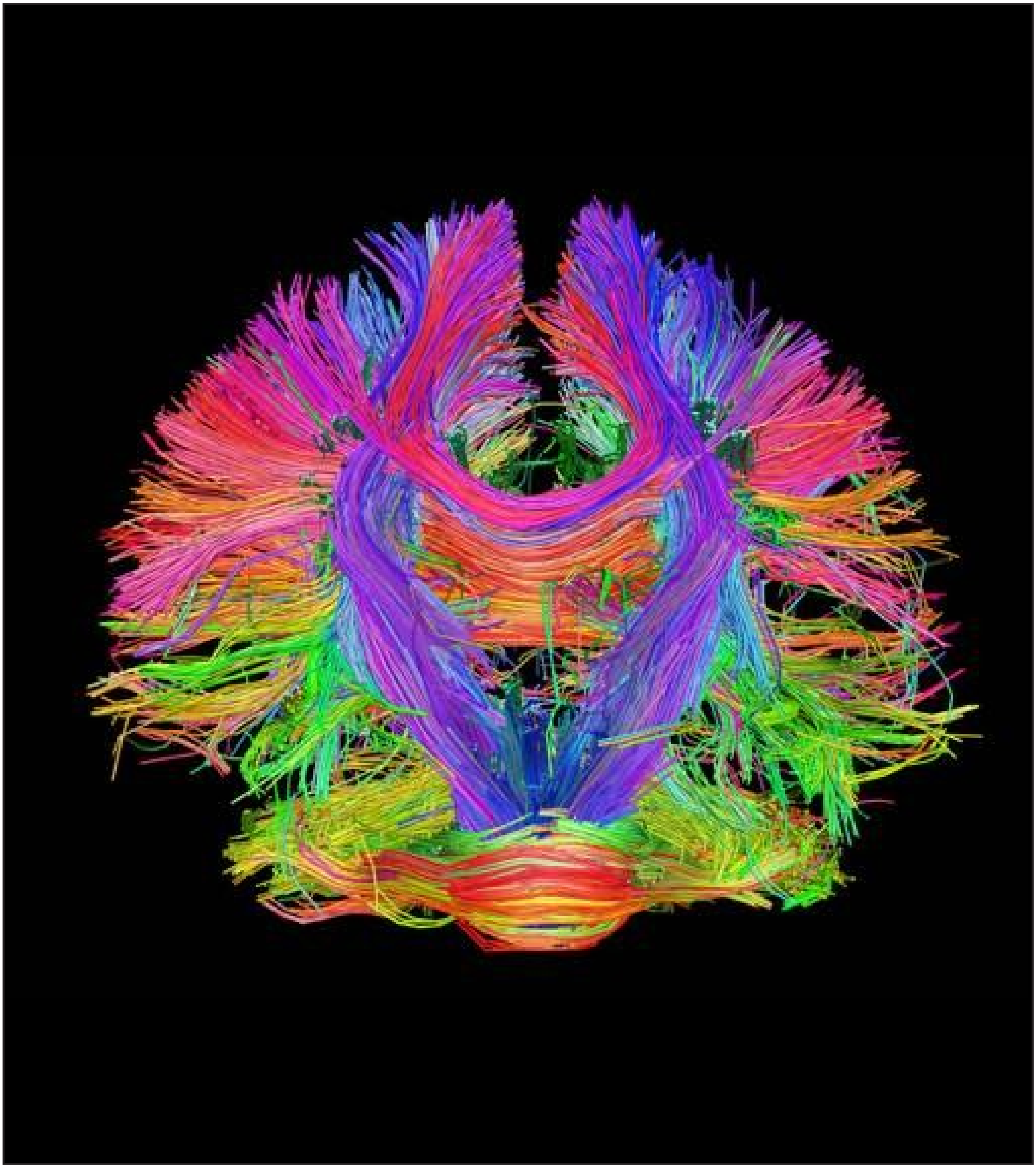


Fig. 2
A map of the connections in a human brain

NEUROTECHNOLOGY AND BRAIN COMPUTER INTERFACES

Over the years, technological progress has provided neuroscientists with new high-tech tools to measure and stimulate the brain in unprecedented detail. Only a few developments leave laboratories and research to become available to the masses in the form of applications. Probably the best known is the Brain Com- puter Interface (BCI) , which describes the connection between brain and computer and thus represents an application of neurotechnology. Here, the control of a computer with the crate of thoughts is used, for example, as an assistance system in cars, in di- verse gaming applications or to control a prosthesis with brain waves.

Neuroengineering uses methods and approaches from neuroscience, neurology, neurosurgery, electrical engineering, signal processing, automation, computer science, and nanotechnology to study the function of the nervous system.[8] BCIs measure and interpret the electrical or hemodynamic activity of the brain, i.e., the movement of blood. Electrical activity is measurable by noninvasive electroencephalography (EEG), discussed in more detail beginning on page 33, or by implanted electrodes. Hemodynamic activity is measurable by imaging techniques such as functional magnetic resonance imaging (fMRI) or Na- hinfrared spectroscopy.[9] Most BCIs use EEGs as input because it is portable and inexpensive to operate. The oepening of scientific results, methods, and applications to the non-scientific world brought enormous attention to the human-machine interface. The mobile EEG Emotiv Epoc from 2008 heralded a new era of BCIs in the consumer market. It was the first EEG accessible to the masses. While it falls far short of the accuracy of clinical devices,[10] its relatively low price and ease of use make it usable by a wide range of users. There are now 14 different BCIs available for purchase on the consumer market - all with EEG technology.

Fig. 3
Prosthesis controlled by brain waves.

Fig. 4
In the project "Brain Driver" of the research group Autonomos,
a car can be steered by the scratch of the thoughts.

INVASION OF THE ELECTRODES

To study the neuronal activity of cognitive and emo- tional processes, brain recordings have been made in a noninvasive manner for some time. However, these tools have reached their limits and the insufficient accuracy and resolution of interceptable neurons has prompted researchers to use novel invasive methods. So-called "direct brain recording," in which elect- rodes are placed directly into the brain and their activity recorded relatively interference-free and in real time, currently represents the fastest-growing area of neuroscience shadows. The limiting factors of EEG are bypassed in direct brain recording because the electrodes have direct contact with neurons. However, its use in humans is only temporarily approved in the treatment of epilepsy. Scientists use the time during which the electrodes are placed in the patient's brain to locate the area from which the epilepsy originates to decipher how the brain works.

In America, this area is being actively promoted by the Obama government under the BRAIN Initiative. Recently, a 90 million investment by the Defense Advanced Research Projects Agency (DARPA) went to 2 universities to advance the development of brain implants for memory manipulation. The aim is to develop new treatment methods, e.g. for trauma management.
In a study using this technique from the University of California, San Francisco, it was possible to
e.g., 12 areas are located in the brain that are used to make sense of words and sentences.[11]
In another experiment at the University of California, Los Angeles, the electrodes were not only passively as input, but also actively as output. An area in the vicinity of the hippocampus was stimulated by electrical potentials in order to achieve an increased memory performance.[12]
However, this type of electrode measurement still involves considerable difficulties, since even the hair-thin cables can damage the tissue and are rejected by the body after a while. However, the manufacture of such electrodes is making great progress and the number of neuro- neurons that can be monitored has doubled every seven years since the 1950s. Hundreds of neurons can now be targeted simultaneously, and the first wireless, miniaturized probes are already available with the help of nanotechnology. A prototype of this technology is the one-centimeter-long and extremely thin "neuroprobe" from the research organization Imec.[13]

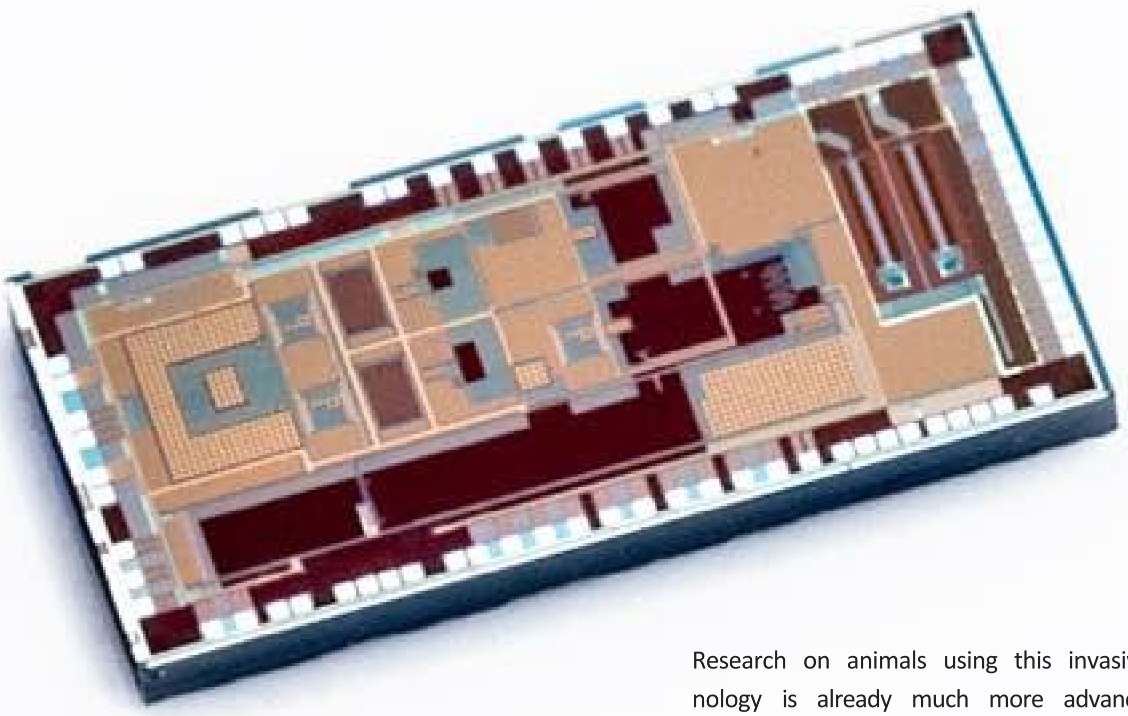


Fig. 5
Neuroprobe, an implantable low-power single-channel electrocardiography (ECG) chip.

Research on animals using this invasive technology is already much more advanced. For example, the work of Miguel Nicolelis at Duke University in Durham on an atfen shows that, after a series of experiments, it was able to precisely control a robotic arm by scratching its thoughts alone.[14]

Even though this technique provides very accurate data from the brain, we are still far from "speaking the secret language of the brain," as Dr. Anthony Ritaccio of Albany Medical Center in New York puts it.[15]

Fig. 6
Mouse with implanted light guide for stimulation of genetically modified

LIGHT SWITCH FOR NEURONS

To gain a deeper understanding of what the brain really does, it was hypothesized that light might die- n as a control tool in stimulating the brain's circuitry.

This method is called optogenetics. The field is a mix of optical technologies and genetics and is currently only used in animals. It allows researchers to control the activity of neurons with extreme precision.[16] In this process, neurons are specifically switched on or off by light.[17] Certain light-sensitive proteins were previously incorporated into the neurons through gene therapy, which cause the cell to build up an action potential when stimulated with blue light. To suppress the activity of a neuron, the ion pump protein ha- lorhodopsin is introduced into the neuron, which is activated by green light.[18] However, the genetically modified brain cells are capable of even more: it is also possible to mo- dify the neurons so that they emit light when active. This makes it possible to visualize processes in the brain.[19]

Optogenetics was named "Method of the Year 2010" by the journal Nature and "Breakthroughs of the Decade "[20 by] the journal Science. The field has many potential applications, for example to alleviate tremor in Parkinson's disease or to gain previously unthinkable detailed insights into the workings of the nervous system and the brain. Gene therapy to restore visual performance in the blind is also conceivable and has already been successfully tested in rats.[21] While pharmaceuticals tend to flood the entire brain and direct stimulation by electrodes is not possible, the field has many potential applications.

While optogenetics has so far also detected neighboring neurons, optogenetics in an ultra-precise procedure only allows to reach those neurons or specific brain parts that would have to be treated, be it due to a disease or for cognitive stimulation.

On the one hand, these methods of neuro-engineering promise new insights into the functioning of the brain, on the other hand, the genetic manipulation of brain cells is unimaginable outside the scientific community and raises a number of ethical questions. Experiments are still limited to nerve cells from fruit flies, mice and fish, but some doctors believe that the first experiments on human neurons will be possible in three to ten years. Such extreme developments are a good example of the willingness to rapidly evolve technology in the neuroscience shadow, but also a sign of the uneven nature of research. Even if we use similar principles as stimulation by light, pioneering is a matter of definition and the gap between DIY neuroscience experiments and current research is large. One thing is certain, the ways and means needed to decode the brain are being explored and tested in all directions.

NEURO-TECHNIK IM WANDEL

For a long time, most of the hardware and software in neuroscience was proprietary and only affordable for well-off research institutes. However, the number of open source hardware and software projects in the field of neuroscience has been growing faster than ever in recent years. The opening up of scientific results, methods, applications, and the decreasing cost of technology is making it more accessible to other disciplines and accelerating research on the brain. We review here the developments and examples relevant to us.

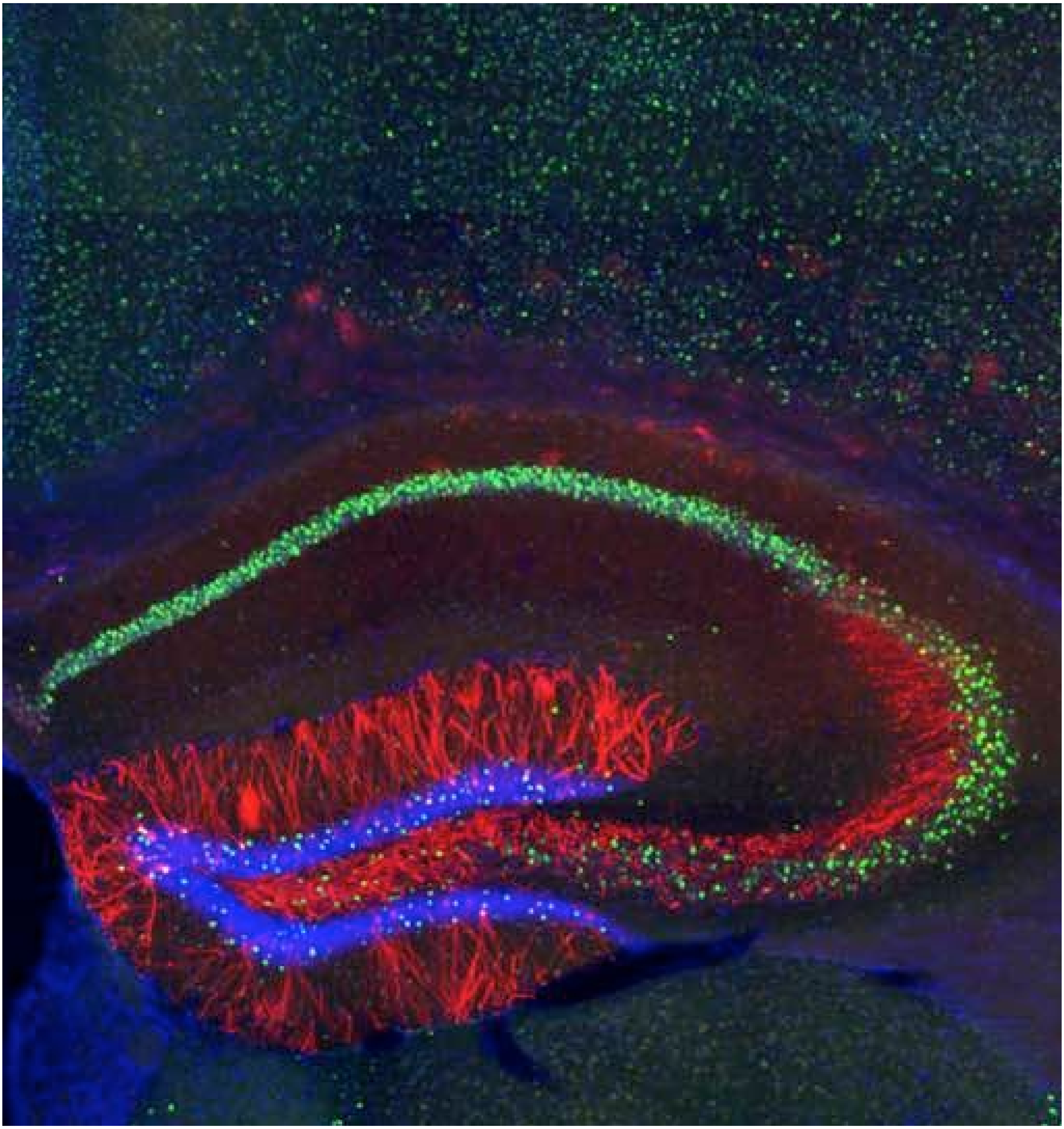


Fig. 7
MIT neuroscientists identified the cells in the hippocampus (highlighted in red) in which memory traces in a mouse are stored.

STATUS AND NEUROHYPE

Brain Computer Interfaces are making ever greater inroads into the consumer goods market. Products such as the Emo- tiv Epoc, the Interaxon Muse or the Open BCI[22] allow a broad public access to this technology, which was previously reserved for specialists. The current applications of the products are limited to simple neu- rofeedback programs or visualizations of the measured data. On the one hand, this is due to the fact that the accuracy of the EEG technology used is not comparable to that of medical devices, and on the other hand, that the current state of research is still very experimental and more precise methods such as direct brain recording already exist.

The renowned Gartner Institute, which publishes an annual assessment of the phases of public awareness of new technologies, assigns BCIs to an "embryonic level". This is justified by the still small number of brain patterns that can be reliably distinguished.[23] The expectations and results are also discussed controversially within the scientific community, which has meanwhile given rise to the term "neuroscepticm".[24]

Other fields, such as art or maker-mo- vement, explore the previously unknown and ex- clusive field of BCI in a playful and creative way, thus gaining attention and acceptance for the techno- logy.

Toys equipped with EEG sensors offer programming interfaces and motivate change or further development. The relaxed approach in exploration creates a fruitful feedback between scientific research and practical application. In this phase between experiment, use and design, interface/interaction design serves as an interface to give new impulses and to create something new.

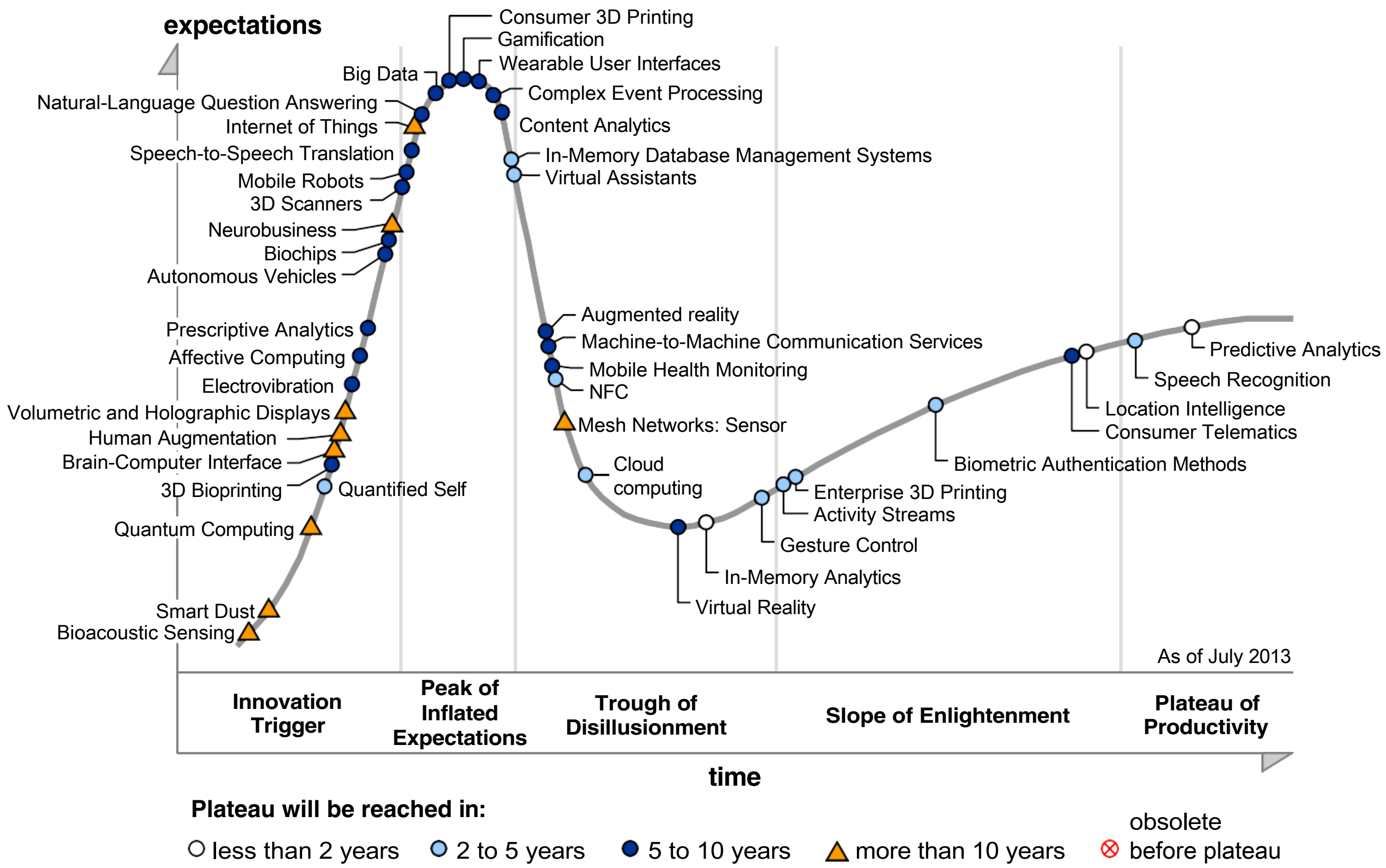


Fig. 8
The "Hype Cycle for Emerging Technologies" from the Gartner Institute , gives BCI more than 10 years until it is used pro- ductively.

Fig. 9
The Star Wars Science Force Trainer lets a ball, through the scratch of thought up or down. move.

CROWDSOURCING THROUGH DARPA

DARPA (Defense Advanced Research Projects Agency) has been closely involved with BCIs since their invention. It is the agency of the United States Department of Defense that conducts and funds research projects for the armed forces. DARPA's mission is to prevent technolo- gical surprise for the United States and to create technological surprise for its adversaries[25]. The term brain-computer interface first appeared in the scientific literature in 1973[26] after DARPA funded research in this area at the University of California Los Angeles (UCLA).

Since then, the agency has been investing in research into the human-machine interface. One of its goals is to reduce the cost of portable EEGs and improve their ergonomics in order to revolutionize access for civilian and military purposes: "If neural monitoring were cheap and open, we'd start to see more science experiments, art projects, mind-controlled video games, and even serious research using brain waves "[27].

Fig. 10
The CT2WS is a threat detection system for soldiers.

Fig. 11
A soldier wearing an EEG headset sits in front of a computer screen and marks potential hazards.

Furthermore, your funding request for research and innovation states that publicly available EEG technology, devices, and apps will enable the field of cognitive neuroscience to take advantage of crowdsourcing to solve complex problems.[28] Challenges that cannot be answered by a group of neuroscientists can be solved collectively in the community.[29] The crowd-sourced OpenBCI (an open-source EEG project) was initially funded by DARPA. Thus, it is not surprising that the crowd-sourced OpenBCI (an open source EEG project) was initially funded by DARPA.[30]

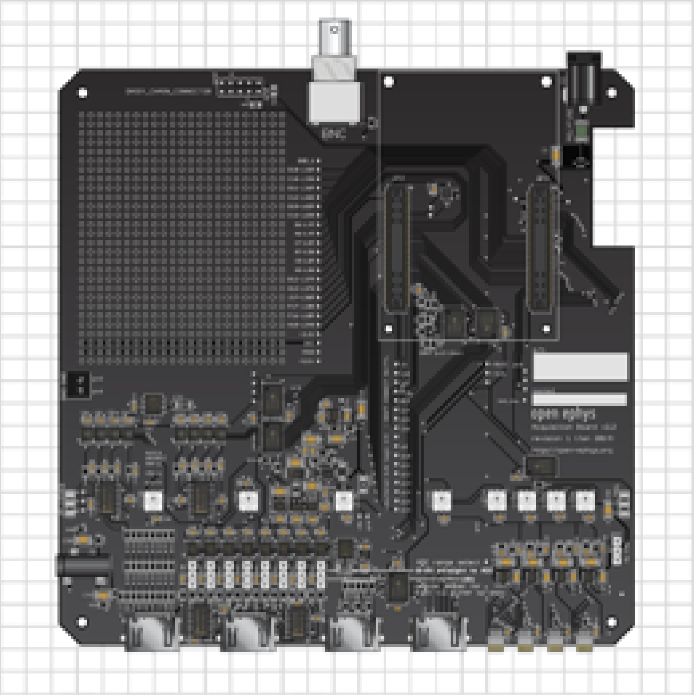
Reasons for researching BCIs from DARPA's perspective are many. They could be used to improve soldier training, treat post-traumatic stress disorder, study the effects of torture, or improve surveillance technology. Research on BCIs is already being successfully applied in the field of surveillance technology. The Cog- nitive Technology Threat Warning System (CT2WS) is a system that uses the brain of a human (operator) as a filter to detect threats to soldiers. 10 images per sec- ond from a surveillance camera (e.g., from a drone) are shown to the operator. The operator's brain is monitored via an EEG according to the P300 wave. The P300 wave is a waveform that occurs approximately 300 ms after a triggering stimulus. Even at these short viewing times, the human brain can perceive motion and shapes and thus subconsciously detect danger. If a P300 wave is detected, the corresponding image is mar- kined and analyzed in more depth for potential hazards. An advantage of this method is that context- and operator-specific threats are detected. With this system, it is possible to reduce the false alarm rate in military surveillance to a minimum.[31]

OPEN EPHYS

In the field of neuroscience, too, something is happening in terms of open source hardware. The project "Open Ephys "[32] (Open Source Electrophysiology) by the two founders Joshua Siegle and Jakob Voigts from the Wilson Lab at the Massachusetts Institute of Technology (MIT) is not aimed at technicians and game developers like the Open BCI, but specifically at neuroscience research in the university context and deals with electrochemical signal transmission in the nervous system. With the Open Ephys, the two techniques of Direct Brain Recording and of optogenetics in an open source platform: special electrodes (tetrodes) listen to neurons whose activity can be simultaneously manipulated by optogenic stimulation. The impetus for this project stemmed from the two PhD students' futile search for an affordable and modular system that would provide accurate data for their purpose of studying the mouse brain. "Neuroscience is currently domi- nated by closed-source commercial hardware, which is otten expensive and ditficult to modify. "[33] Josh Siegle explains. For this reason, the two decided to construct their own system: "Neuroscience tends to have a pretty hacker-oriented cul- ture. A lot of people have a very specific idea of how an experiment needs to be done, so they build their own tools."

Thanks to a donation from Texas Instruments, over 150 Open Ephys platforms have already been sent to research institutes around the world. The founders' hotf- nition is to encourage neuroscientists to open up their work to the open source commu- nity, so that in the end there is more time together for actual research.[34]

Fig. 12
an image of the assembled Open Ephys Boards



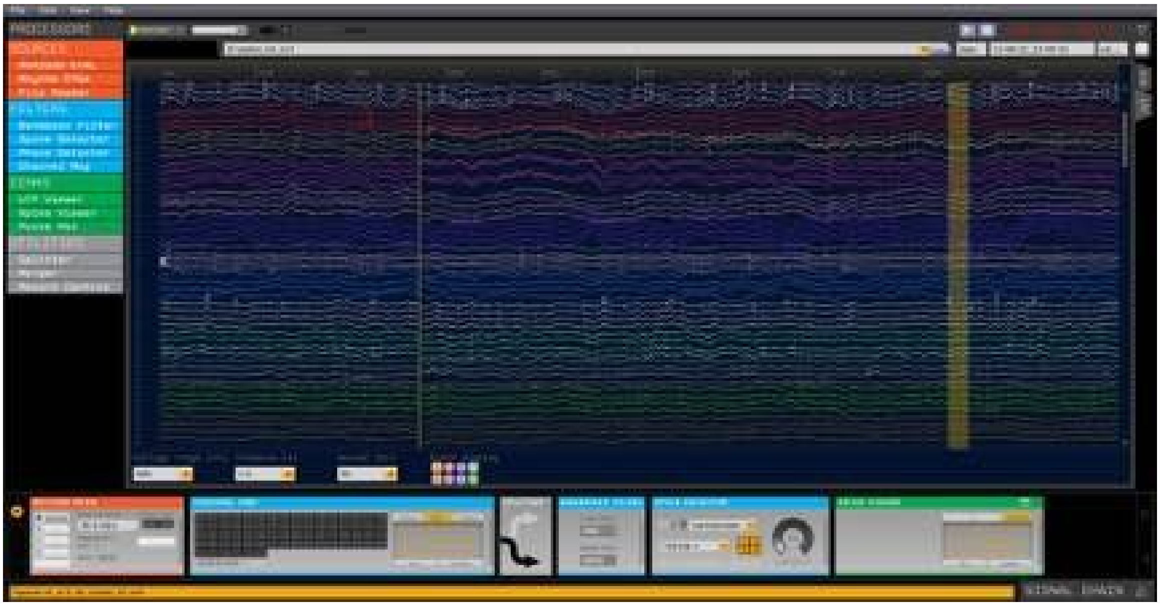


Fig. 13
Screenshot of the Open Ephys GUI, that can record, analyze and visualize neural data in real time

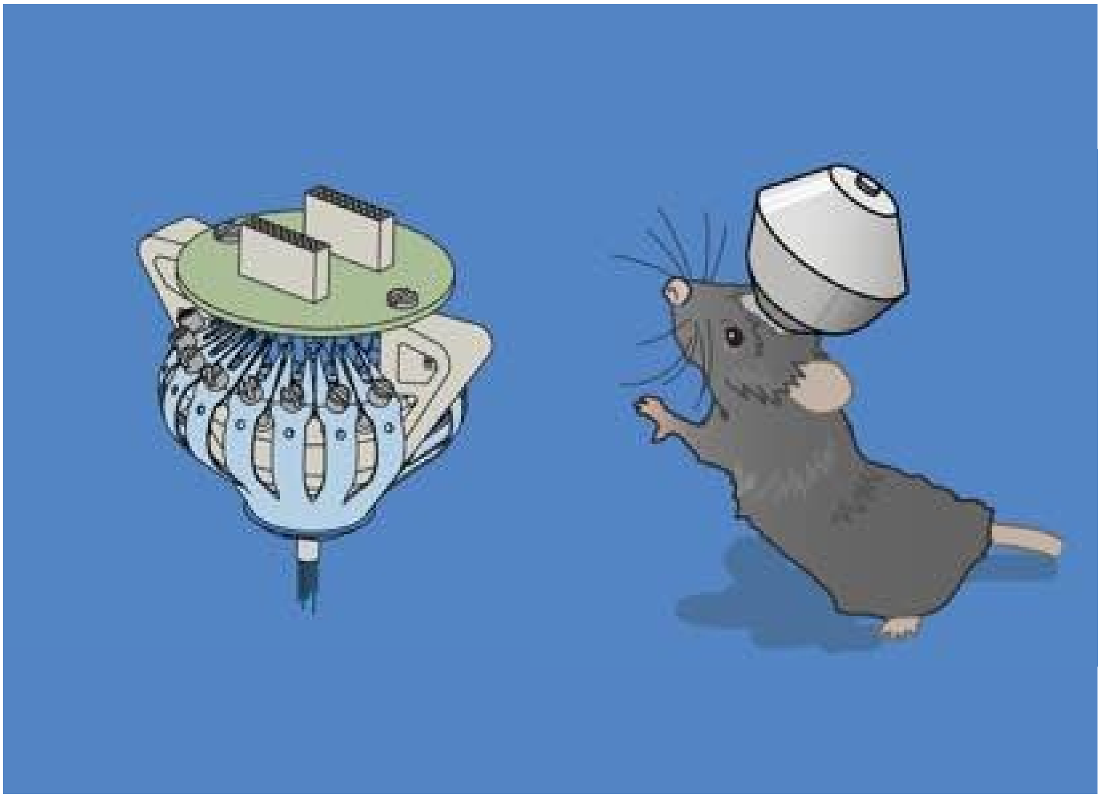


Fig. 14
The Flexdrive is an implant for extracellular electrophysiology of mice, which allows the individual positioning of up to 16 microwire electrodes or electrode bundles.

PROODUCTS UNO WERK\EURE

In recent years, various manufacturers have used simplified EEG technologies to produce inexpensive BCIs. The technology is mainly used in toys and gaming equipment.
The company NeuroSky plays a central role in this. It was founded in Silicon Valley in 2009 and, according to its own statements, has developed EEG technology from scratch in order to create consumer-friendly applications: "The core technology behind NeuroSky devices has been built from the ground up. This has allowed NeuroSky to inexpensively produce a chip that filters out the ambient waves present in most uncontrolled conditions and etfectively measures neural activi- ty in virtually any condition with 96% the accuracy of similarly configured research grade EEGs. "[35] Another unique feature of NeuroSky technology is that the electrodes do not require contact fluid as in conventional EEG electrodes. This allows a much wider range of applications, as the use of dry electrodes reduces the time-consuming preparation phase of EEGs to a minimum.

The quality of the EEG signals of NeuroSky technology should be comparable to those of a clinical EEG: "Raw EEG signals with dry electrodes of NeuroSky system were compared to those with wet electrodes with Biopac system. FFTs were performed to compare signal characteristics of the EEGs, especially power spectrums. Results show that EEG signals of NeuroSky system are compatible to those of Biopac system. "[36]

Fig.15
NeuroSky ThinkGear ASIC
Module(AM), front view

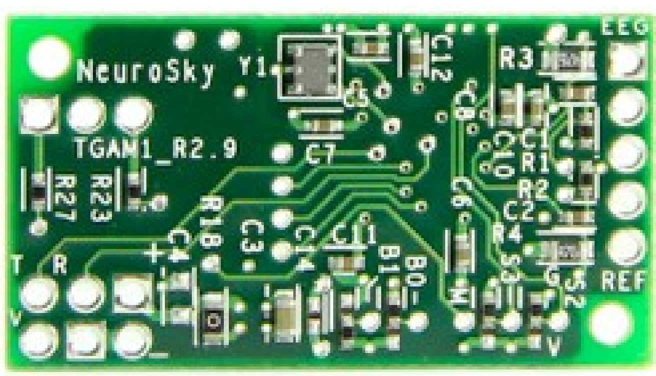


Fig.16
NeuroSky ThinkGear ASIC
Module(AM), rear view

NeuroSky is primarily a manufacturer of low-cost consumer EEG technology (ThinkGear AM[37]), which is used in other companies' products. Examples are the Mindflex toys from Mat- tel and the Star Wars Force Trainer from Uncle Milton or the EEG headsets such as the in-house MindWave or the Muse from InteraXon. The MindWave and the Muse are aimed at developers, among others, and are delivered with the corresponding documentation and programming interface (API). They serve the Quantified Self movement:
"The Quantified Self is a network of users and providers of methods as well as hardware and software solutions, with the help of which they record, analyze and evaluate, for example, environmental and personal data. A central goal is to gain knowledge about personal, health-related and sporting issues, as well as habit-specific questions. "[38]

The otficial interface to the Muse EEG data provides a channel for creative exploration in addition to the otficial app for relaxation training and evaluation. For this reason, the Muse EEG headband, with an EEG sampling rate of up to 500Hz, 7 dry electrodes, a fast and intuitive setup phase, good portability, and a very good developer interface, represents the optimal tool for our project.

Emotiv

EPOC headset

Fig. 17
Emotiv EPOC Headset

The device published by Emotiv is the EPOC headset. The EPOC headset is a multi-channel radio BCI system. This headset is equipped with 14 wet contact resistance electrodes for measuring EEG, electrooculogram (EOG) and facial electromyogram (EMG). In addition, the EPOC headset also has a 2-axis gy- roskop for measuring head rotation. The use of 2.4 GHz wireless connectivity provides wide accessibility to devices such as PCs, laptops and smartphones. The EPOC headset is gel- erated together with a sottware that includes a set of integrated signal processing algorithms for interpreting EEG signals. The integrated algorithms detect the user's conscious intentions, emotional states and facial expressions based on the measured EEG, electromyogram (EMG) and electro-oculogram (EOG) signals. Through this sottware, the user can interact with various applications such as games, virtual reality, or brainwave monitors. These applications can be downloaded from the Emotiv website.

NeuroSky

Mindwave and MindBand

Fig. 18
NeuroSky Mindwave and Mindband

The Neurosky Mindwave and MindBand come with their own WLAN BCI system. Both headsets use the ThinkGear "Applicati- on-Specific Integrated Circuit" (ASIC) module. This module was developed by NeuroSky and equipped with ei- gently developed signal acquisition components. These devices are usually in the form of a headset or headband. Various applications such as media players, cognitive state visualization and arcade games for PC and mobile devices can be controlled with it.

NeuroSky
MindSet

Fig. 19
NeuroSky MindSet

NeuroSky MindSet is a wireless headset equipped with an EEG sensor. The headset with headphones and microphone has a single dry contact electrode for measuring EEG si- gnals on the forehead. Along with the raw EEG recording capability, the MindSet has a patented algorithm called eSense. This algorithm interprets mental states such as attention and meditation. These translations are determined by analyzing power levels in specific frequency bands, such as alpha, beta and theta rhythms. These determined values are used for control commands in applications.

Interaxon
Muse

Fig. 20
Interaxon Muse, Brain Sensing Headband

Muse is a slim headband equipped with seven dry electrodes. The ergonomic fit and the elastic electrodes on the ears provide a very good hold. Muse is compatible with iOS (iPhone, iPad, iTouch) and Android. For developers, there is an above-average SDK that is com- patible with Mac or PC operating systems. A high battery life of 5 hours allows continuous use. The Muse Calm app is the only application so far, but due to its ease of use, more applications are expected in the near future.

I N T E R P R E
- T A T I O N0
E S B E C A U S
E S - S E I N S

In order to understand the language of the brain and the connection between different states of mind and brain waves, an introduction to electroencephalogy is necessary. In the following the most important basics and methods for "Beyond Perception" are described.

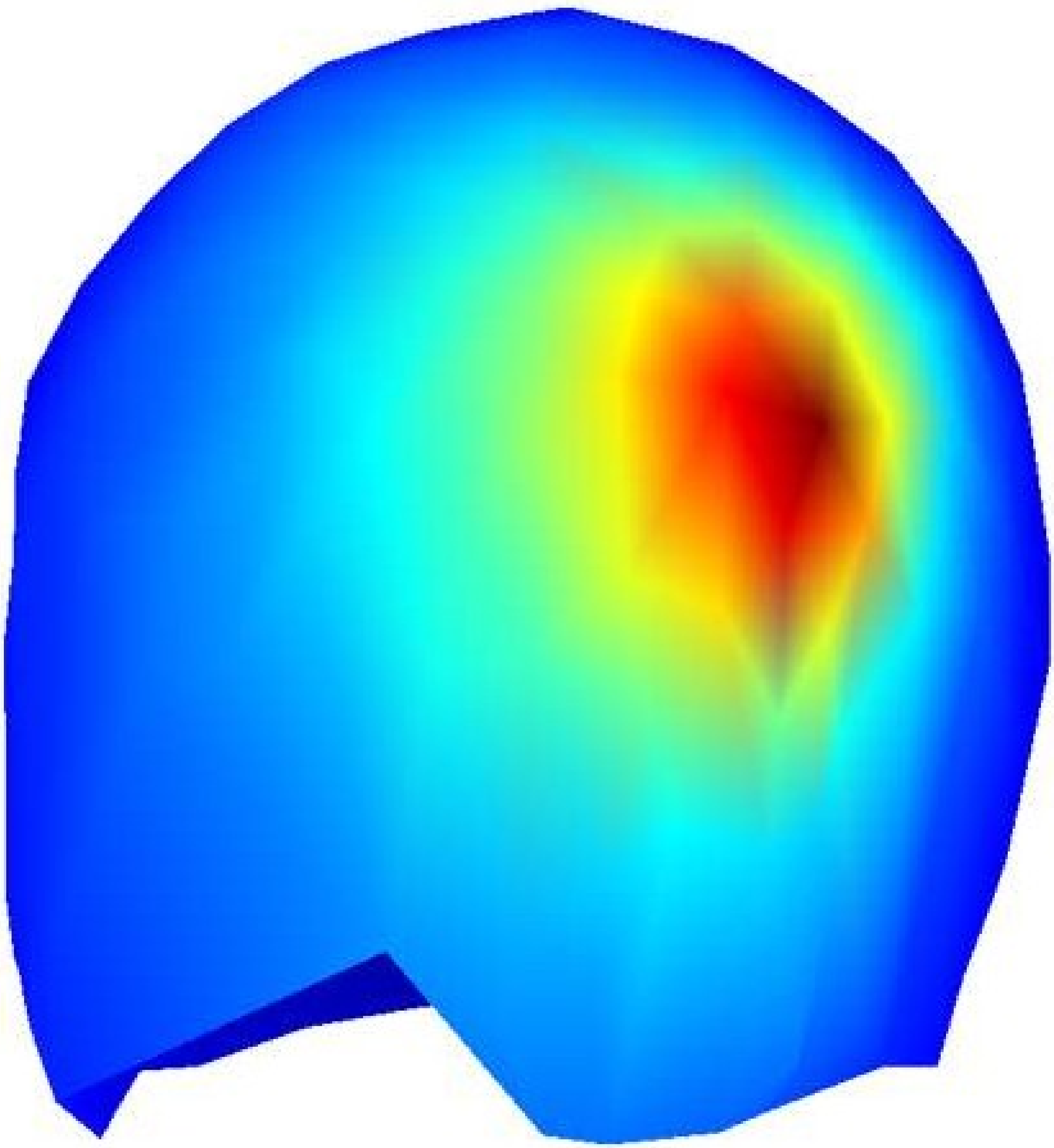


Fig. 21
Topographical representation of the potentials at the scalp, measured by a EEG.

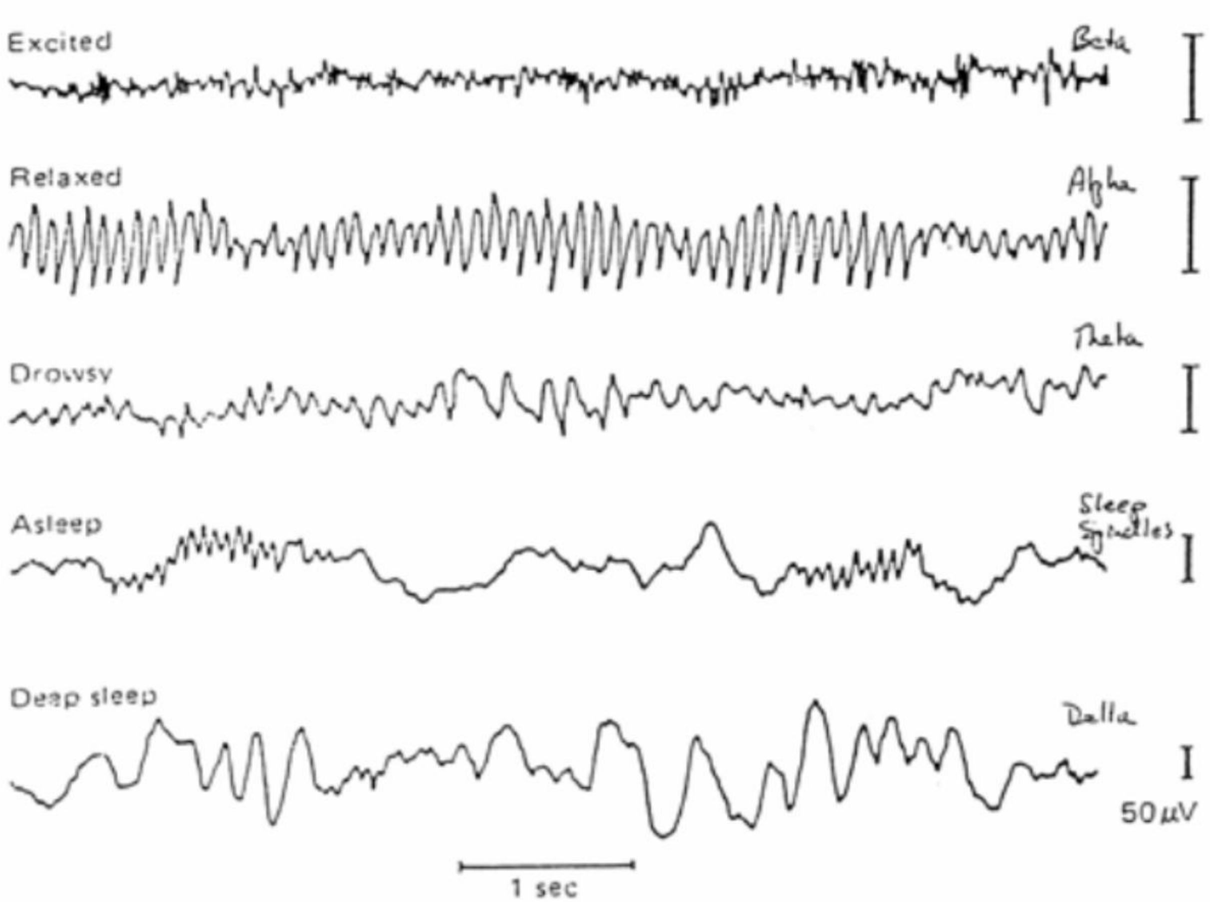


Fig. 22
Characterization of the EEG frequency bands.

EER - WINDOW INTO THE BRAIN

Electroencephalography (EEG) is a method of measuring and visualizing electrical potentials of the cerebral cortex derived from the scalp. It is sometimes simplistically referred to as a "window into the brain" because it is a simple way to "watch the brain work. "[39] Twenty to 256 electrodes are placed on the surface of the head to measure the summed electrical activity of the underlying tissue. These signals are made interpretable to humans through a system of amplifiers, filters and visualizations.[40]

The EEG, or the method of measuring brain waves in humans, was developed in 1924 by the Viennese neurologist and psychiatrist Hans Berger.[41] Berger's motivation for studying brain waves stemmed from a formative experience in which, in his opinion, he experienced "spontaneous thought transmission".[42] Later, the EEG was used as a diagnostic tool to detect functional disorders and diseases affecting the brain. The study of epilepsy in particular was first made possible by the EEG: it was possible to visualize how the wave patterns typical of epilepsy propagate in the brain and spread from area to area.[43] Most EEG signals come from the outer layers of the brain (cerebral cortex). The neurons located there generate electrical signals that change on the order of 10 to 100 milliseconds and are between 5 to 100 µV in strength. EEG is the only available technology that can measure these rapid changes.

In contrast to good temporal resolution, EEG has relatively poor spatial resolution. Imaging techniques such as computed tomography (CT), positron emission tomography (PET) and magnetic resonance imaging (MRI), on the other hand, offer good spatial resolution but poor temporal resolution. Because the electrodes of EEG are located on the surface of the head, each electrode records the electrical activity of the underlying tissue area, but not a well-defined range of neurons. Mathematical models can be used to account for this inaccuracy, but the result is only a more accurate estimate.[44] The electrical potentials of the affected tissue are generated by 10 million to 1 billion neurons. Only when 2-3 cm^2 of neurons in the cerebral cortex fire at the same rate and thus produce a sufficiently strong signal, this frequency becomes measurable with the EEG.

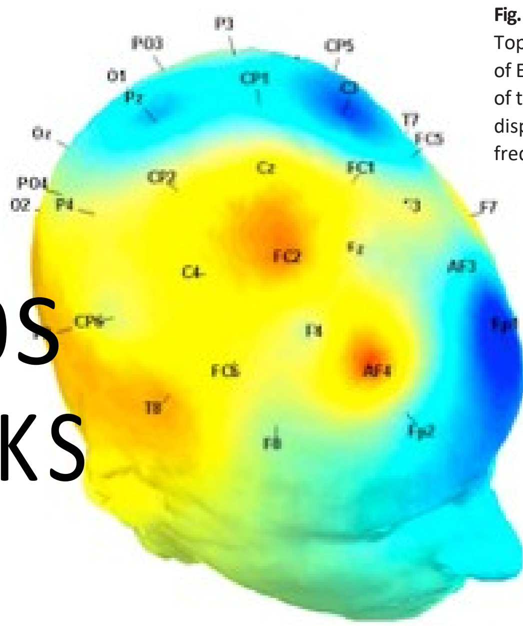


Fig. 23
Topographic or brain map of EEG activity. The power of the EEG signal is displayed in a specific frequency band.

BEOEUTUNR OS FREQUEN\BANKS

Brain waves can be classified into certain frequency and amplitude groups, which are as excitation states of the brain can be analyzed with the EEG and can be interpreted as states of consciousness derived from it in the course. For this purpose the frequency distribution curve and the differences between different electrode points are considered. However, there is no generally valid subdivision, because the division of the frequency bands and their limits are historically conditioned and do not consistently coincide with the limits, which are considered reasonable on the basis of modern investigations.[45]

During strong concentration or during the processing of sensory perception, the brain generates gamma waves. Gamma waves are EEG signals with a frequency above 30 Hz. An alert and focused person normally shows primarily beta waves. Beta waves have relatively small amplitudes (less than 10 µV) and their fre- quence ranges from 14 to 30 Hz. When arousal in the brain subsides and approaches a state of relaxation, bursts of alpha waves (8-13 Hz) may be noted. These have a higher amplitude than the beta waves (150 µV or more) and thus exhibit the strongest amplitudes in spectral analysis, also called power spectrum. When the brain approaches a sleepy state, theta waves are recorded. These are characterized by small amplitudes (5-20 µV) and an even smaller frequency of 4-7 Hz. In dreamless deep sleep phases, the brain generates delta waves, which have a very low frequency of 0.1 to 4 Hz.

These EGG bands do not necessarily have to occur separately, but can also be measured together at the same time at the electrode. Usually, a dominant frequency is mixed with other frequencies.[46]
From the brain waves measured by the EEG it is not possible to read thoughts, but only to interpret a general state.
Since certain thoughts are accompanied by characteristic patterns, computers can be taught to draw conclusions about our thoughts from these patterns. However, reading thoughts is excluded. For example, the successful use of a brain-computer interface is dependent on a training phase, in which
which the person pre-thinks to the computer which intentions lead to which brain patterns.

Frequency band		Frequency	State	Possible Effects
Delta		0,5 - <4 Hz	Deep sleep, trance	
Theta	Low (Theta 1)	4 - 6.5 Hz	Hypnagogic awareness (falling asleep), hypnosis, waking dreams	
	High (Theta 2)	6,5 - <8 Hz	Deep relaxation, meditation, hypnosis, waking dreams	Increased memory and learning ability, concentration,creativity.
Alpha		8 - 13 Hz	Light relaxation, Super Learning (subconscious learning), inward focused attention, Closed eyes	Increased memory and learning ability
Beta	Low	>13 - 15 Hz	Relaxed attention directed outward	Good receptivity and attention
	Medium	15 - 21 Hz	Wide awake, normal to increased outward attention and concentration.	Good intelligence performance
	High	21 - 38 Hz	Hectic, stress, anxiety or overactivation	Jump had thought leadership
Gamma		38 - 70 Hz	Demanding activities with high information flow	Transformation or neuronal reorganization

Fig. 38
EEG frequency bands with associated possible defects

In addition, it has so far only been possible to recognize different types of thoughts, but not their exact content. It is possible to recognize whether the user of the BCI is currently thinking about a piece of music or a movement - but not which piece of music he is listening to in his mind or what the imagined movement looks like. Nevertheless, this can be used for communication by the user and the computer agreeing on a common assignment of thoughts and intentions.[47]

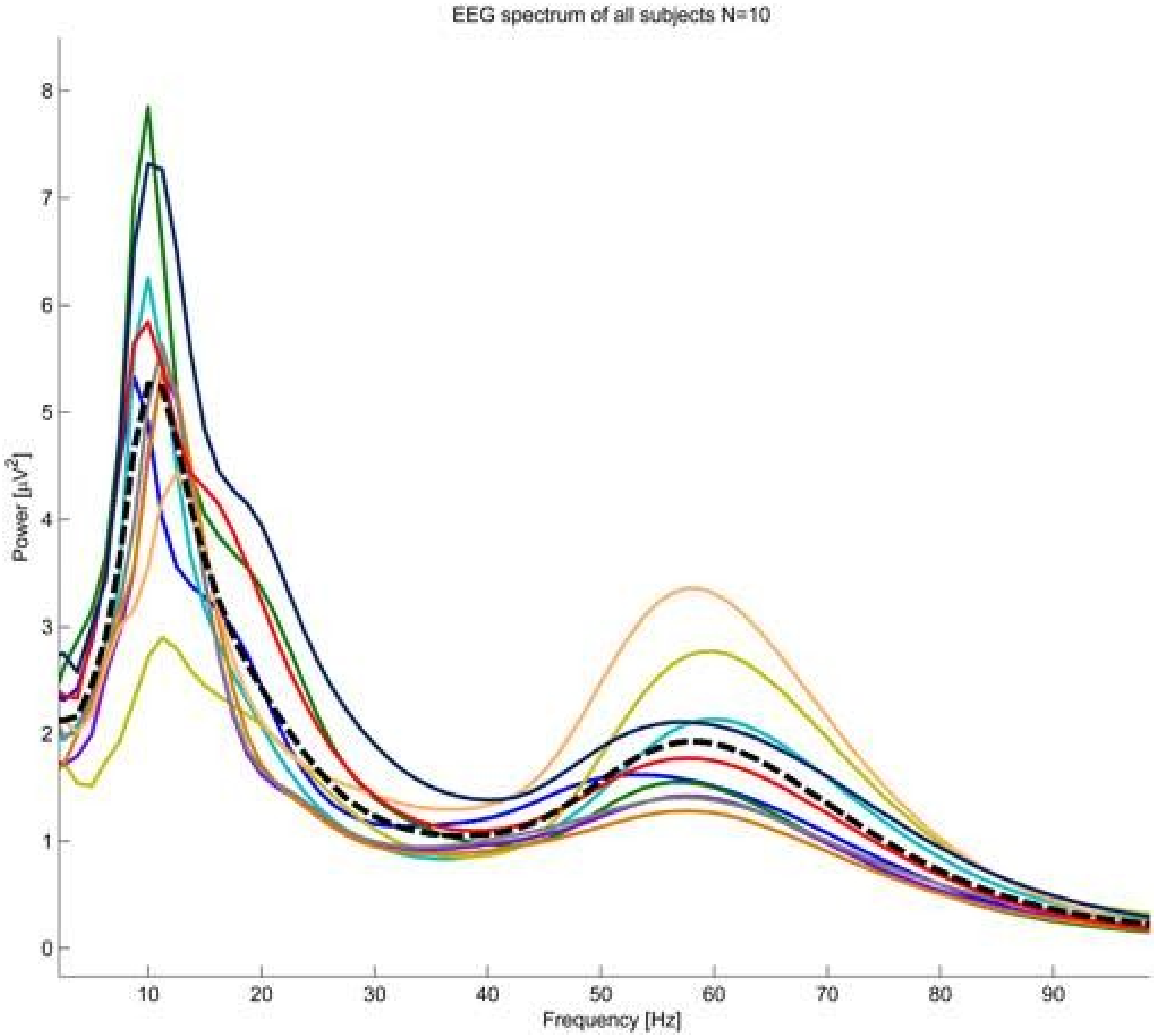


Fig. 24
Indivdual EEG power spectrum of 10 subjects: Although the strongest frequency lies within the conventional alpha band, there is considerable interindividual variability in alpha strength and frequency peaks.

Frequency band	Customized tape
Delta	IAF-8 to IAF-6 Hz
Theta	IAF-6 to IAF-4 Hz
Alpha 1	IAF-4 to IAF-2 Hz
Alpha 2	IAF-2 to IAF Hz
Alpha 3	IAF up to IAF+2 Hz

Fig. 43
Formula for calculating the frequency bands using the IAF.

OIE INOIVIOAL ALPHA-FREQUEN\

Every person has different preferences and every brain ticks to its own rhythm. Through the EEG one has the possibility to read in which frequencies the respective brain prefers to work. Because of these individual differences in the extension of frequency bands, there are models that are designed to determine personal frequencies. The easiest to calculate is the alpha frequency, the dominant frequency in the brain, which is generally associated with the absence of co- gnitive performance and relaxation.

When the eyes are closed, the regular alpha frequency at the back of the head can be easily detected in the EEG. When the eyes are opened, the frequency disappears. This phenomenon is called Berger effect or alpha blockade.[48]

Strong alpha activity is associated with high intel- ligence: "We found a strong positive correlation between intelligence and alpha power." [49]

What is special about the alpha rhythm is that its amplitude and frequency differ greatly from person to person. This is also referred to as the individual alpha frequency (IAF).[50 In] addition, the individual alpha frequency changes in the course of life. From puberty onward, the frequency steadily decreases. At the age of 20, it is around 11 Hz, until it can be around 7 Hz in a 90-year-old. From this, a general formula can be established:

Alpha Peak Frequency (APF) = 11.95 - 0.053 x [Alter51]

There are different methods to identify the individual alpha frequency in the EEG. One widely used method is to identify the strongest frequency of the EEG in the alpha band with eyes closed.[52] This method is relatively simple and thus applicable to non-clinical EEGs.

Once the IAF has been determined, it is then possible to adjust the adjacent frequency bands accordingly, especially the theta band. The IAF is used as an anchor point: "However, since interindividual differences of a similar magnitude (about 2 Hz) are to be expected even in age-homogeneous groups of subjects, an individual adjustment of the frequency bands, taking into account the individually dominant alpha frequency (IAF) of each individual subject, is appropriate.

The possibility to calculate the IAF with an EEG is of enormous importance for our project to construct an individualized mindmachine. The EEG represents a sensor (output) of the brain, which is used as input for the stimulation by the mindmachine. The mindmachine can react to the states of the brain and adapt itself accordingly. A classical feedback loop is created, where a dyna- mic system between human and machine influences excitation states of the brain. The IAF can also be used to calculate the excitatory frequencies of the other frequency bands and to increase the effect of the stimulation. The calculation of e.g. the theta band by means of the IAF behaves as [follows54]: IAF-6 to IAF-4 Hz.

THETA-
TWILIRHT STATE

The transition from alpha waves to theta waves is called twilight state because so-called fantasy journeys can be induced in this phase. The theta frequency, which can be measured with the EEG, ranges between 4 and 8 Hz. It is the dominant frequency in infants and arises in adulthood during drowsiness and light sleep: "Theta power decreases from early childhood to adulthood and increases during the late part of the lifespan. During the hypnagogic state (i.e. the transi- tion from waking to sleeping) when the ability to re- spond to external stimuli decreases, theta power in- creases "[55] . A person in the hypnagogic state may experience visual, auditory, and tactile pseudohalluci- nations. "Outwardly directed attention is lowered, but abstract thought is not completely shut down. Thoughts string together more loosely and untargeted, more ana- logically than logically linked."[56] Not surprisingly, the link between rapid eye movement (REM) sleep and increased theta [activity57] is that "upon awakening from the REM stage, subjects very frequently report dreams (characterized by bizzare, unrealistic content), whereas after awakening from other sleep states, more reality-like thoughts are reported. "[58] This "illogical" state of thinking promotes the Eigenschatt of creativity. "There is little doubt that the hypnogogic-like state of consciousness has been a productive source of creative ideas. "[59]

In an EEG study on the effect of meditation on the EEG bands, it was shown that the intensity of both theta and alpha waves increased during meditation.[60] In meditation, the mind is supposed to calm down and collect itself through mindfulness or concentration exercises. ''We found theta to be associated with a deeply internalised state and with a squealing of the body, emotions, and thoughts, thus allowing usually 'unheard of things' to come to consciousness in the form of hypnogogic imagery.''[61]

Theta waves also play a central role in how the brain records, stores, and retrieves information: "When neurons involved in memory formation send signals in time with theta waves, the stored memories are better retained. "[62] This process occurs during so-called theta synchronization. In this process, the alpha waves are replaced by stronger theta waves. For this reason, the theta 2 band, which is directly adjacent to the alpha band, is associated with "encoding of new information as well as episodic memory. "[63].

Fig. 26
"Landschatt with Jacob's dream", Willmann, M. (1691).

Theta activity originating from the prefrontal cortex (area at the front of the brain) is associated with working memory[64], error processing[65], attention[66], and episodic memory[67] (part of long-term memory). If working memory effort increases, the activity of theta waves in the prefrontal cortex also increases. The opposite is true for stress: Stress reduces the performance of working memory as well as the activity of theta waves.[68]

TECHNIQUES O HE BRAIN STIMULATION

Brain waves can not only be measured in various ways, but also influenced by non-invasive techniques. Parts of the brain are stimulated electrically, magnetically or optically. The methods differ in their technique, accuracy and e†ficiency. In the following, a short overview of the common methods is given.

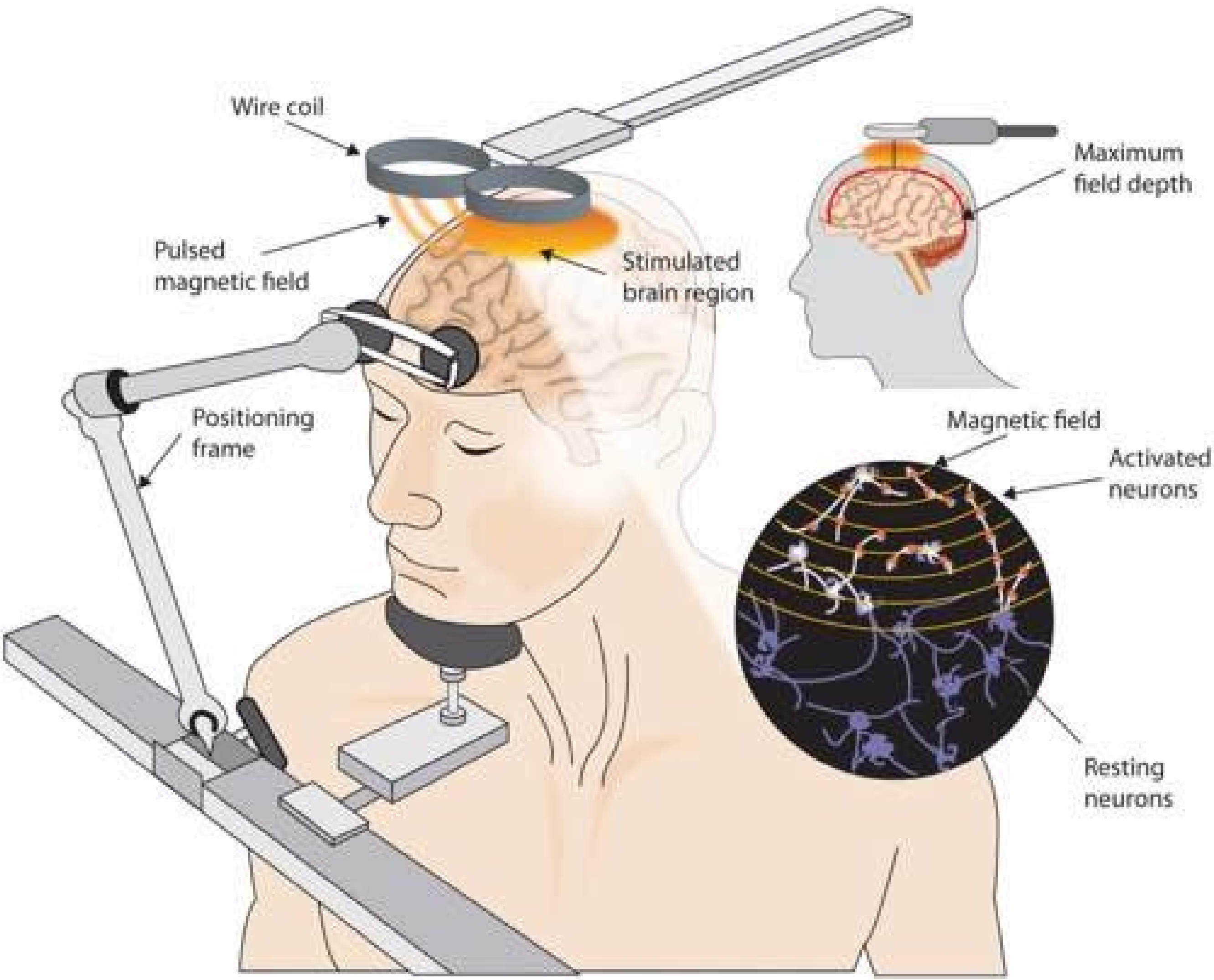


Fig. 27
This figure shows how non-invasive transcranial magnetic stimulation works by using a magnetic field to electrically stimulate the brain. stimulate.

Fig. 28
Neurofeedback for the treatment of ADHD can have the effect that no medication is needed or existing medication is reduced.

NEUROFEE0BACK

So-called neurofeedback is a computer-assisted training method: EEG frequencies are analyzed in real time, broken down into their frequency components and returned to the user after filtering. The predefined parameters of brain activity are mirrored by auditory or visual stimuli and thus made perceptible. Thereby
it is possible to better regulate the brain activity itself to compensate for dysregulation. For this reason, neurofeedback is often used for the therapy of ADD, ADHD, autism, depression, obsessive-compulsive disorder, tics, epilepsy and also migraine.

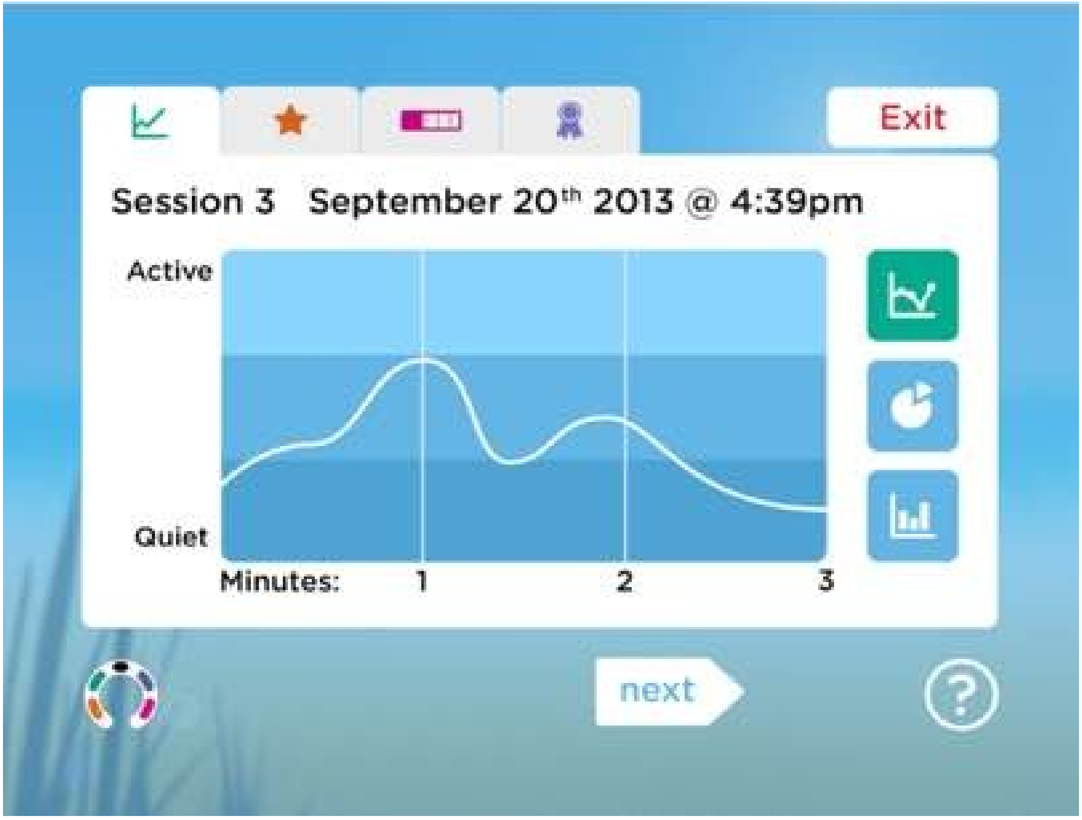


Fig. 29
Screenshot of the Muse Calm app. Here, the course of the brain activity of a session is given.

Fig. 30
Screenshot of the Muse Calm app. Countdown to the neuro-feedback function, in which by relaxing one e.g. let clouds clear up can.

NON-INVASIVE METHOOEN

tDCS
Transcranial Direct current stimulation

In tDCS, a weak electrical current is applied to the scalp via electrodes, which changes the electrical charge on the membrane of the nerve cells in the underlying tissue. In this way, the excitability of the nerve cells is either amplified or attenuated. This technique can be used to selectively influence frequency ranges in the brain. Applications can be found in the treatment of pain or depression and in performance enhancement.

TMS
Transcranial Magnetic stimulation

TMS is used for neurological diagnostics because it can be used to stimulate or inhibit areas of the brain with pinpoint accuracy. Strong magnetic fields are generated, which are discharged in a targeted area of the brain at once.
TMS is used in the treatment of neurological diseases such as tinnitus, apoplexy, epilepsy, Parkinson's disease and depression.

AVE
Audio-Visual Entrainment

AVE is based on flashing lights and pulsed sounds that are used to guide the brain into different stages of brainwave activity. AVE is used in the form of mindmachines e.g. for the therapy of ADHD, dementia, de- pression and migraine. In the next section this method will be discussed in detail.

CES
Cranial Electrostimulation

CES is a treatment procedure in which low levels of alternating electric current (<1mA) are applied via two electrodes over the auricles or the scalp. The currents are not perceived and are used to influence the neurotransmitter concentrations in the brain. CES is used as a form of therapy for drug withdrawal, sleep disorders, depression or chronic pain conditions, among other things, but is controversial due to the inconsistent nature of the studies.

EKT
Electroconvulsive therapy

In ECT, electrodes are placed unilaterally over the non-dominant brain area and a 600 mA current is applied. Short pulses of current induce an epileptic seizure under brief anesthesia and muscle relaxation. The stimulation is thought to cause a release of neurotransmitters and neurohormones and has been used since the 1930s to treat severe mental illnesses such as manic depression and schizophrenia.

Fig. 31
Audio-visual entrainment
with mindmachines.

AU0IO-VISUAL ENTRAINMENT

Audio-visual entrainment (AVE), is a subset of brainwave entrainment and uses flashing light and pulsed sound to guide the brain into different stages of brainwave activity. This process of bringing the predominant brainwave frequency closer to the externally applied frequency is called entrainment[69] . Entrainment is a principle of physics and means synchronization of two or more rhythmic cycles/systems.

All of our senses, except smell, access the cerebral cortex via the thalamus. Since the thalamus is strongly connected to the cerebral cortex, sensory stimulation can easily affect cortical activity and thus the area close to consciousness. To affect brain activity, sensory stimulation must be in the frequency range of approximately 0.5 to 25 hertz (Hz). Pressure, as well as visual and auditory stimulation, are both suitable for affecting brainwave activity. However, a large area of the skin must be stimulated to affect brain waves, so auditory and visual stimulation remain as the most effective and simplest means of affecting brain activity. Direct transmission of impulses is from retinal cells in the eyes and cilia in the cochlea in the ear. The nerve pathways from the eyes and ears carry the evoked electrical potentials to the thalamus. From there, the electrical activity carried "amplified," and into other areas of the limbic brain cortex via the cortical thalamic loop. AVE can take a variety of forms and produce different, subjective as well as clinical ef- fects. The simplest form of stimulation (as described earlier) is a composed sequence of pulsed light and sound. Another variation is repetitive stimulation at a specific frequency for a specific period of time, reflecting the sti- mulation frequency within the EEG. This is referred to as "open-loop" stimulation.
"Closed-loop" AVE would adjust visual and auditory stimulation in response to its own EEG. [70] A simultaneous recording and stimulating combination allows the loop to be closed to send an adjusted signal to the brain based on the same brain's default. Clinical AVE devices are thought to alter EEG activity, induce hallucinations, contribute to limbic stabilization, enhance neurotransmitter pro- duction, and stimulate cerebral blood flow.[71] AVE devices are also called mindmachines.

LICH TUN

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INTERFACE

The focus of our work is on the modulation of light and sound waves as a tool for stimulating desired states of consciousness. In order to understand the extent to which modulation and frequency produce different effects, it is necessary to have a basic understanding of the physiology and capabilities of our senses.

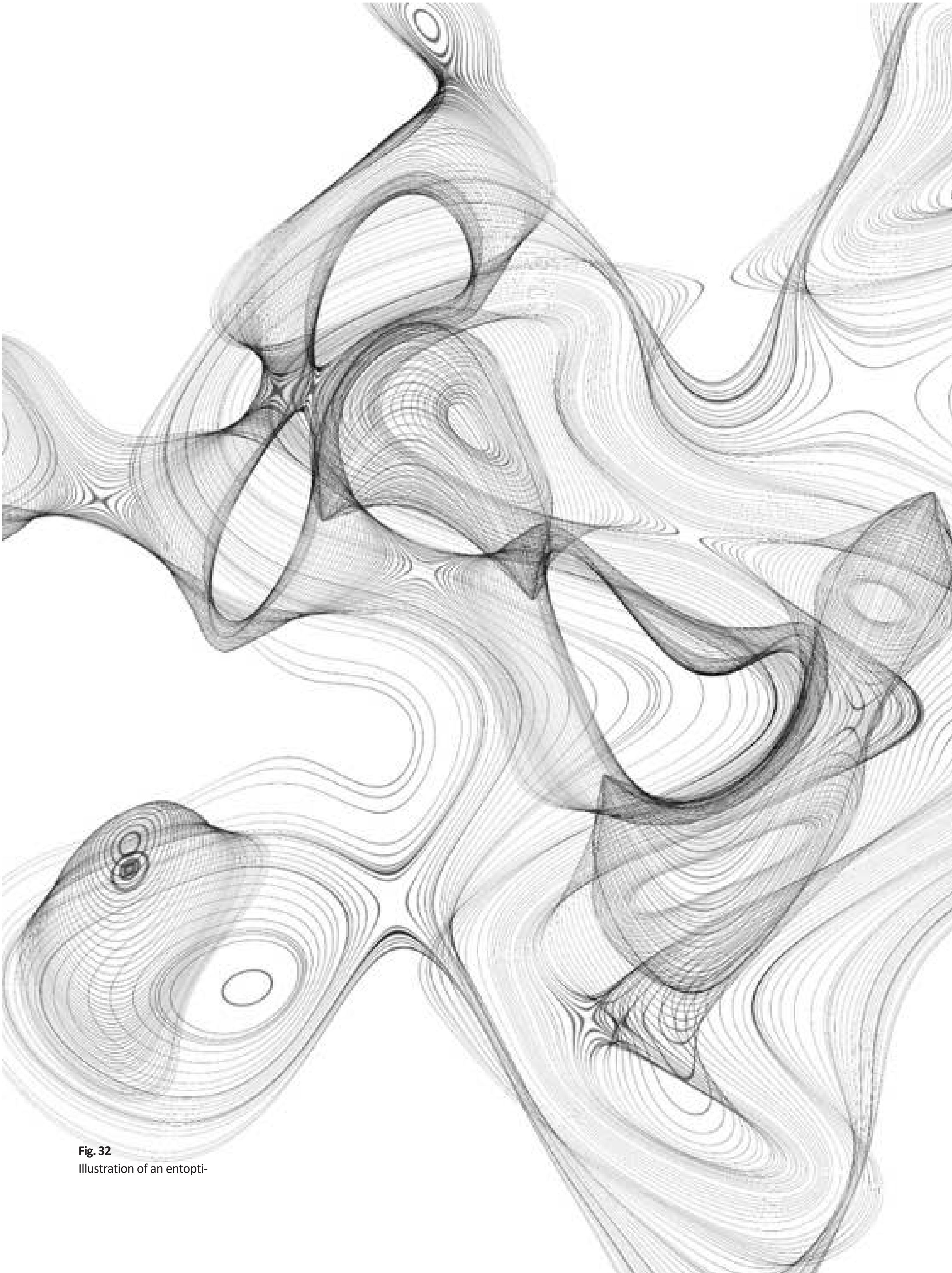


Fig. 32
Illustration of an entopti-

EVOLUTION 0S MIN0MACHINES

A mindmachine consists of a pair of headphones and a pair of glasses covered with LEDs. The glasses stimulate visually through a
Flickering in an adjustable range from 1 to about 30 Hz, while sounds are emitted in a suitable frequency via the headphones. Currently available systems usually offer integrated programs for various application areas. Most compositions have to be added separately and contain programs for relaxation, concentration, memory, creativity, imagination, meditation, trance, sleep and the like. Some manufacturers offer the option of creating your own programs, or using them in conjunction with biofeedback systems. "Biofeedback is a therapeutic method based on measuring and amplifying body signals that cannot be perceived consciously and then feeding them back to the conscious mind as perceptible stimuli (visual, acoustic). "[72] A special form of a biofeedback system is the neurofeedback already mentioned. In the following section, the important technological developments for mind machines are mentioned, described and explained in historical order.

1956
Brainwave Synchronizer

As a result of observations of U.S. military radar operators ott falling into trances, hypnotist and obstetrician William Kroger teamed up with Sidney Schneider of Schneider Instrument Company. They produced the world's first electronic clinical photostimulator.

The product was a simple but working laboratory device for photic stimulation. The Brainwave Synchronizer used a large xenon bulb, similar to modern strobes or camera flashes. The bulb was mounted in front of a silver reflector and the desired flash frequency could be set by a corresponding control dial.

Fig. 33
Brainwave Synchronizer
Model MD-5

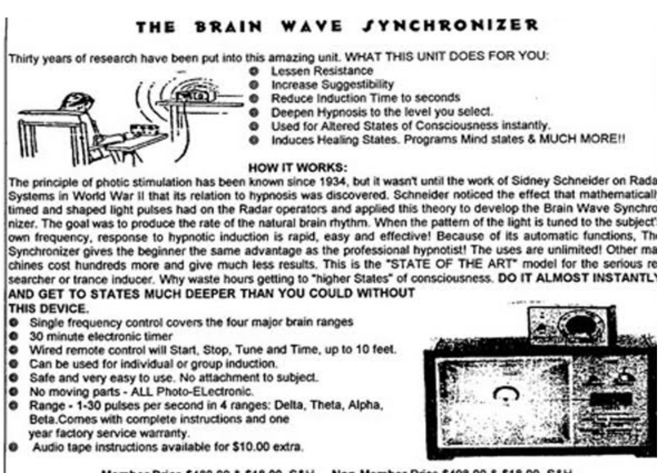


Fig. 34
Advertisement for the Brainwave Synchronizer as a tool to promote relaxation.

1960

Dreamachine

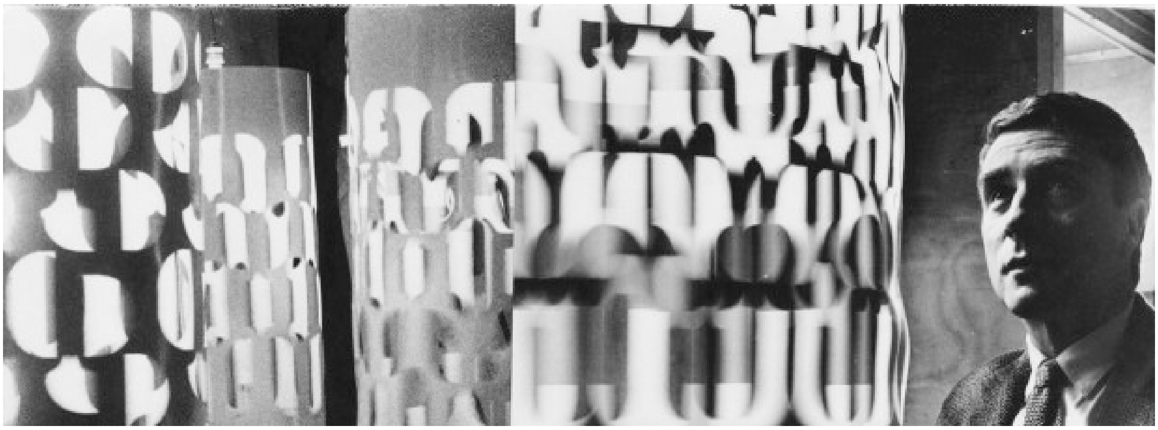


Fig. 35
Photography of Brion Gysin in front of several Dreamachines.

In the early 1960s, artist Bri- on Gysin, together with Ian Sommerville, invented a kind of stroboscope machine, popularly known as a "Dreama- chine." Brion Gysin had a kind of hallucination during a bus ride to Marseille, caused by the play of lights from the setting sun on an avenue of trees. He noted about the experience in his diary:

> "*Had a transcendental storm of color visions today in the bus going to Marseilles. We ran th- rough a long avenue of trees and I closed my eyes against the setting sun. An overwhelming flood of intensely bright colors exploded behind my eyelids: a multidimensional kaleidoscope whir- ling out through space. I was swept out of time. I was out in a world of inflnite number. The vision stopped abruptly as we left the trees. Was that a vision? What happened to me?*"

His concern was to produce a stroboscope for private use. Gysin persuaded one of his friends, Ian Sommerville (1940-1976), to construct a prototype. Sommerville, who was originally a mathematician, came up with a simple but effective cut-up design. He built a cardboard cylinder with holes at regular intervals, which was placed on a 78 rpm turntable with a centrally placed light bulb. When the turntable starts spinning, the light is interrupted at a regular frequency of 8-12 Hz. They called it the Dream Machine, which would be changed to Dreamachine for marketing purposes. It didn't take long for the first beatniks to sit in front of the machine and share their experience with each other. In 1961, the Dreamachine was patented as a "method and apparatus for producing artistic sensations."

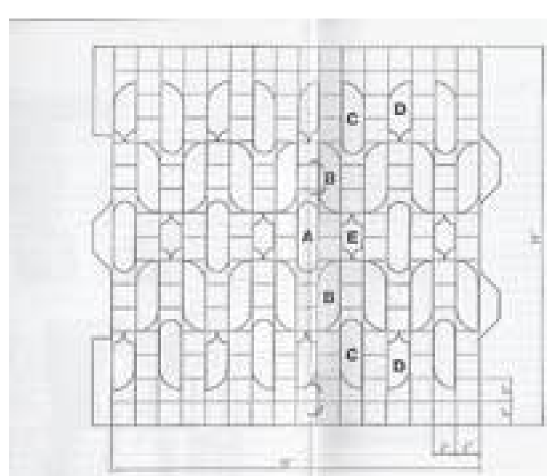


Fig. 36
Stencil of the cut-up model of Ian Sommerville.

Fig. 37
I.S.I.S. glasses and
module for control.

1968
I.S.I.S. - Integrating Stimulating Intensity Stroboscope

I.S.I.S. is the first battery-operated light-sound system for audiovisual stimulation, which was intended for the public. The device could generate light and sound pulses with different stimulation frequencies. The I.S.I.S. had a control dial that allowed the user to select either beta, alpha, theta or delta frequencies for stimulation. Pulsed synchronously with the light, Pink Noi- se could be heard through headphones and adjusted through a volume control. I.S.I.S. was marketed as an aid to relaxation.

Fig. 38
I.S.I.S. glasses from
the inside, reminiscent of a
converted
Welding goggles.

Fig. 39
Synchro Energizer in use in nature by the sea.

1982
Synchro Energizer

The Synchro Energizer's light goggles were a modified pair of glasses in which, instead of the lenses in front of each eye, there was an interchangeable ring with four responsive light bulbs. The sound impulses were also transmitted via stereo headphones.

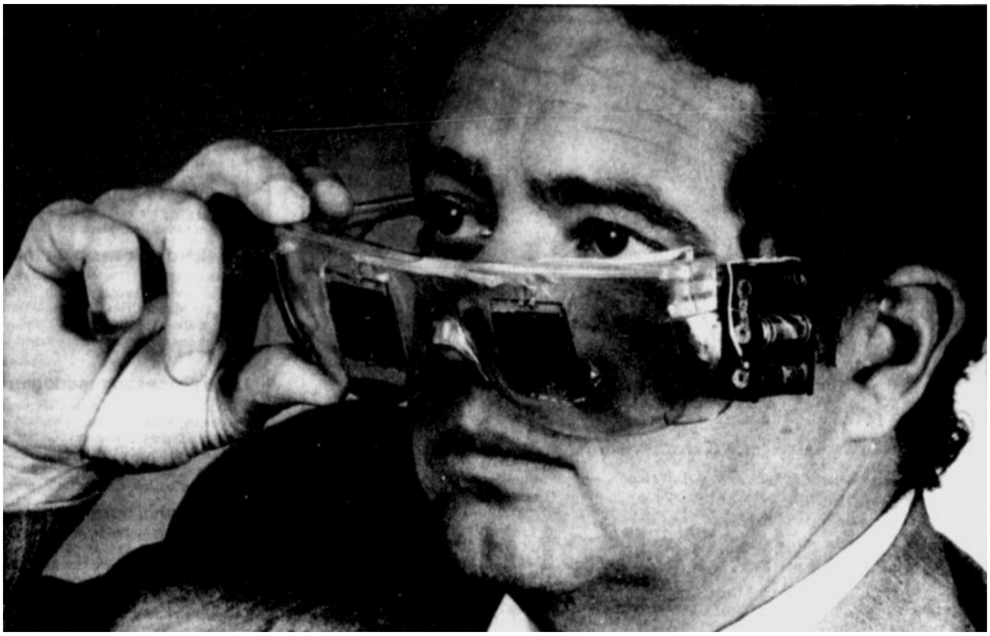
Fig. 40
Close-up of the Synchro Energizer with headphones.

Fig. 41
D.A.V.I.D. 1 - developed by Dave Siever.

1984
Digital Audio Visual Integration Device (D.A.V.I.D. 1)

The D.A.V.I.D. 1 is the first high-quality, clinical system for audiovisual brainwave entrainment. The DAVID1 was developed in a university context as a means to relieve students of stage fright. The light pulses were delivered by responsive bulbs mounted in ski goggles. Four different variations of sound pulses and white noise could be generated. A microphone and stereo mixer were also incorporated. 150 devices were produced.

Fig. 42
The Dzidra glasses worn by inventor Dr. Glen Whitten.



1986
DZIDRA Glass

The DZIDRA Glass is a pair of glasses with pulsating LCD lenses from the 1980s. It is designed to promote relaxation, reduce muscle tension, and has been used to relieve muscle-related headaches (tension headaches). The liquid crystals in the lenses are polarized by electrical voltage, making them opaque to light. In the absence of voltage, the lenses switch to translucent. In this way, a pulsating stimulation of the transmitted light on the eyes can be achieved. Since LCD technology was not yet so advanced in the 1980s, only light-dark switching of 1-3Hz was possible. These slow oscillations are similar in frequency to slow delta waves. Glen Solomon, a US Air Force doctor, examined the glasses in the study "Slow Wave Photic Stimulation in the Treatment of Headache - a Preliminary Report" and came to the conclusion that they indeed promote relaxation and thus represent an effective treatment method for tension headache: "We conclude that in this preliminary report, slow wave photic stimulation appears to be an effective treatment method for tension headache. be effective in the treatment of acute and chronic muscle-contraction type headache. "[73].

Glasses with LCD lenses are another method of visual stimulation: Instead of actively generating light in a pulsed frequency, here we work with the suppression of ambient light. This phenomenon is very close to the technique for generating pseudo-hallucinations according to Purkinje. Since the necessary speed for the generation of light-dark switching of up to 400 HZ in the LCD technology is available in the meantime, completely new possibilities of a Mindmachine with LCD glasses for visual stimulation open up. As light source an unlimited number of combinations of natural and electrically generated light can be tested. Furthermore, a stimulation is possible under all day conditions with reddened eyes and a mindmachine can be used for visual stimulation.
"camouflaged" in inauthentic eyeglass lenses could encourage acceptance of the technology.

Current systems

The systems available today offer integrated programs for various areas of application such as the promotion of relaxation, concentration, perception, memory, vitality, well-being, creativity, imagination, meditation, trance, sleep. Various other features, such as the possibility of creating your own programs, interactive use together with biofee- dback systems or the use of external stimulation programs, which are available as downloads, are included in the more expensive devices. Physiologically based and more serious AVS systems cost about 500z and offer optionally available Session Editor sottware, which is in a similar price segment. So if you want to use scientifically tested devices, the price is a big hurdle, which is not easily accepted without accumulated experience.

Mind Alive
David Alert Pro

Fig. 43
David Alert Pro with CES function for 570 z.

Psio
Psio Eyes

Fig. 44
wireless Psio Eyes with multicolor glasses for 370 z.

Neurotronics
Laxman

Fig. 45
Laxman Light and Sound Machine with the patented "All-Color Full Field Open-Eye Goggles."

VISUAL STIMULATION

Looking with closed eyes into intense, flickering light, you begin to see dynamically swirling geometric patterns with vibrant colors. You know that they disappear when your eyes are closed, and yet their appearance is as real as any other perception. The visual impressions are at the core of the experience of using mindmachines and are a difficult experience for any person to describe. Some report un- tainly complex patterns, others tell of dream-like states. To understand how they occur, a look at the physiology of the nervous system and the application in research is helpful. In the following part an overview of the historical development is given.

Flicker-induced hallucinations have been the subject of research since the early 19th century. Scientific investigations of the phenomenon have identified their biological origin and developed mathematical/dynamic models of visual pattern formation and recognition to compare them with other types of hallucinations, e.g., caused by epilepsy or drug use.

One of the first otficial reports was summarized in 1819 by Purkinje, who had perceived the various patterns such as crosses, stars and spirals when he waved his hand between his eyes and a gas light74. Intrigued by the phenomenal experience, Purkinje experimented with the procedure and encouraged subjects to draw the perceptions they experienced. He identified two main categories of patterns: basic patterns consisting of geometrical shapes (rectangles, circles, hexagons) in checkerboard or honeycomb arrangements and se- cundary patterns[75].

His contemporary Brewster, a physicist from Scotland, created similar images when he walked along evenly spaced vertical railings while looking at the sun behind. Brewster compared the resulting checkerboard pattern with that of the sun.

"most luminous tartan stotf".[76] Further examinations were made by Helmholtz in his physiolo- gical optics, he also coined the begritf "Shadow Patterns" [77].

The phenomenon was largely forgotten until the invention of the EEG by Berger in the 1920s. The effects of flashing light on the brain suddenly became of interest when they could be translated into changing patterns of electrical activity. Using a car headlight shining through a spinning wheel with spokes, Adrian and Matthews showed in 1934 that flickering (frequencies in the 8-12 Hz alpha range and higher) could impose "a coordinated beat" on the alpha rhythm of a subject sitting in front of the lamp with eyes closed[78]. However, a limitation of the method was that in order to increase the frequency of the flicker, the wheel had to spin faster, shortening the duration of the flashes. The problem of inconsistent flashes was overcome by the use of the first electronic stroboscope shortly after World War II. After that

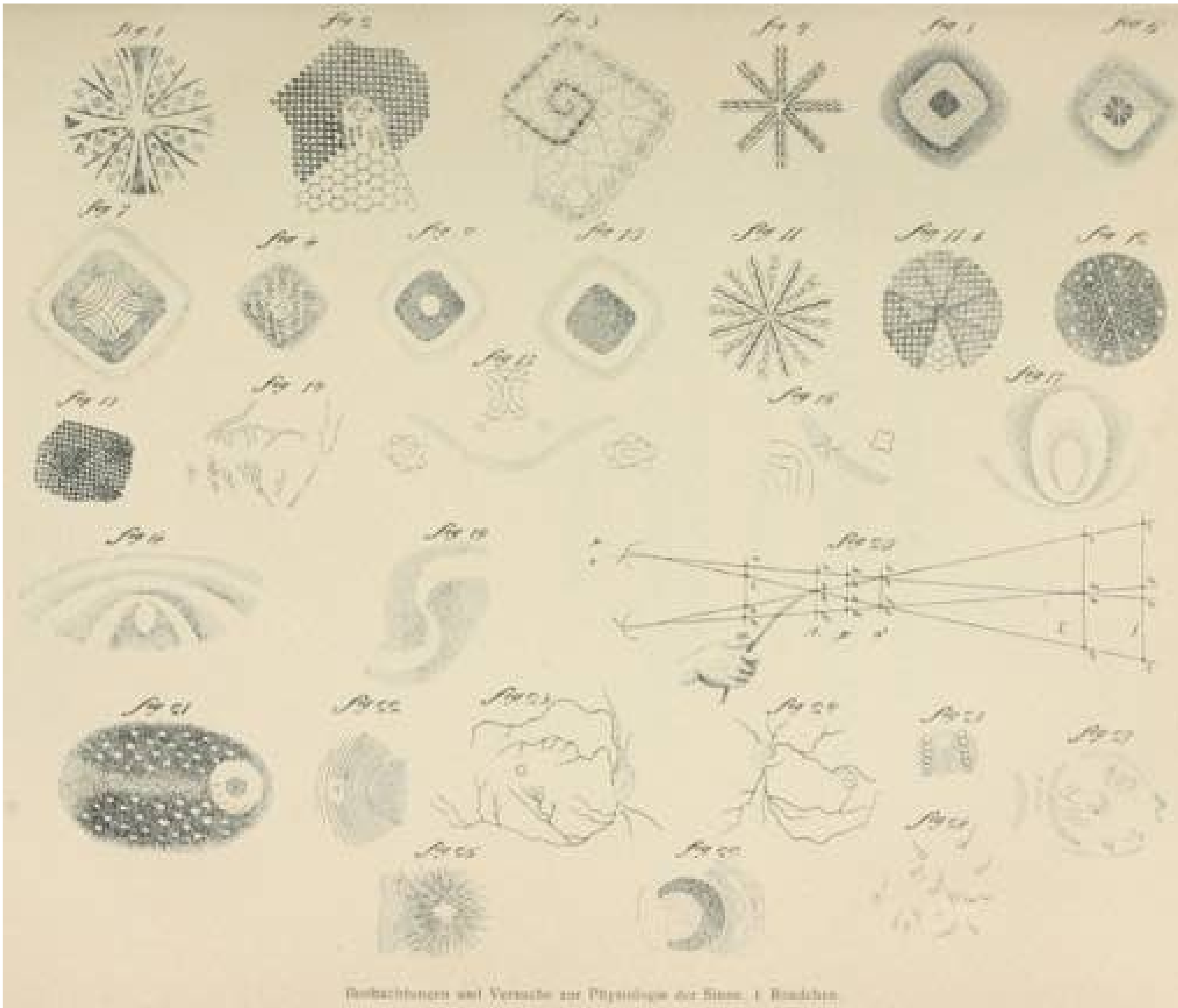
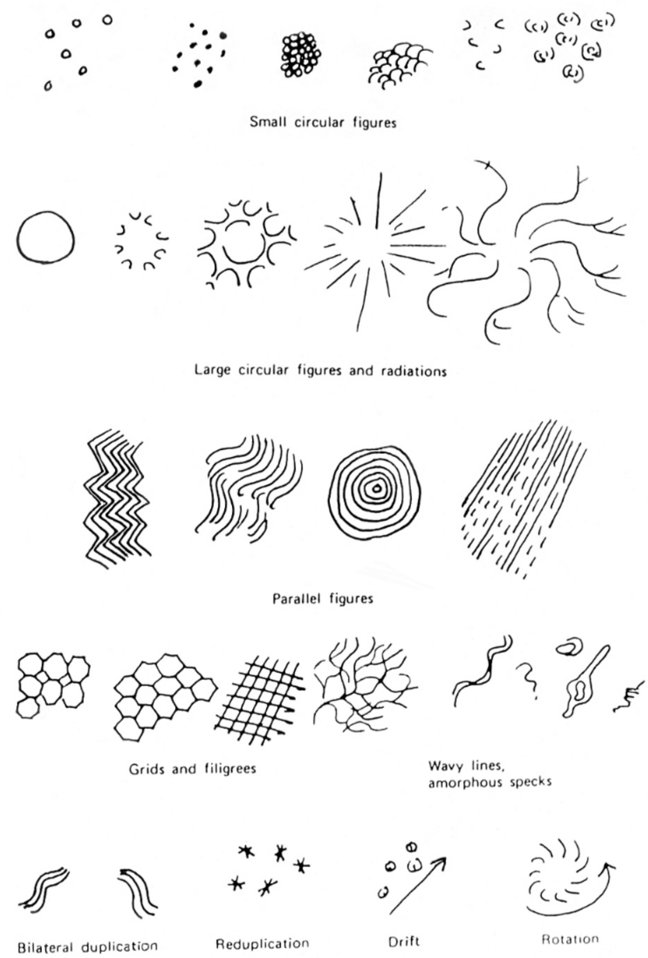


Fig. 51
Drawings by Purkyne of observations and experiments in physiology. of the senses.

visual hallucinations were studied more closely in the laboratory. In his book "The Living Brain", the neurophysiologist and robotics researcher William Grey Walter wrote about "whirling spirals, whirlpools ([and] explosions (…) in testing a device for the treatment of epilepsy we stumbled upon one of those natural paradoxes which is the surest sign of a hidden truth" [79].

Fig. 47
Heinrich Klüver's shape constants



In the early 1960s, Smythies undertook several large-scale studies at the Psychological Laboratory in Cambridge, UK. To investigate the patterns scientifically, he proceeded similarly to Purkinje before, only with modern technology. He evaluated the descriptions of the pro- bands and classified the geometric patterns into different groups. The recurring geometric figures are also known as "form constants" and can be caused by other means, such as psychedelic drugs, sleep (hypnagogic hallucinations) or near-death experiences[80].

Smythies[81] suggests several explanations for the hallucinations. In his first hypothesis, he assumes that the patterns represent retinal structures, such as vessels or pigmented cells. His second hypothesis is based on Walter's idea that the alpha waves represent a visual scan me- chanism and that the hallucinations are caused by interference between flicker and scan me- chanism [82]. The shapes of the images could represent different scanning rasters, for example, scanning with parallel or radiating lines (Fig. 48). In his third hypothesis, he describes that the images come from spon- taneous activity of cortical neurons that have no idea of the stimulus they are exposed to and create "their own hypotheses." His fourth hypothesis is that the images are caused by excitation of specific circuits between the retina and cortical neurons (patterned ac- tivity).

Based on the latter hypothesis, Ffytche elaborated in 2008 on the assumption that imagery represents a shift in thalamocortical activity.[83] During this shift, acti- on potentials of different types are transmitted, on the one hand states that are active during wakefulness and on the other hand states that occur predominantly during deep sleep. The spontaneous volleys of different action potentials can partially dissociate input and output, resulting in halluci- nation-related activity. Central to Ffytche's idea is that hallucinations are not caused by altered activity in specific brain areas, but by altered connectivity between different areas. Ffytche's studies have shown that the stroboscope is a suitable and reliable tool for the in- duction of visual images through changes in neuronal activity from thalamus to cortex.

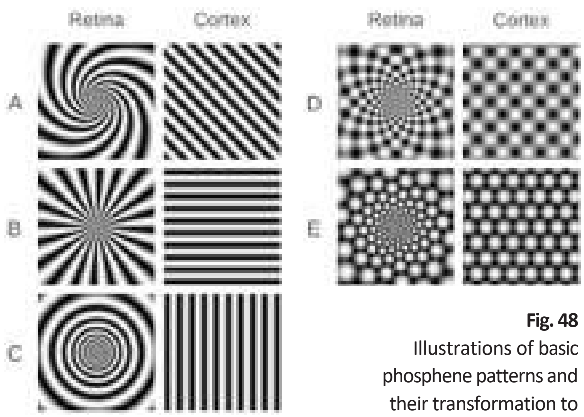


Fig. 48
Illustrations of basic phosphene patterns and their transformation to cortical coordinates.

Another study by Michael Rule, Matthe Stoof- regen and Bard Ermentrout 2011 demonstrates that the geometric shapes of the patterns are closely related to the frequency of [flickering84]. Modern computational methods are used to create mathematical models that can be used to describe the generation of the patterns shown below.

Figure 49 shows a two-parameter phase diagram. Each small square is a simulation of a network with amplitude shown vertically and time on the horizontal. As with a space dimension, there are two islands of pattern formation. At short distances (high frequency), most of the patterns are striped (including labyrinthine patterns), while at long distances (low frequency), the patterns are dominated by hexagons.

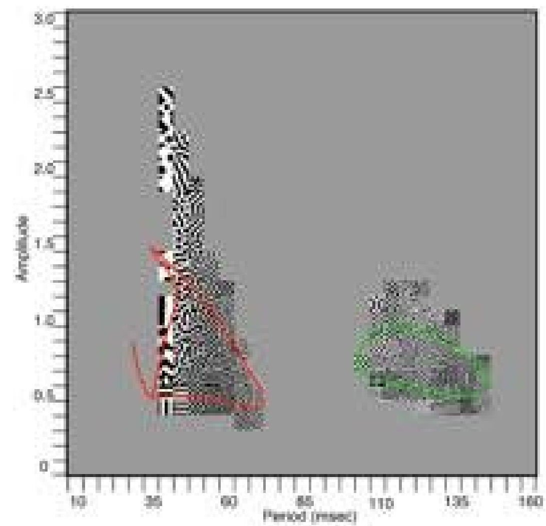


Fig. 49
The changes of the patterns are shown over time and amplitude in corresponding intervals.

The so-called "flickering phenomenon" was considered mainly a curiosity in the early days of science and became a cult object in the 1960s through the Dreama- chine. Today, flickering light is used to model the complex mechanisms underlying most visual hallucinations. Similarly, new scientific findings explain how a relatively simple technology can alter brain activity and which parameters play a role. What is exciting for our work is how states of consciousness are reflected in the formal language of images and that we can evoke certain patterns and associated effects in a targeted manner through AVE. The complexity of the sub- jective experience is not covered by this in any way, but an approximate assessment of the visual perceptions becomes apparent and more usable for an evaluation.

AU0ITIVE STIMULATION

While one group of scientists explored the field of visual stimulation, another group was concerned with the study of auditory stimulation. At first, auditory stimulation was limited to rhythmic sound impulses, but due to its simple use with existing technology and its catchy effect, it became widely accepted as a relaxation technique. Experiments confirmed that the brain reacts with increased brainwave activity to the corresponding frequency and that both brain parts are brought into a state of greater hemispheric coherence (synchronization).

The biophysicist Dr. Gerald Oster discovered in 1973 that brainwave activity can also be influenced by exposing both ears separately to sounds of different frequencies85 . If one combines two oscillators set to different frequencies and sends their signals through one or two separate loudspeakers (so that they mix only in the loudspeaker), then they produce a very regular interference oscillation, which can be perceived with both ears, but also with one ear. He called these signals monaural beats. However, a completely different phenomenon occurs when stereo headphones are used and the signals are fed to the two ears separately. In this case, too, under certain circumstances, one perceives

He perceived rhythmic oscillations, which, however, were clearly different from the monaural ones. He called these signals binaural beats.

However, most of the frequencies that generate the electrical impulses in our brain are below the perceptual limit of our auditory sense. With the help of binaural beats these frequencies can be generated directly in the brain, whereby not the beat frequency is decisive, but the frequency with which it pulsates or oscillates. The brain is offered a certain frequency depending on the state of consciousness to be reached. The perceived frequency corresponds to one of the five neurologically relevant frequency ranges (delta, theta, alpha, beta, gamma) and causes the brain to approach this frequency due to the resonance principle, also called frequency-following principle (FFP)86 , as EEG measurements have shown.

The FFP is more effective when the perceived frequency of the binaural beats is close to the prevailing brain frequency and then slowly lowered, for example, for a relaxed state. Thus, for example, if the right ear is stimulated with a constant and steady tone of 400 Hz and the left ear is stimulated with a constant tone of 400 Hz, the FFP is more effective.

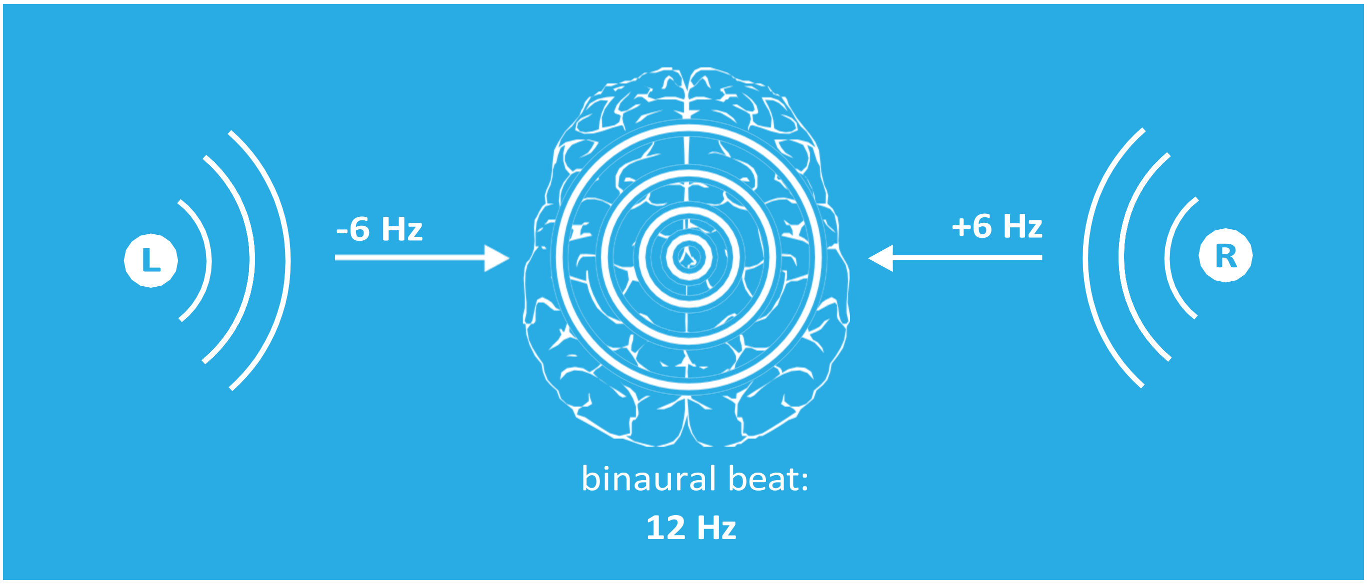


Fig. 50
Schematic explanation of the emergence of a binaural Beats from 12Hz.

tone of 410 Hz, a binaural vibration of 10 Hz is generated in the brain, in this case a frequency in the alpha range. Researchers assume the origin of the bin- aural beats in the nucleus olivaris superior, a part of the brain stem. It is part of the auditory pathway and its neurons are involved in the localization of sound sources by evaluating travel time and level differences between both [ears87].
Some find the sound of pure sine waves unpleasant, so the binaural beats are usually embedded in carrier sounds like nature sounds and harmonic compositions. The fre- quence compositions of the mindmachines are called sessions and usually consist of these three sound tracks. All available sessi- ons are static and the listener is guided to let the events take place. As we have already found out, the FFP increases the etfect by matching stimulation and brain activity. The similarity of the effects of both methods confirms our intention to generate individualized sessions with the help of the own brain waves.

NEWFINOUNR OS MINO-MACHINE

The following part describes our practical series of experiments in using the Mindmachine and its further development as a tool for transmitting states of mind. The process in the course "Messing with our Minds" and the continuation of the project in the following two years are presented in depth and in a comprehensible way.

Fig. 51
Preparations and setup at the Freqs of Nature Festival.

Fig. 52
Mitch Altman's Guide glasses
aka MAKE Brain Machine.

MAKER BRAINMACHINE

As an introduction to AVE systems, we (Christopher Pietsch, Luis Grass and Michael Härtel) rebuilt Mitch Altman's Maker Brain Machine with the Arduino. Compared to commercial AVE systems, which are with 100 - 500 z too expensive for simple experiments and in most cases difficult to modify, the Brain Machine gave us the opportunity to get a first impression of the technology for little money. For the reconstruction we used headphones with 3 LEDs on the left and 3 LEDs on the right side. The Arduino and the circuit board were mounted in a closed housing. The production of a portable and open system, which exceeds the function range of average mindmachines with the possibility of own programming, cost us less than ten euros. We thus had a means to gain our own experience in the use of audiovisual stimulation and a simple tool for the exploration of further concepts.
With this prototype, we first conducted self

The first time I tried the device, I tried to see if it really worked (as stated) and, if so, what the effects would be. The conclusion was that the device really worked. The programmed composition of frequencies starts at 14.4 Hz, takes one 15 minutes into lower frequencies down to 2 Hz, and within another 5 minutes back up again, ending at the level of the entry frequency. We had no practice in meditation at that time and were deeply impressed by the effect. We exchanged the built Brain Machine among each other, so that everyone could try it out further at home in a relaxed way. In the course "Messing with our Minds" at the FH Potsdam we had the opportunity to consult the neuroscientist Matti Gärtner to learn more about the background of the effects.

Fig. 53
Trying out the replica of the MAKE Brain Machine.

The decision was made to further explore the possibilities of this tech- nology in the course. With the combination of Arduino and processing and the associated option for exploration, expansion and modification, we had an exciting framework for conducting further experiments.

Fig. 54
Converted headphones become a brain machine converted.

EER-BRAINMACHINE EXPERIMENT

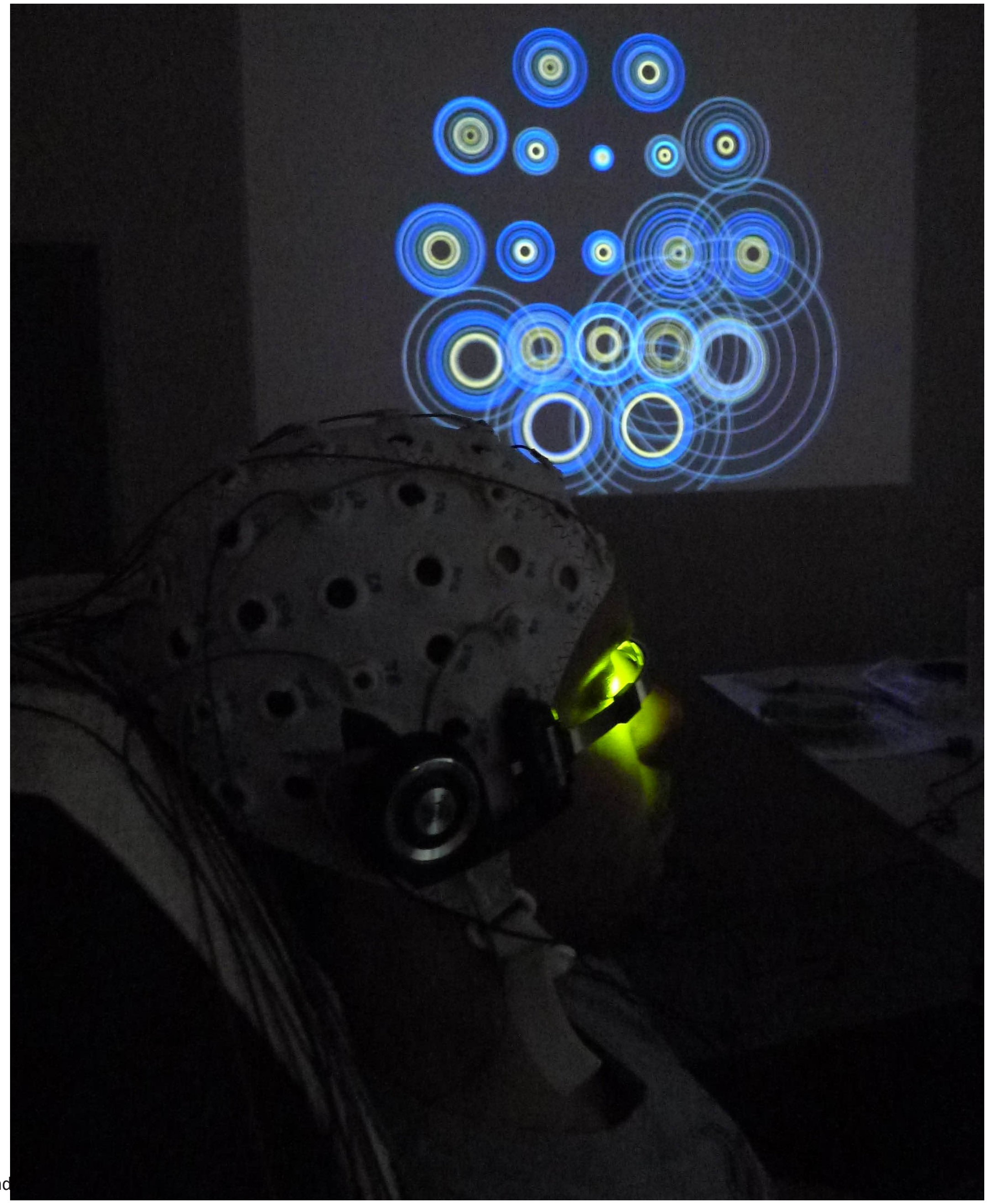


Fig. 55
Brain machine and EEG, visualization of the EEG in the background

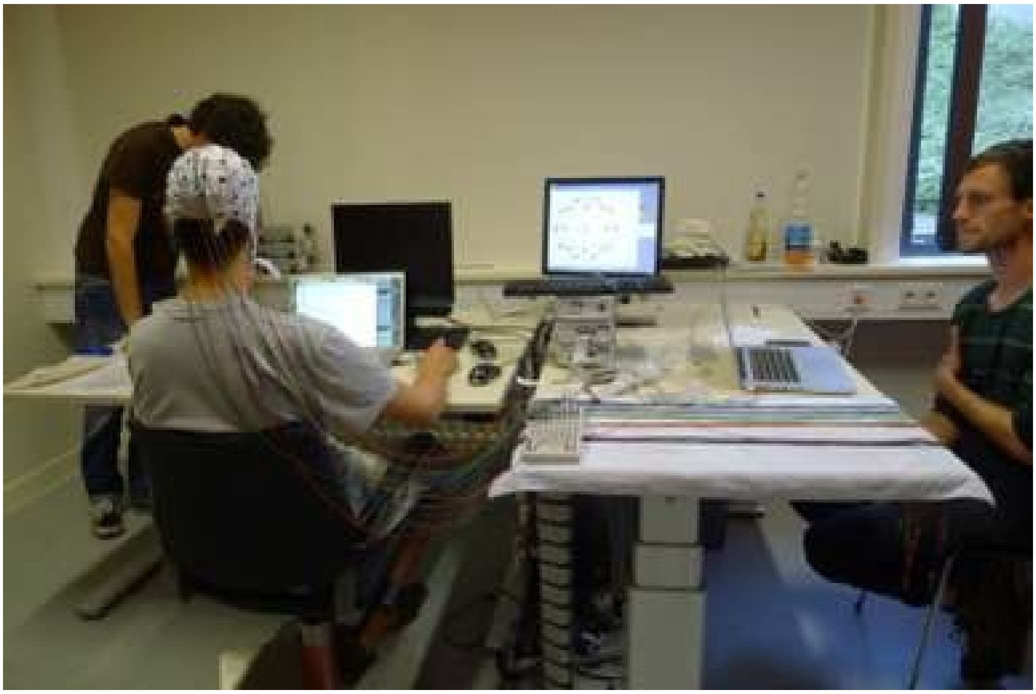


Fig. 56
Overview of the experimental setup in the EEG laboratory.

In the cluster "Languages of Emotion" at the FU Berlin we were able to verify the effects of Brainmachine in the EEG lab. The use of Willy Sengewald's OSC/ Processing Bridge allowed us to visualize the live EEG data from MAT Lab, the widely used software for brainwave analysis among neuroscientists. To try out visualization ideas for the live data as early as possible, we were given a recorded EEG set with normalized values-19 signals with three sub-signals each-that we could easily query and then display. For the experiment, we developed a sketch that colors the predominant frequency of the elect- rode and describes the amplitude by changing the radius of the rings.

The subject was Chris and since he was pro- gramming at the same time to op- timize the display results, neurofeedback situations occurred. This means seeing one's own EEG signals and thereby influencing one's EEG signals. The session lasted several hours - if only because connecting it EEG is a time-consuming affair.

Equipped with a clinical EEG hood and our modified Brain Machine, we were able to conduct basic research. Among other things, we found that the frequency down-

The results of the session are comprehensible and in part clearly recognizable in the EEG. Enthusiastic about the result and visibly impressed by the new way of presenting EEG data, Matti Gärtner assured us that the evaluation of this topic was also very exciting from a scientific point of view and that we should definitely pursue our project. Our assumptions were now confirmed by a neuroscientist and validated by EEG analyses. Inspired and with a good feeling that one can give new impulses in a scientific field, we conceived our project for the Long Night of Knowledge Shadows (LNDW). The transmission of brainwaves from one person to another was fixed as an outlook.

BRAINSTATESHARINR

During a demonstration with Willy Sengewald we came to the conclusion that we wanted to try to manipulate the test person, who was to be connected to the EEG, with our brainmachine. The measured signals were then to be transmitted to a group of volunteers for whom we needed further brainmachines.

These ideas turned into the project with the striking name "Brain State Sharing". We now wanted to find out whether EEG data can be forwarded to other people and how such a thing can be realized. For the "big" Brain Machine there were two variants of implementation. The obvious solution would have been to use several brain machines. We had sketched a scenario for this, but the construction and parallel control of several glasses would have been more expensive than the alternative. A processing program would project the visual signals (simple change between red and black background) onto a screen and additionally output the acoustic signal via the audio output of the computer. The volunteers, to whom the EEG signals should be transmitted, would then sit in front of the beamer - but directly exposed to its light. On the other side of the screen, the audience would only see the silhouettes and the headphone cables hanging from the ceiling in the flickering light of the projector.

We had to figure out the best way to protect the eyes of the test subjects from the projector light and still ensure adequate light transmission. We set up the scenario and tried different materials - mainly foils. Despite interesting results, we decided to build our own ditfusors, into which we could also let in the headphones. As a basis we used transparent spheres, which consisted of two holders, based on Richard Altcrotts's "Infinity Projector". Out of these we wanted to create both the "glasses" build, as well as - from a smaller variant - the headphone shells. The whole thing should then be connected with a rubber band and a buckle to ensure the firm hold of the MIndmachines.

Fig. 57 top
Session for three with new goggles and the Beamer Mindmachine.

Fig.58 left
View from behind.

Fig.59 below
ready-made goggles for the Long Night of Knowledge Shadows.

Mindmachine construction
We milled slots in the plastic covers and filed them out smoothly. Then the sleeves were slit from the inside so that the coating would hold better. This was done to allow enough light to reach the eye, but to prevent it from shining directly through. Since all the spheres had relatively sharp edges, we had to prepare them with rubber bands for protection. In the end, the parts were sewn together and assembled.

2011

Demonstration at the Long Night of the Sciences

We had our first Brain Machine on display for testing during the afternoon and soon many interested people came to try it out. Some could stand it for up to 20 minutes, others said after less than a minute that it was unpleasant for them and they wanted to stop. For better effect, we had the Arduino board integrated into a box to which the Brain Machine was then connected. The box not only provided the power supply via an electrical outlet, but also served as a "pseudo control" of the Brain Machine, on which we pretended to set the respective frequencies.

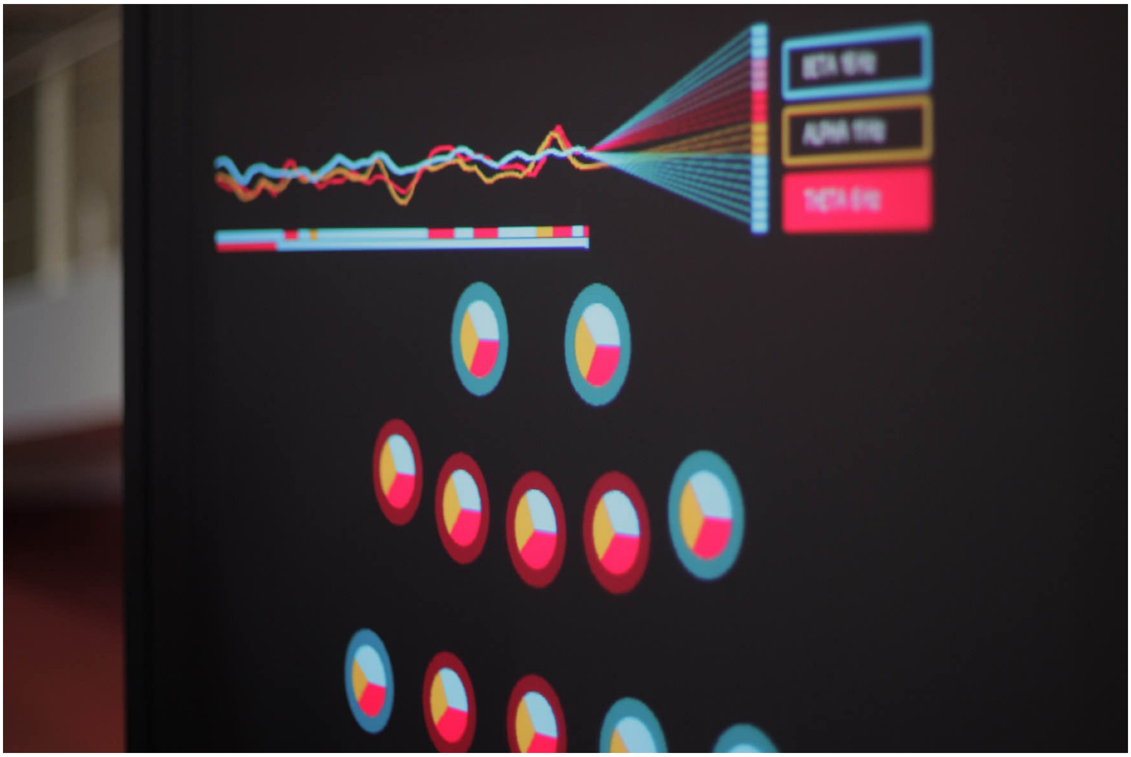


Fig. 60 left Meditating person with EEG and three subjects with mindmachine behind the screen.

Fig. 61 Bottom left Visitor with Brain Machi- ne prototype.

Fig.62 right
Live visualization of the EEG data.

Data visualization

In LNDW there was a meditating subject equipped with a clinical EEG. The visualization of the brain activity and the process should have explanatory character at the same time. The 19 electrodes were positioned centrally on the screen in the same way as they were placed on the head. The electrodes, each shown as pie and gate diagrams, indicated which of the three frequency bands in the electrode were active at the current time. The pie chart above showed the individual proportions of the bands in the total value of the electrode. In addition, there was a history at the upper edge, in which the data were additionally entered live. The prevailing frequency of all electrodes was transferred to a timeline. It recorded the current highest value and the average values at earlier points in time. This way we visualized the values we received from the subject and the ones we used for controlling the mindmachine.
We then began the actual experiment. We asked the audience for volunteers. ligen who wanted to test the broadcasting of states of mind. Three volunteers were able to take a seat on the back of the screen at the same time and sit in the light of the beamer. They were put on the mindmachines and shortly afterwards we started the program. The audience saw the silhouettes of the participants and the headphone cables hanging down in the flickering of the beamer light. The live presentation of the EEG data originally shown on the screen was now projected on a wall so that the audience could continue to follow the data. Since many volunteers wanted to test, the experiment dragged on for a long time. The testers' reports ranged from dream-like states to excited descriptions of the patterns they experienced. One volunteer even fell asleep while the volunteer providing the data was quietly meditating.

Fig. 63
View of the dome projection in the Powerdome 360° in the Orania Potsdam.

2011
Immersive Mindmachine - Fulldome Installation

Until the end of the semester, when our projects were to be displayed in the fulldome, there was still a lot to do for the visualization. The geometry of the dome requires a special display and the one we had used at the FU was not suitable for a dome projection. We again used the same experimental setup in the dome as in LNDW - this time with four subjects instead of three. The data were projected as a grid onto the full-dome ceiling.

The aim of the visualization was to identify patterns in the brain waves. The EEG data were translated into a 4x4 matrix and coded by colored rectangles according to the predominant wave type - beta,alpha or theta. For the purpose of overview and abstraction we repeated the matrix space-filling a few times on the dome surface. The resulting visualization had a slightly intoxicating effect as a side effect, since the pulsing of the signals from the subject's brain triggered a simultaneous flickering in the full dome.

Fig. 64
View of the projection and the four subjects with mindmachines.

Fig. 65
Close-up view of the participants during a Session.

Fig. 66
Setup of the first installation on the Freqs of Nature Festival.

2012
Beamer Visor Brainmachine

After the course was finished, we didn't want to let our project gather dust but to continue. Matti Gärtner asked us if we would like to set up the Brainmachine at a festival - we immediately agreed. Of course it was not possible to use the expensive EEG from the lab for festivals. Likewise, the long hour-long setup and the subsequent difficult procedure of washing off the lead paste is not an attractive invitation for festival visitors. Due to the organizer, we had a small budget for hardware and chewed the very nie- dercomplex Neurosky headset, which was equipped with a electrode on the forehead and a reference electrode on the ear, it cannot be compared with a clinical EEG, but it can be applied to test subjects all the more quickly. In addition, the Neurosky headset has been used in many projects because of its ease of use, has already been hacked and is well documented. To increase the performance of the Brainmachine and to work around problems like asynchronous flickering or unexplainable crackling in the audio, we switched to Openframeworks. The tracks could now be edited in XML and loaded and played via a simple interfa- ce without restarting the program. The projection of the flicker

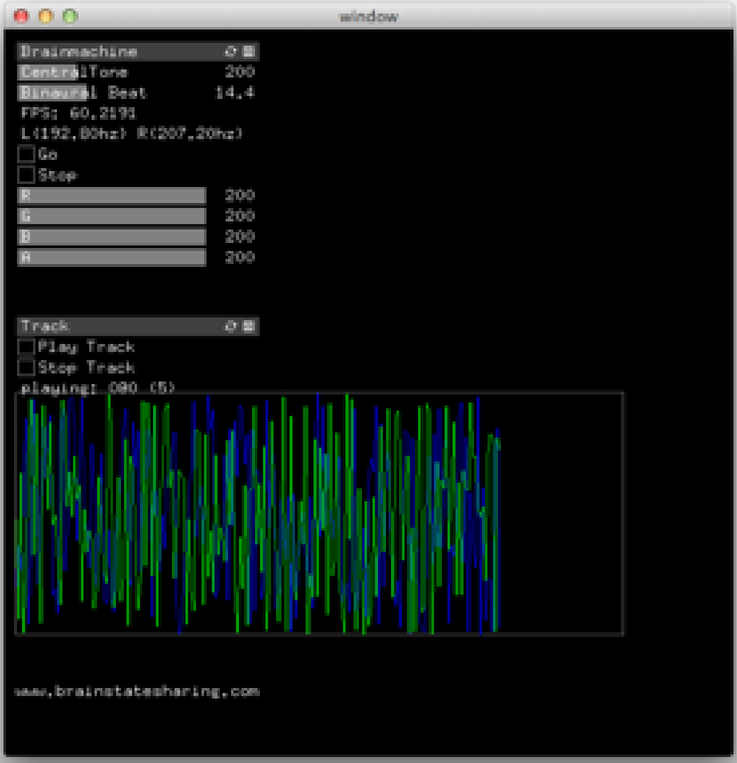


Fig. 67 openframeworks GUI for controlling the beamers Mindmachine.

We also enhanced the visual stimulation with moving images and changing colors for a more complex visual sti- mulation. We also invested in the quality of the headphones to improve auditory stimulation and reduce ambient noise with larger ear cups. We attached visors to the earpieces, which, unlike the goggles, do not exert pressure contact and are therefore more comfortable to wear and easier to put on. In an old airplane hangar, we ended up using a cinema bench with four seats, each with a visor brain machine placed in front of the projector. The colorful flickering attracted interested people to participate in the experi- ment. To quench the thirst for knowledge of the curious audience, we designed posters with detailed explanations and put up warning signs for epileptics as a safety precaution.

Unfortunately, the connection to the Neurosky didn't work at the festival and we had to settle for a collective mindmachine. While it is not surprising that on a psyche-. delic Festival, the interest in consciousness-altering methods is very high, yet we were amazed by the positive and euphoric feedback from individual people. After each session, we asked people about their experiences. From reports of hallucinatory states to euphoric descriptions of patterns, we were inundated with individual experiences. Aside from requests for more comfortable seating and quieter environments, feedback regarding progression was interesting in that individuals wanted to adjust tracks, change speeds, and individualize stimulation. Using festivals to get feedback and input for further development and, in turn, getting a group of people "on the same wave" has paid off for us.

Fig. 68
Participant with LED Mindma-
chine experiences a
personali-
sed session.

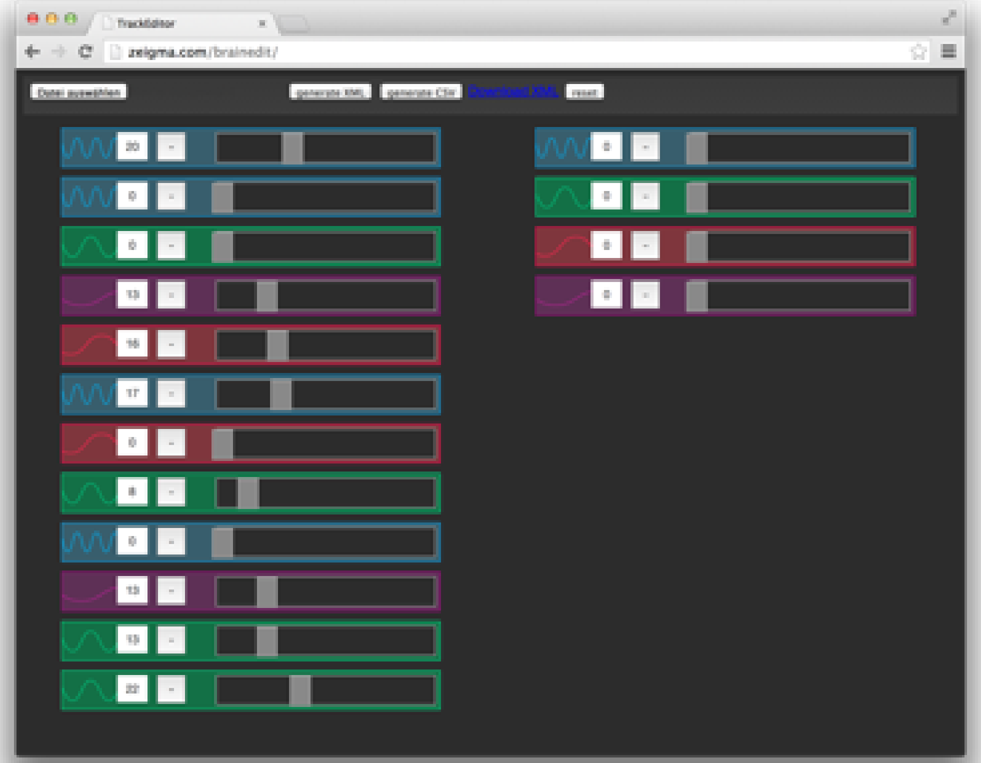


Fig. 69
first web editor for creating
sessions.

2013
LED Mindmachine and Session Editor

While the appearance at the first festival with cinema benches and omnipresent flickering of the beamer seemed almost obtrusive, we moved the event to a quieter place with comfortable couches and blankets. In the further development of the Mindmachines, we focused on the individualization of the sessions via a simple interface. In the product design, we switched to a more intimate experience by using LEDs and a darkening, larger visor.

We used Openframeworks for control and Arduino as LED controller bridge. In the session editor, the respective frequency ranges were combined into a new session via drag'n'drop and saved in XML. In total, we had space and hardware for three people per session. Although the location seemed somewhat hidden, the seats were always full; with the difference that people stayed on the couches for an average of 45 minutes, almost three times as long. Before the people started with the first session, a short explanation about the functioning was given and they were asked what their preferences were, so that we could make a better selection of the prefabricated tracks. After the first session, which lasted about 15 minutes, we gathered initial feedback and in the next step let the participants co-design the sessions through the editor, after which the second session began. Through the intensive conversation with or questioning of the subjects and the attention to the personal needs of the participants,valuable conversations and constructive feedback occurred... Although the second session was consistently found to be more enjoyable after the adjustment, most wished they had the option to change several parameters in the composition, such as new audio tracks, the volume of the binaural beat, or by simply pausing. Unfortunately, two of the three mindmachines were destroyed on the first night, leaving only one person to sti- mulate per session. As a result, the sessions became more personal and even longer; over an eight-hour period, only six sessions were conducted. After the extensive discussions we had the impression that a simple individualization of the sessions via an interface was not possible and that we had to pursue our approach of letting the brain decide for itself which frequencies it would prefer to hear.

Fig. 70 Group photo of the Neurovillage crew.

2014
Neurovillage

At this year's festival we had the opportunity to use our Mindmachine for the third time. Together with Matti Gärtner, Willy Dö- ring, Masahiro Kehata and Meta we founded the Neurovillage. This time we had our own wooden hut as a central contact point for all interested people and a space for interesting experiments with EEG, mindmachines and neurofeedback. Our intention was to illuminate the field of neuroscience from a different point of view and to create a simpler and more interesting approach through creative use of EEG installations.

The crowds and the increased interest in visualizing brain activity far exceeded our expectations. Every day the Neu- rovillage was filled with an inquisitive audience. With Masahiro Kahata, we had a team member who has been involved in brain research for over 40 years, and who, among other things, built the first portable EEG and worked with renowned artists like Mariko Mori and the "guru" of the hippie movement Timothy Leary. His development is the Interactive Brainwave Visualizer (IBVA), an easy-to-wear portable EEG headset with specially developed software for brainwave monitoring and the possibility to influence 3D visuals through neurofeedback.

In combination with the IBVA and our mind-machine, we were able to better understand the effect of the individualized sessions. Masahiro's Sottware specialized in the coherence of both brain states and provided exciting results. The experiments confirmed that we should combine EEG and Mindmachine in one product. For the festival, we further developed the Session Editor in terms of operation and function. The solution was a web-based version, where sessions can be saved and thus as many variants as possible can be created, which are available to us for analysis afterwards. Our intention to develop a web

Fig. 71
Impressions from a feedback session together with a mind machine.

We have successfully tested and evaluated the idea of providing a platform where mind machine sessions can be easily started and adjusted at the festival. However, the introduction and education of the participants was very important every time for a relaxed attitude and a neutral attitude towards the mind machines. When we did not explain the functionality to the participants beforehand, it was questioned very skeptically and cri- tically. Again and again the question came up whether the brain is programmed by using it. Although we answered the question in the negative each time, a certain skepticism remained with some people. We wanted to change the fact that one has no direct influence on the stimulation and surrenders to the session without knowing what is happening to one. Equally interesting were the sometimes very specific questions about Personal Alpha, coherence experiments or lucid dreaming.

Fig. 72
Neurofeedback experiment with Emotiv Epoc headset.

OUTLOOK TO 0 IE PRACTICAL WORK

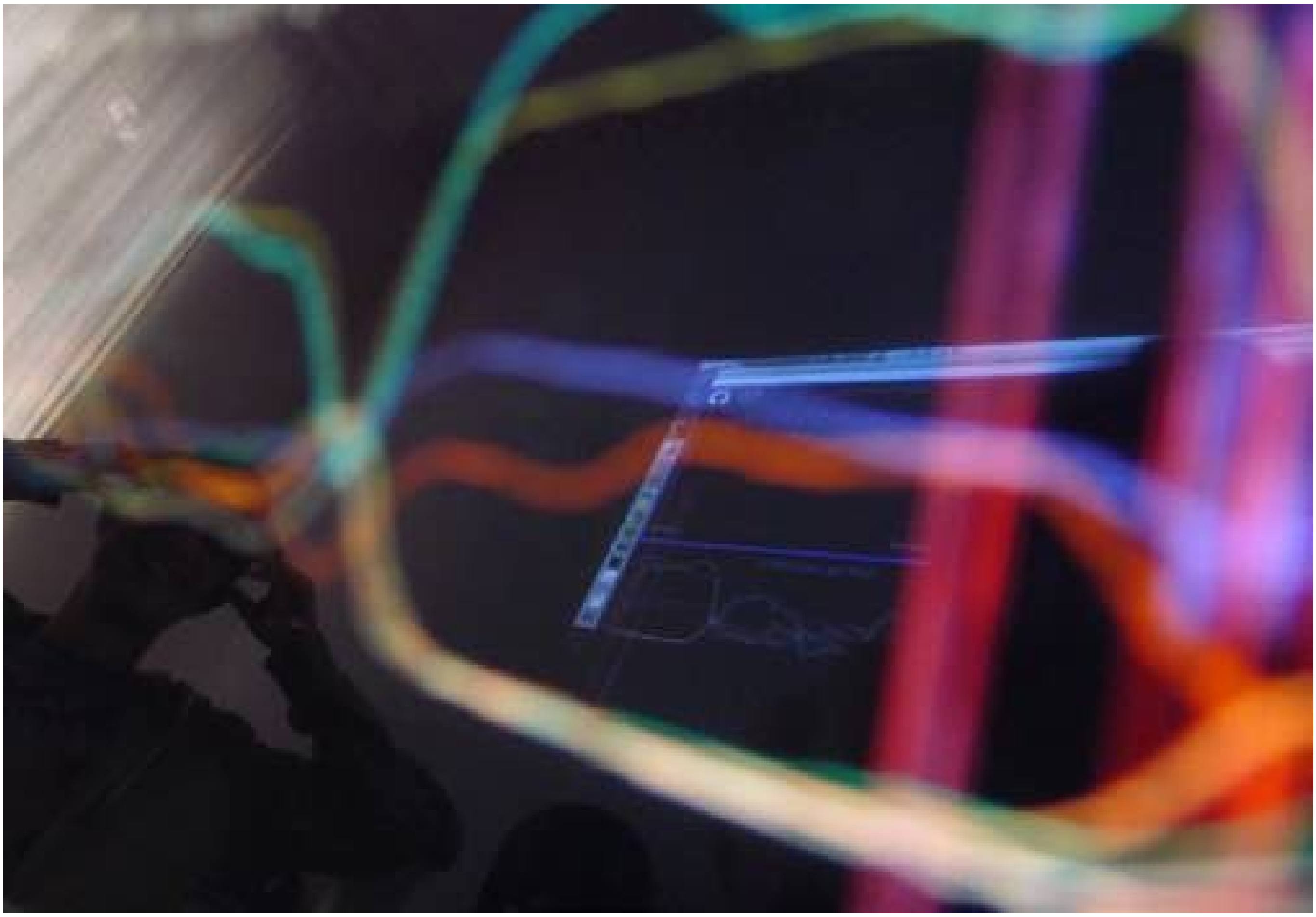


Fig. 73
The photo shows a session
with the Muse headset and
a mindmachine.

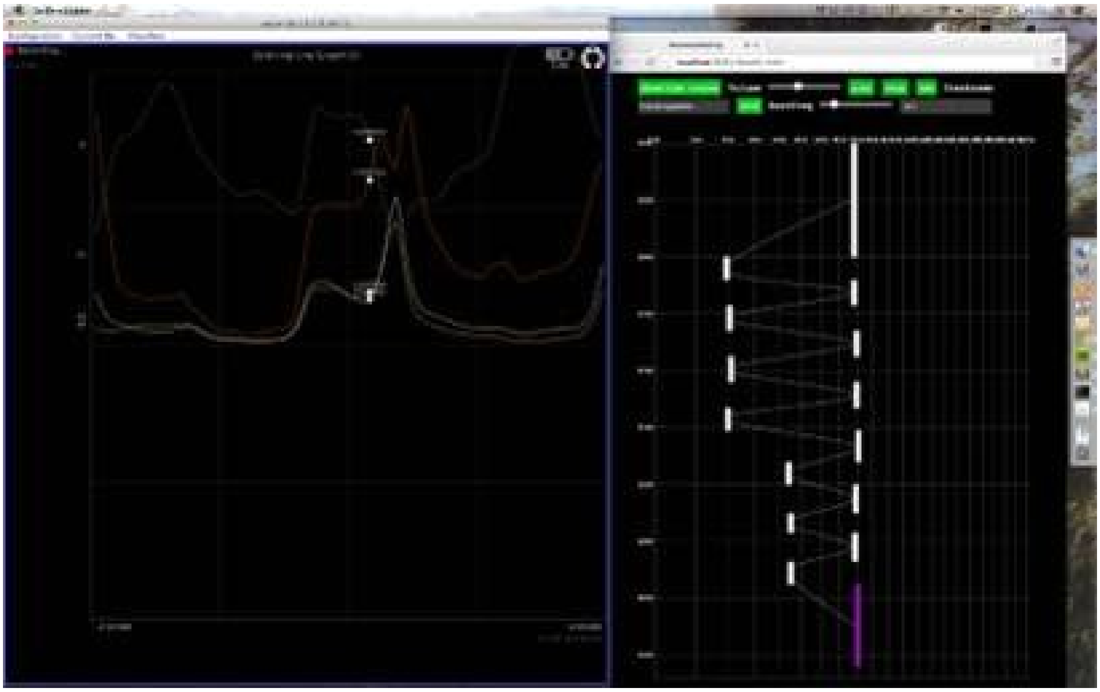


Fig. 74
Analysis and comparison of EEG data and generated mindmachine session in the actual Session Editor.

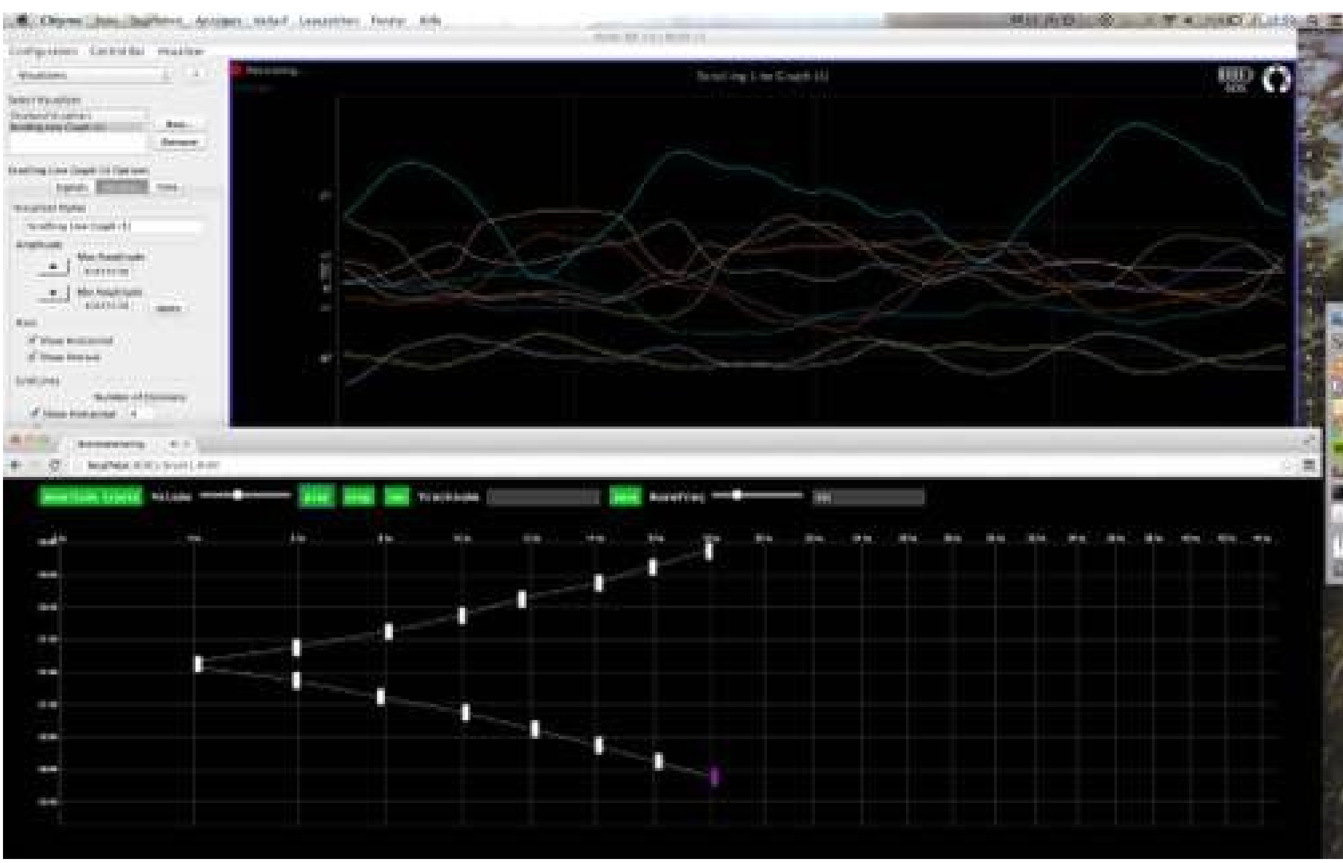


Fig. 35
Evaluation of the relevant EEG values of the Muse headset during a Mindmachine session.

OUTLOOK

During the research and elaboration of the theoretical part of our bachelor thesis, we became aware that current research in neuroscience shadows is already much more advanced than thought. However, there are also parallels to our use of surface stimulation by light and sound. It is beyond imagination to think that neuronal implants are being worked on, which on the one hand could specifically fight diseases, but on the other hand would also be able to program the body by precisely injected light pulses or even to change memories. In DARPA's scenarios, the brain is used as a medium to solve complex tasks and humans are instrumentalized as tools.

We, on the other hand, want to develop a newly conceived mindmachine with our approach, which communicates the applied technology in an open way. The viewer should understand how it works in order to be able to draw conclusions and enter into a dialog.

Our new prototype will combine the freely available EEG headset Muse with the Mindmachine and the forgotten technology of the DZIDRA glasses to a new BCI. By deepening the necessary scientific foundations, we gained insights that we want to explore in a series of experiments.

RESONAN\

The frequency sequence of the audiovisual stimulation is essential for a stimulating experience of the mindmachine. By means of a cali- bration phase by the EEG, the mindmachine could adapt to the prevailing arousal state of the brain. Thus, the mindmachine generates an individual session each time it is used. Tendencies of relaxation or arousal influence the stimulation, so that a direct feedback loop between mindmachine and user can develop. In this respect this experiment combines neurofeedback and direct stimulation to an unconscious interaction model.

SELF RERULATION

Sensorimotor access would be testable through a series of peripheral sensors. By simple head movements, the gy- roskop in the Muse can be used to control parameters of the mindmachine. Preferred frequencies can be held, for example, by blinking the eyes and then returning the head to a comfortable position. Another possibility is the conversion of a Sphero, a ball-shaped toy robot, into a control element that is staged as an artifact. The controllable center of gravity of the ball could indicate the changes in the measured EEG bands. The haptic feedback of the Sphero can therefore be used as a medium for neurofeedback.

A0APTION

In our previous Mindmachine prototy- pens we stimulated with artificial light. First via flickering projection with a beamer, where the color choice can be easily adjusted. The two-dimensional projection can be used for several participants, but the directed light must be dimmed with ditfu- sors. Later, we used different brightness LEDs and tried out several colors, which produced different effects. However, with each variant we received occasional feedback that the light was too bright or that people wanted different colors. In short, each person has specific ideas about the optimal light for stimulation. Why not create a more flexible system that adapts to the ambient light? Instead of artificially generating light, we can also pulse existing light through a pair of shutter glasses that are not designed for this purpose. In this way, it becomes possible to make our own choice of light source and even use sunlight.v

QUEŁŁEN-NERRE ICE CREAM

ŁITERATURNER\EISHNIS

Note on Internet sources:
The availability of internet sources was checked by the author before printing. Unless otherwise indicated, the sources listed in the bibliography and list of image sources were last available on September 1, 2014. Therefore, a separate label has been omitted.

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EI0ESSTAATŁISHE ERKŁÄRUNR

I hereby declare that I have written this thesis on my own. I have not used any sources or aids other than those indicated, and I have marked quotations as such.

Christopher PietschLuis Grass Berlin, September 5,

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