Chapter 8
New Ways of Knowing Ourselves. BCI Facilitating Artistic Exploration of Our Biology

Laura Jade and Sam Gentle

Abstract As rapidly advancing technologies become more widely available, having access to tools that collect biometric data and in particular BCI technology, is providing artists with new ways of exploring our biological selves as well as creating new modes of audience interaction. Brainlight is a large illuminated interactive sculpture that integrates biology, lighting design and BCI technology to explore the hidden aspects of our minds. The installation is controlled with a wireless EMOTIV EPOC+ EEG headset that detects live neural activity which is translated into a light display within the brain sculpture. In real time it visualises the brain frequencies of Theta (3.5–7.5 Hz) as green light, Alpha (7.5–13 Hz) as blue light, and Beta (16–32 Hz) as red light. Previously, in more traditional art, when an audience views an artwork their own psychological process would be a passive, hidden, private experience. The aim of Brainlight is to harness the brain as the creator of an interactive art experience where no physical interplay is required except for the electrical activity of the mind. The project exposes some key developments in the use of BCI technology for artistic purposes, such as how to accurately collect and process EEG data aesthetically, and what license the artist can take with this data in order to facilitate meaning or allow space for the audience to bring their own meaning to the work. This chapter will explore these developments and outline the collaborative process behind the research and development of the work and the contexts in which it has subsequently been exhibited and used by the public.

Keywords Electroencephalography (EEG) · Brain-computer interface (BCI) · Brain data visualisation · Neurofeedback · Interaction design · Mind-controlled art · Illuminated brain sculpture · Interactive art · Biofeedback art · Art-science · Audience

L. Jade (✉) · S. Gentle
Sydney, Australia
e-mail: laura@laurajade.com.au

S. Gentle
e-mail: sam@samgentle.com

A. Nijholt (ed.), *Brain Art*,
https://doi.org/10.1007/978-3-030-14323-7_8

8.1 Introduction

8.1.1 Technology: An Artist's Tool

Technology and art have always been bound. Art, like technology, shapes and is shaped by the social and cultural environment in which it is created. In recent years, as rapidly advancing technologies become democratised, access to tools that collect biometric data and in particular brain-computer interface (BCI) technology, have expanded the boundaries of what are considered artists' tools. When methods are appropriated from other disciplines (such as science), new artistic mediums are generated. Biosensors that collect heart rate, breath or skin conductance are turning our biological data into mediums for artistic exploration. When brain-computer interfaces (BCI) become the tool, the brain and consciousness itself become the medium for inquiry.

8.1.2 Hybrid Artists and Biologically-Driven Interactive Artworks

In our globalised world, contemporary artists increasingly have access to research outside their field, which is facilitating cross-disciplinary and interdisciplinary practice. This is creating a new ecology of hybrid artists, who use scientific tools to harness the body's bio-rhythms and generate live artistic interactions. Artists creating mind-driven interactive artworks are exploring the capabilities of augmented BCI technologies to interface directly with the brain. The most common technique applied in these devices, is Electroencephalography (EEG)—a recording of small electrical currents along the scalp generated by the synchronous activity of neurons in the cortex—the outer layer of the brain.

One of the earliest and most well-known examples of sonifying brain activity, was conducted by Adrian and Matthews (1934), who listened to human brain alpha oscillations; the sound of which they dubbed the "Berger Rhythm" (after Hans Berger who invented electroencephalography and discovered the Alpha wave in 1924). Subsequently, artists have been among the pioneers of EEG use outside clinical settings, designing situations and applications for EEG use in "real-life contexts" since the 1960s. The composer Alvin Lucier applied Adrian and Matthew's idea in his 1965 work *Music For Solo Performer,* where he amplified his alpha rhythms through percussive instruments for a live audience (Lucier 1976).

Fifty years later, the creative potential of BCI in contemporary art practices has only increased due to the availability of affordable, easy to use EEG technologies. In the last decade in particular, BCI has proliferated across a wide variety of artistic practices. Many artists using BCI are curious to see how their inner mental states can inform their art practice and offer new forms of expression. Sculptural work such as Ian Popian's *Mental Fabrications* (2014) translates EEG data into 3D printed topographical sculptures, exploring how our emotional responses could inform architectural design practices. Random Quark's *The Art Of Feeling* turns the collected EEG data of a person's emotional memory, (such as "the birth of my son"), into digital paintings (Papatheodorou and Chambers 2018). *Neuro-knitting* is a project which translates EEG activity into textiles (Guljajeva et al. 2018). Media artist Refik Anadol's *Melting Memories* (2017) turns EEG recordings focused on long and short term memory into mesmerising large-scale projections and animations. Lisa Park gives the invisible energies of her brain an auditory and visible form in her work Eunoia II (2014) where real-time EEG signals translate Park's changing brain activity into sound vibrations that manipulate 48 pools of water. When describing her work, Park says "I wanted to make a connection that our brainwaves, feelings and sound waves are all frequencies of energies… my work attempts to embody this idea of giving the invisible a physical form to create an external representation of myself" (2014).

These artists are demonstrating how electrical data generated by the brain can be transformed artistically into a wide variety of cross-modal sensory experiences. According to Gsöllpointner, experiencing your brain's electrical activity modified into an artwork can result in an altered perception of the self by inducing "digital synesthesia" (2016). Synesthesia is a phenomenon of perception where sensations experienced in one sensory domain are translated and expressed in another, such as sounds experienced as colours. Digital synesthesia is produced when a sensory stimulus is transferred across other sensory domains by way of a digital interaction. For instance, brain data collected from an EEG can be translated via software into visual images or sounds allowing you to experience the activity of your mind through visual or auditory sensory channels which alters the way you naturally sense yourself.

The virtue of this practice in art lies in its capacity to reveal biological systems that are otherwise imperceptible, offering revelations on aspects of humanness that come from the extension or alteration of the self through technology. Artists working with BCI are contributing to the convergent field of practice that seeks to explore the juncture between art, technology and the mind; a framework that has been defined by Roy Ascott as the "technoetic arts". Ascott says that "the body is no longer a solid biological entity but a technologically connected or enhanced cyborg". Ascott calls "cyberception", "the emergent human faculty of technologically augmented cognition and perception," which acts not only as an extension or enhancement of the senses, but as a unification and distribution of the mind, producing new human faculties (Ascott 1999). Artistic research of this nature may offer new pathways within the field of human computer interaction by introducing novel sensory methods of interfacing with computer systems that aim to amplify human qualities (Vygandas 2018).

8.2 Brainlight

8.2.1 Introduction to Brainlight

Brainlight is an artwork that explores how technology can aesthetically interface with the mind. It integrates biology, lighting design and BCI technology into an interactive brain sculpture, lasercut from transparent perspex and engraved with neural networks. The installation is controlled with a wireless EMOTIV EPOC+ EEG headset which detects and outputs live neural activity, translating electrical signals from the user's brain, into a vivid and dynamic light display within the brain sculpture. In real-time Brainlight visualises the brain frequencies of theta (3.5–7.5 Hz) as green light, alpha (7.5–13 Hz), as blue light and beta (16–32 Hz) as red light (Fig. 8.1).

The project highlights some key developments in the use of BCI technology for artistic purposes, such as how to collect and process EEG data in an artistic context, how to translate it into a live interaction that communicates the data aesthetically (explored in Sect. 8.3), how the work has been experienced in various contexts (Sect. 8.4), and what license the artist can take with this data in order to allow space for the audience to bring their own meaning to the work (Sect. 8.5). Further developments of the work are explored in Sect. 8.6, and evaluation methods and future directions are explored in Sect. 8.7.

8.2.2 Artist Aims

Various methods for exploring the mind have been used throughout human history. Yet most of us live with very little understanding of the underlying processes within our own minds. Consciousness continues to be one of the more enigmatic problems for both the natural sciences and philosophy. One of its most perplexing properties is that it materialises as an intimate, subjective, experiential sense of self (Menon et al. 2014).

Fig. 8.1 Brainlight and the illuminated colours that represent each brain frequency

What can interactive art tell us about the self? According to Rokeby, the interactive artist holds up a mirror to the spectator, resulting in a shifting reflection. These "transformed reflections are a dialogue between the self and the world beyond. The echo operates like a wayward loop of consciousness through which one's image of one's self and one's relationship to the world can be examined, questioned and transformed" (Rokeby 1995).

While all art engenders a relationship between the audience and the work, in Brainlight's case, the audience also enters a relationship directly with the self. The artwork transfers neuro-feedback therapy, a technique used to teach self-regulation of brain activity (e.g. Hammond 2007; Peper et al. 1979), from a clinical setting to an artistic one by creating a sculpture that aesthetically embodies a live visualisation of brain activity, allowing a participant to have an intimate and unique interaction with their inner selves—to "meet their own mind"—externally. The work aims to facilitate a curiosity to know and sense oneself more intimately, while at the same time explores the creative potential of BCI technologies.

Wadeson et al. (2015) identifies four types of user control of artistic BCI's: passive control, selective control, direct control and collaborative control. Brainlight can be classified as a '*selective control*' BCI as users can intentionally control their brain activity through emotion, relaxation or excitement etc. in order to influence the artworks pre-determined parameters. The artwork is partly an extension of the user, however the relationship between the user and the work is externally defined by myself the artist.

Experiencing Brainlight as an audience member invites not just a dialogue with their own mind, but also invites them to question and engage with their experience of BCI technology. Brainlight's visual simplification of the brains complexity through coloured light, makes tangible only a small glimpse of the true reality of the brain's electrochemical processes. The work inevitably reveals a tension between our desire for self-reflection and the inexplicable gap between the physical brain and the ethereal mind.

8.2.3 Communicating Emotion

There is considerable neuroscience research into understanding how humans best communicate with one another (e.g. Sherry 2015). Particularly important appears to be empathetic communication and the transfer of feelings and emotions. The field of affective computing aims to bridge the gap between human emotions and computational technology (Heanue 2018). One approach to communicating emotion via a computer, without using language, is by using pattern recognition algorithms to pick up facial expressions (Ekman 1994) or body gestures (Kleinsmith and Bianchi-Berthouze 2013). Other techniques for non-verbal emotional measurement include, heart rate, blood pressure, temperature, electro-dermal responses and respiration (Molina et al. 2009).

Since the early experiments with EEG on humans in the 1920s, the use of EEG in the study of the brain has been mainly focused on clinical diagnostics and trying to understand neurological processes and functions in a research laboratory environment (Maskeliunas et al. 2016). Only recently has EEG received specific interest for its potential to be harnessed as a communication channel for BCI. The advantage of having access to real-time brain activity with EEG means that a person's current emotional state can become a passive or active method for BCI control (Molina et al. 2009; Mühl et al. 2014). As Gürkök and Nijholt suggest, if art is a way to express emotion (emotions we might not yet understand), then BCI generated art could even help us understand the emotions we are experiencing (2013).

The universal struggle to express our innermost feelings led me to the question of what it might be like to be able to transfer internal states and emotions to one another through BCI communication. As an artistic exploration, Brainlight uses BCI technology to tune in as best as possible to the unspoken, subtle forms of communication of the electrical activity that produces our thoughts and emotions. Despite the complexity of emotions and the limitations of EEG, I was curious to see if a simplification of live brain activity, symbolically visualised through colour, could communicate a sense of a person's inner reality to an audience and generate a meaningful experience. In doing so, the artwork asks the audience to imagine a future where technology may be able to enhance our ability to capture and share inner qualities that are innately human, and inevitably ask themselves whether or not this would be desirable.

8.2.4 Light, Art and the Brain

One of the most fascinating biological relationships is between our bodies and light. We depend on light for all kinds of important metabolic functions, such as vitamin D and melatonin production and maintaining healthy circadian rhythms. Beyond this, light is also our connection to the universe. Through light we can observe distant galaxies, nebulas and look back at the beginning of existence itself.

There is also an interesting connection between light frequencies and brain frequencies. Light is a photon travelling through space in an electromagnetic wave. The visible light spectrum is the particular electromagnetic frequencies that interact with our visual system in order to stimulate the perception of colour. Because colour does not actually exist in nature—it is all generated in our mind—our own brain is essentially collaborating with light in order to perceive the world around us.

Brainlight takes this idea a step further by harnessing BCI interaction to create a neuro-feedback loop of this process of perception. The artwork is activated by your brain's electrical activity; it transforms these electrical frequencies into light waves, which are then re-translated by your brain into colour. The colour which your brain is now seeing, is a visual representation of this very perceptual process, meaning you as viewer bear witness to a real-time loop of your brain transforming the image of your brain transforming the image etc. This is no different to the constant input-output mechanism performed by the visual cortex, with the exception that the input is now also the output. The recursive nature of the feedback demonstrates the potential of artistically devised interactive technologies to bring us closer to the pure process of perception itself.

8.2.5 Communicating with Colour

Brainlight displays, as coloured light, a live stream of dominant brain frequencies, creating a neuro-feedback loop between the artwork and the viewer. Red, blue and green (RGB) light was chosen to represent the brain states beta, alpha and theta respectively, in order to make use of the artistic symbolism associated with each colour.

Because of connotations with speed, fire, heat and intensity, the colour red was used to represent beta (16–32 Hz) frequencies, which have a higher energy and can signify states of alertness and intense emotions such as excitement and stress (Alonso et al. 2015; Ray and Cole 1985). Dominant alpha oscillations (7.5–13 Hz) have been correlated with calm, meditative and relaxed states, particularly in the occipital channels when the eyes are closed (Ahani et al. 2014; Chiesa and Serretti 2009; Khare and Nigam 2000; Lutz et al. 2007), and so the colour blue was chosen due to its association with peace, introspection and tranquility. Green, symbolic of nature, was used to represent Theta (3.5–7.5 Hz) which has been linked to a large number of cognitive processes, such as integrating affective and cognitive sources of information in working memory tasks and action monitoring (Cavanagh et al. 2011; Kawasaki et al. 2010; Klimesch 1999), heightened expressiveness and creativity (Gruzelier 2008; Gruzelier et al. 2014) and deep meditation and present-moment awareness (Cahn and Polich 2006) to name just a few.

As RGB are the three primary colours of light, they have the added benefit of being visually distinct, allowing each dominant brain state to be communicated clearly.

The electrode positions on the EEG headset were mapped to corresponding positions on the brain sculpture via the projected light. The dominant frequencies in each electrode could then be individually visualised, creating a dynamic multi-coloured array of light displaying the rhythm and movement of the dominant electrical activity emanating from the brain.

Although the software doesn't explicitly mix the colours in the sculpture, early in the process we were surprised to notice additive secondary colours emerging when neighbouring regions of the brain were displaying different dominant frequencies. This allowed for interesting subjective meanings to be created by audience members. One example, at Illuminate, a light festival in Wagga Wagga, Australia, an 8-year-old girl was asked to imagine what made her most happy, after which the entire brain sculpture radiated a warm magenta light. She told us she was thinking about her guinea pig, which she loved very much. The magenta was created because her brain produced equal amounts of calm alpha frequencies (blue light) and excited beta frequencies (red light), and the coincidental mixing of the two states appeared to communicate a "loving" state of mind to the audience.

The nature of this subjective interpretation opened up interesting questions in relation to public interpretation of the data and my role as an artist facilitator in allowing subjective meaning to be created during an individual's personal experience with the Brainlight. (This is explored in more depth in Sect. 8.5.)

8.2.6 Limitations of EEG

It should be mentioned that analysis and interpretation methods for EEG are still limited and a consensus on the relationships between complex cortical dynamics sensed through an EEG is not apparent in the literature. It is well established that EEG is best suited for sensing fast temporal dynamics, which makes it ideal for interactive artworks which rely on fast and responsive feedback in order to facilitate a perceivable interaction with an audience. In this respect, EEG works well for studying responses to stimuli by showing real-time changes in regular brain activity (Zioga et al. 2014).

In contrast to high temporal resolution, a significant limitation of EEG is poor spatial resolution. EEG is most sensitive to the electrical activity produced in the outer layers of the cortex which means that the activity produced by deeper structures inside the brain contribute far less to the EEG signal. Because of this we can only observe how the outer brain signals change in response to various types of activities or stimuli and then make inferences about the brain processes involved in such situations. Indeed, it is very unlikely that a single cerebral rhythm is associated with a specific cerebral function, particularly when it has been shown that even single neurons have the ability to oscillate at multiple frequencies (Mantini et al. 2007).

In an article by Herrmann et al. (2016) the authors state that "almost every cognitive process has been associated with an event-related EEG oscillation. However, there are many more different cognitive processes than the five different well-established frequency bands (delta, theta, alpha, beta, and gamma). Therefore, it is obvious that one cannot establish a 1:1 mapping between cognitive processes on the one side and EEG oscillations on the other side. It is more likely that EEG oscillations contribute to different cognitive functions depending on where in the brain and with what parameters (amplitude, frequency, phase, coherence) they occur."

In light of this, Brainlight's visualisation of theta, alpha and beta frequencies and the associations with particular conscious states referred to throughout this chapter, are based on the most frequently replicated and widely accepted findings within the literature.

Another limitation that should be mentioned is that EEG recordings can easily pick up noise and non-brain artifacts such as signals produced by muscular movement, heart activity or other exterior disturbances that interfere with the purity of the signal. Commercial grade EEG headsets are particularly prone to this and therefore offer only a rudimentary accuracy. According to Stamps and Hamam (2010) the EMOTIV EPOC+ is the most usable low cost EEG device and Maskeliunas et al. (2016) show that it performed better in attention/meditation tasks than other devices of similar value on the market. Duvinage et al. (2013) demonstrated that the EPOC's performance is above random and is therefore suitable be used for gaming or for communication for the disabled. It is for these reasons that we chose to use EMOTIV.

It is also worth noting that EEG frequencies in humans vary widely according to the brain anatomy of the person, stress, mood, age, neurological diseases, memory performance, therefore any specific analysis of EEG must be interpreted with caution (Klimesch 1999).

It seems unavoidable that BCI technologies will continually need a high level of processing and human decision making in order to interpret the raw data and extract meaning from it. Unlike heart monitors (ECG) or electrodermal sensors, which access a more direct expression of a person's biological inner life, EEG devices may never accurately "read our minds" in a pure sense due to the distortion inherent in interpreting EEG signals. Despite this, it seems likely that future advances in our interactions with computers through BCI will become ever richer as we increase our understanding of the brain's inner states (Mühl et al. 2014).

8.3 Context and Collaboration

8.3.1 University of Technology, Sydney and Culture at Work

Brainlight was created as a research project for a Masters of Design in Lighting at the University of Technology, Sydney (UTS). Two professors were of particular influence in their unique approach to technology and lighting design, Michael Day, head of the Lighting Studio, and Bert Bongers, leader of the Interactivation Lab, both in the faculty of Design, Architecture and Building.

Alongside UTS, Brainlight was created through Culture at Work's (CAW) 2015 art + science residency program. CAW is a non-for-profit organisation that connects art and science through artist residencies, educational programs and exhibitions. The residency provided mentorship, curatorship, and a studio space for four weeks, followed by a two-week exhibition at CAW's Accelerator Gallery.

The values of both these institutions, in terms of encouraging experimental cross-disciplinary practice as well as the conditions they provided, such as access to new research, were highly influential in Brainlight's creation. It is important that environments such as these continue to encourage and engage in innovative methods of working, where experimental, cross-disciplinary collaborative projects can be nurtured and explored.

8.3.2 The Collaborative Process

An interdisciplinary approach was important in the research and development of Brainlight. The team included software engineer Sam Gentle, neuroscience and medical innovation researcher Peter Simpson Young, industrial designer Neill Wainwright and electronics engineer Sami Sabik.

One of the most important aspects of collaborating with an interdisciplinary team is learning how to communicate. In order to understand each other we needed to spend time learning each other's disciplinary approach; grasping new vocabulary, language and terminologies in the process. As the artist, being able to communicate aesthetic ideas and conduct experiments with the lighting visualisations required grasping the possibilities and limitations of the software architecture that Sam was designing. In turn, he had to learn to work within an iterative artistic framework by designing software that allowed for versatility.

A large part of my role was synthesising everyone's input in order to realise an over-all creative vision, balancing what was inherently important to each discipline and cultivating alternative directions to tackle obstacles. Different components of the project also moved at different speeds and here communication was particularly important for remaining on schedule and maintaining momentum.

Brainlight required three key components to come together:

1. The design of the physical artwork, including a brain sculpture, portable base and lighting system.
2. The science of electroencephalography (EEG), data collection and processing.
3. A soft and hardware architecture to transform EEG data into a light display.

Neill Wainwright assisted with the 3D development and design of the physical sculpture. Using an MRI scan of a 35-year-old healthy male we translated the 3D model into a slice-form which was laser cut out of clear 5 mm perspex (see Fig. 8.2). The brain sculpture consists of 25 vertical slices that slide into a central

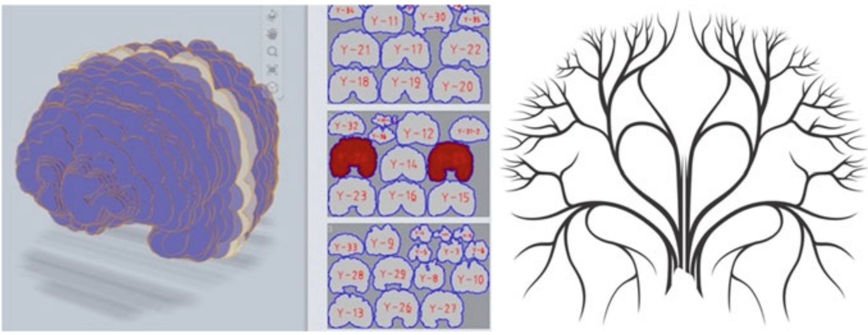

Fig. 8.2 Slice-form brain sculpture (left) created from an MRI brain scan and neural network design (right) laser etched into each brain slice

spine which delineates the right and left hemispheres. Each slice is etched with neural pathways creating the illusion of a three-dimensional neural network within the sculpture (Fig. 8.2).

Peter-Simpson Young guided us on the anatomical and neuronal organisational structure of the cerebral cortex (and its various sensory, motor and cognitive functions) and then advised us on current neuroscience research into EEG technology and its capacity for capturing the electrical activity associated with different brain states. We tested several low-cost commercial EEG headsets, which had between one and four channels but decided that their resolution and feedback potential was too limited, instead choosing to work with an EMOTIV EPOC+ which provided a better EEG resolution via its 14 channels.

Sam Gentle developed the custom software and hardware architecture (detailed in Sect. 8.3.3). A Raspberry Pi was used to run the software which processed the raw EEG data received wirelessly through a USB. The visual output was sent over HDMI to a 5000 lm data projector which was positioned above the brain sculpture.

An important quality of the collaboration was the mutual gain that emerged from learning about each other's disciplines, as well as extending our skills in our own practices. Seeing one discipline through the lens of another can offer valuable perspectives and new insights.

After our collaboration it is interesting to note how the payoffs for each collaborator varied. As Brainlight is primarily an artwork originally designed to be experienced in an art gallery, the recompense for myself as the artist are the rewards of the art industry; exhibitions, invitations for artistic performances and conferences within that field. While these were valuable to myself as an artist by way of career development, these rewards were less valuable to the other collaborators. However, indirect benefits for the team emerged later in the form of further collaborations and career opportunities. Sam became creative technologist in residence at CAW, moving away from commercial software development to develop his own artworks. Peter and Sam worked together on a BCI sound project titled "Mind Music" for Spotify, and Neill and Peter are currently developing a non-invasive brain stimulation device within the Science Of Innovation Lab at UNSW, Sydney.

8.3.3 EEG Processing

EEG signals were acquired from the 14 channels of the EMOTIV EPOC+ at 128 Hz, 14-bit resolution. We used a 5th-order Butterworth filter to remove frequencies below 3 Hz which are more vulnerable to noise and artifacts. We further improved signal clarity by applying a Blackman-Harris window function and a fast Fourier transform at 0.5 Hz resolution to deconstruct the time domain of the EEG signals into the frequency domains of Theta (3.5–7.5 Hz), Alpha (7.5–13 Hz), Beta (16–32 Hz).

8.3.4 Software Architecture

Creating software and hardware systems for artworks requires flexibility and stability. To support creativity, a system must be able to respond to its artist, to iterate and improve as the work takes shape. However, an exhibition demands a system that is reliable and predictable. Neither audiences nor artists want a canvas that reboots to apply updates, or suddenly fails during a show and cannot be replaced.

Achieving both stability and flexibility in a single system is difficult: if it is easy to change on purpose, it also tends to be easy to change accidentally. It is possible to overcome this problem by creating one larger system out of a number of smaller systems, known as modules.

In our system, the modules were completely independent, so that editing one component of the software did not require a complete overhaul of the entire code. For example, the "epoc" module, responsible for acquiring the EEG data, hardly changed at all during the design process. The "freqs" module, which did the bulk of the data processing, changed more often as we experimented with time-delays and neuro-feedback potentials. While the "vis" module, which displayed the visualisation, was in a state of constant flux until the final artistic output was chosen. This independence allowed each individual module to have its own trade-off between flexibility and stability. Key to this was the knowledge that changes in one module could not cause problems in another.

Despite changes and tweaks to the system right up until opening night, it worked without failure or further modification, not just during that exhibition, but through years of subsequent exhibitions both locally and internationally.

8.3.5 Visualisation

The visualisation needed to achieve the aesthetic goals of the artwork, while communicating the brain's activity as accurately as possible, while working within the limitations of the hardware.

To make the visualisation fast and responsive, we tuned our signal processing to achieve a compromise between accuracy and speed, but even so it took 2 s of EEG data to produce 1 frame of visual output, an unavoidable limitation of the Fourier transform. To work around this, we used pipelining: multiple overlapping transforms running simultaneously. For example, one transform could run from 0:00 to 0:02, another from 0:01 to 0:03, 0:02 to 0:04, and so on. The processing still takes 2 s, but because of the overlap there is an update every second. In fact, we overlapped 8 transforms so the data would update 4 times per second.

Although 4 updates per second is quite fast by EEG standards, it is slow for animation, where rates of 25, 30 or even 60 frames per second are common. It became clear as we worked with the perspex sculpture, that it looked best having rapid changes in brightness, colour and movement which caused the light to twinkle

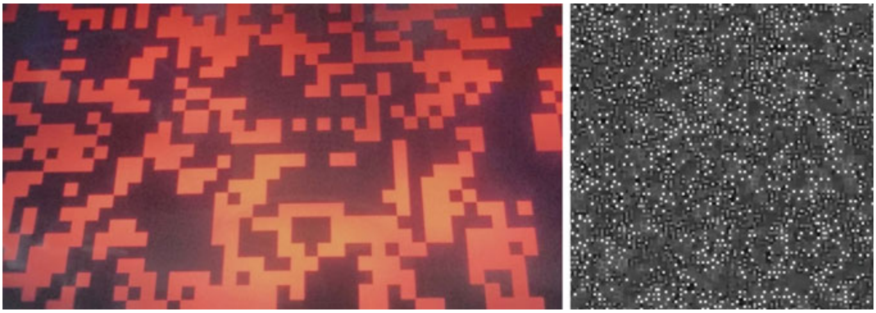

Fig. 8.3 Still images of cellular automaton patterns used to animate *Brainlight's* visualisation of EEG data

and reflect between its interior surfaces. To bridge this gap, we added an additional layer of animation based on cellular automata.

A cellular automaton is a grid of cells, where each cell obeys rules governing its interactions with its neighbours. By carefully tuning the rules, it is possible to achieve a variety of organic patterns. In our case, the grid nature of cellular automata matched quite naturally to pixels on a projector, and the organic movement complemented the behaviour of the EEG data.

The final visualisation consisted of a cellular automaton animation layer (Fig. 8.3), which created organic patterns of light and dark using colours derived from the EEG frequency bands layered on top. This layering technique allowed the animated visuals to make the best aesthetic use of the perspex brain while still providing a clear representation of the underlying EEG data.

8.3.6 Visual Experimentation

During the four-week residency at CAW we developed interactive interfaces which translated the electrical data from the EEG headset into various forms of visual communication, including projections (Fig. 8.4), prototype brain maquettes (Fig. 8.5) and the final Brainlight sculpture (Fig. 8.6).

8.3.7 Testing Prototypes

During the CAW residency we had several opportunities to engage with the public and test the prototypes we had created for visualising brain activity. In May 2015, during Pyrmont festival, we presented Cerebral Orb (see Fig. 8.4), a circular light projection that allowed participants wearing the EEG headset to observe their dominant brain frequencies (mapped to corresponding locations within a circular light

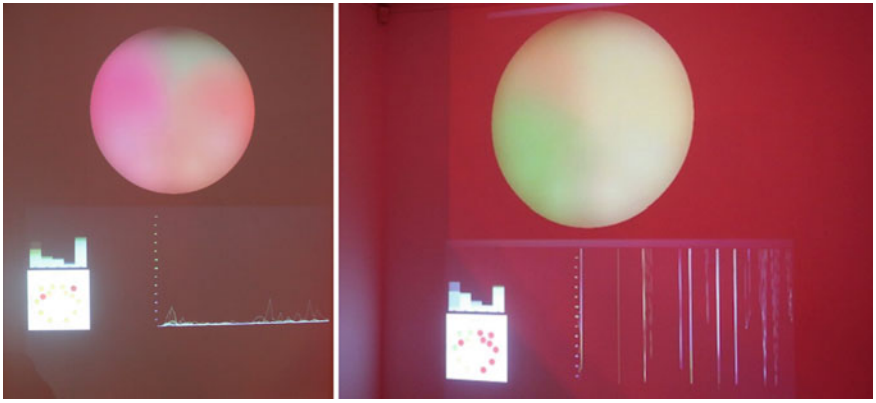

Fig. 8.4 *Cerebral Orb*, interactive light projection and EEG frequency graph

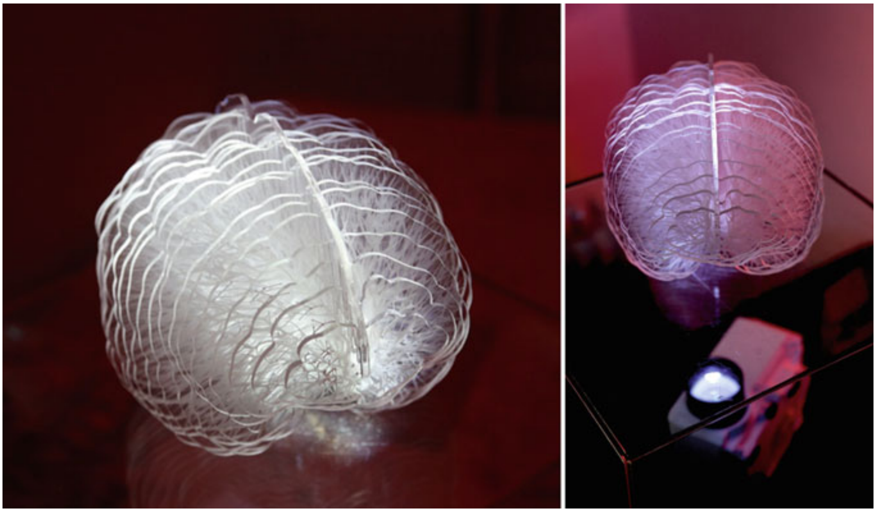

Fig. 8.5 *Cerebral Nebula*, laser-cut and hand-etched perspex

display) change colour depending on their state of mind. A second projection displayed a graph showing the frequency ranges as well as the connectivity level of the EEG electrodes to the scalp in order to present a measure of the connectivity of each electrode and the purity of the signal.

As interactive artworks invite audience participation there is a level of unpredictability in how they will be used. In the case of Brainlight, in order to observe as wide a range of natural interactions as possible, I gave very little guidance to the public other than a basic understanding of what the headset was capturing and which colours correspond to which frequencies. There was substantial variation in how the public approached the artwork. Some were nervous about what might be

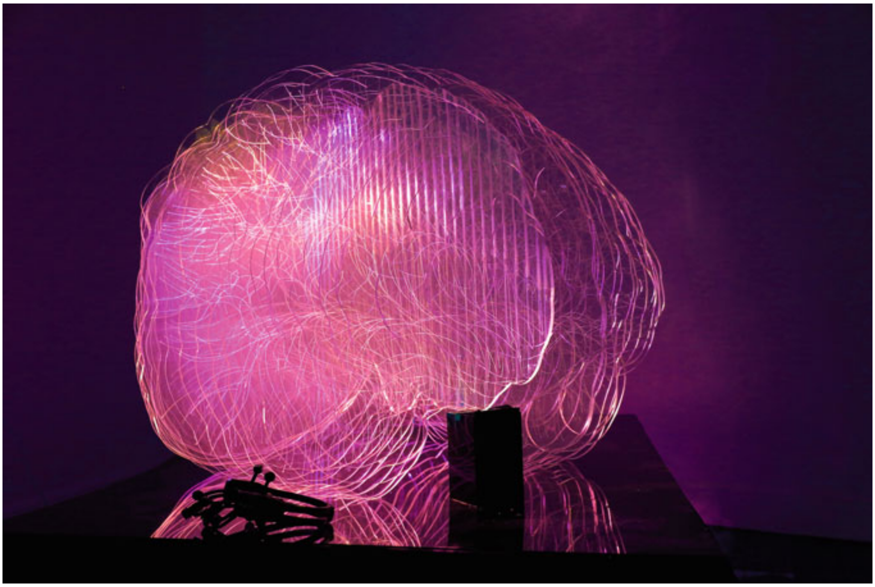

Fig. 8.6 *Brainlight*, laser-cut perspex, 120 cm × 120 cm × 110 cm

revealed, leading to cautious interactions, others were more outgoing and curious, eager to experiment and stimulate their own brain in order to activate colour changes. Some gained a level of control over their mind by using the visual neurofeedback to practice retaining particular states, while others found it challenging to gain any sense of control over the work.

This test period was useful for two reasons. First, it enabled us to see a much wider spectrum of brain activity with noticeable variation from person to person in terms of rhythm and frequency dominance. Second, it gave me a chance to observe audience behaviour, which informed the way I facilitated future interactions with the work. It allowed me to develop a sensitivity towards different participant's temperaments and to test a range of emotion or memory based "triggers" in the form of questions that stimulated people to access different brain states in order to more easily see the resulting colour change (discussed in Sect. 8.5).

8.4 Exhibition Journey

Since the launch in 2015, Brainlight has been experienced in a wide range of contexts; from science museums, art galleries, festivals and conferences, to universities, schools, corporate offices and private homes. Each of these settings have their own cultural codes and conventions which influence the interaction, interpretation and response to Brainlight, affecting the aesthetic impact of the work and its subjective meaning and significance.

In Australia, Brainlight has exhibited at a number of Sydney's cultural institutions, including The Museum of Contemporary Art, The Museum of Applied Arts and Sciences (an institute focused on the impact of technology, engineering, science and design), The Australian Museum (the oldest museum in Australia dedicated to anthropology and natural history) and Vivid Light Festival Ideas Conference on neuroscience and creativity.

Internationally there have been further opportunities to exhibit Brainlight in contexts that specifically celebrate the nexus of art, science and technology, including Hoy Es Diseno (Design of the Future) in Cali, Colombia, Ars Electronica Festival, Austria, Athens Digital Art Festival, Greece, Starmus festival, Canary Islands and GOGBOT (AI and Robotics festival), Netherlands.

An important characteristic of Brainlight has been its ability to create links from one disciplinary context into another by generating integrative dialogues with the public. Within the domain of art, audience members have often asked me more questions about the scientific or technological aspect of the work than the artistic. Surprisingly, I have found the converse to also be true and have ended up in numerous discussions about art history, the nature of beauty and aesthetic sensibilities with neuroscientists and computer programmers.

8.4.1 Brainlight and the Sydney Art Quartet

Playing and listening to music is a multi-sensual experience involving numerous higher order, motor and sensory areas of the brain which stimulates emotions, memories, and drives reward centers (Chanda and Levitin 2013). There is even neurochemical and physiological evidence to suggest music may have played a central role in the evolution of the modern human mind (Cross 2006; Harvey 2018). In light of this, collaborations between BCI and musical performers have provided opportunities to explore the links between music and the brain.

Since Lucier's sonification of brain signals in 1965, a wide variety of experimental brain-driven interfaces for musical expression have been created. Among these, many use EEG signals as a trigger for music generation, such as the MoodMixer by Leslie and Mullen which composes new music based on the combined EEG signals of multiple participants (2011). To a lesser extent, brain-driven interfaces have been created in order to show or study music's effect on the brain (Mullen et al. 2015). One example is Ringing Minds (2014), a collaborative installation by David Rosenboom, Tim Mullen and Alexander Khalil which uses the collective brain responses of multiple audience members listening to music to influence a live music composition.

In 2017, Brainlight was invited to perform with the Sydney Art Quartet (SAQ) in a series of three evening concerts titled *Light Fantastic: Music + Neuroscience + Light* (see Fig. 8.7). The performances focused on the concept of "genius" in music; bringing to life five to five-hundred-year-old compositions, from Beethoven

Fig. 8.7 *Light Fantastic: Music + Neuroscience + Light*, Brainlight performance with Sydney Art Quartet

to Bach, Dvorak to Tool. The music was chosen to contrast the historical with the contemporary as well as the technical with the emotive. The role of Brainlight was to visualise the brain activity of the musicians performing in order to compare it to the brain activity of the audience listening.

Across three evenings, Brainlight exposed some remarkable differences between the brain patterns of the musicians and the audience. Lead cellist (and SAQ director) James Beck wore the EEG headset for the first two compositions. His performance was both technically complex and highly emotive, yet rarely did Brainlight flicker into the upper frequencies of beta or alpha (associated with highly analytical and calm states of mind respectively) remaining instead in a dominant state of theta.

Similarly, when the headset was placed on violinists Anna Albert and Thibaud Pavlovic-Hobba, their brain activity remained in a steady state of theta throughout their performance with very little dynamic fluctuation (Fig. 8.8).

The audience members who subsequently wore the EEG headset displayed a remarkable contrast; exhibiting unstable fluctuations of predominately higher frequencies (alpha and beta) suggesting a larger, more constantly changing range of brain activity and emotions. Visually this contrast was obvious, having remained bright green while worn by the musicians, when the headset was passed to the audience Brainlight began cycling quickly through red and blue, often displaying all three colours simultaneously, visualising the varying emotional and physiological reactions to the music's own fluctuations in mood and rhythm.

Fig. 8.8 SAQ and Brainlight performance featuring violinists Anna Albert (wearing the EEG) and Thibaud Pavlovic-Hobba

The collaboration between SAQ and Brainlight demonstrated how BCI technologies can visualise underlying neurological phenomena in musical performance, adding a new layer of interest for the audience by revealing the hidden differences between performing and listening to music.

8.4.2 Brainlight and Science Communication

Science exhibitions and museums are increasingly employing tangible interactive technologies in order to provide a higher engagement with information. As Wellington has previously illustrated, "one of the achievements of hands-on science centres has been to relate science and technology to the things that most people see and use" (1990).

In 2018, the University of Nottingham's "Quantum Sensing the Brain" exhibit at the Royal Society's Summer Science Exhibition in London included an immersive "brain room" where visitors could wear an EEG headset and perform some basic actions to influence an illuminated installation to learn how the brain works (Brookes 2018). Exhibitions such as this demonstrate how interactive models are playing an important role in a learners' investigation of complex phenomena (Fleck and Simon 2013).

Brainlight has proven to be a captivating medium for science communication and public engagement with neuroscience. ABC's Catalyst (an Australian national science communication television series) used Brainlight in an episode titled "Brain Stimulation" featuring scientists (including Brainlight collaborator Peter Simpson Young) discussing brain-enhancing devices. In a follow up episode titled "Sleep

Matters" they used Brainlight's colour coded light display to communicate brain activity cycling through the stages of sleep.

The work has also acted as a creative stimulus in more unusual scientific encounters. In 2017, I was invited by Professor Avi Schroeder to the Technion, Israeli Institute of Technology, to present Brainlight to his research team. Schroeder's research lab is focused on nanotechnology for targeted medicine, creating miniature medical devices that can couple diagnosis and therapy, called theranostic devices. These drug-loaded nanoparticles can be remotely triggered with ultrasound to release an anti-cancer chemotherapeutic inside tumours (Schroeder 2018). Schroeder's interest in Brainlight was to take his researchers out of the traditional scientific realm in order to encourage them to think laterally and creatively about the brain's natural frequencies and how they might be harnessed for nanomedicine. Utilising Brainlight, Schroeder asked his lab researchers to consider the possibility of using neurofeedback training to trigger a medical therapeutic device targeted to a tumour site within the brain.

Brainlight has also recently been commission by Dr. Adrian Ivanescu, assistant professor of Anatomy and Embryology at the University of Medicine and Pharmacy in Târgu Mureş Romania. Ivanescu is planning to use the artwork as an educational tool for his students and has since presented it at their annual NEURON conference (Neuron 2018).

8.4.3 Experiential Learning and Education

Brain activity is hard to understand because it cannot be sensed like other bodily systems, for instance respiration, therefore it needs to be conceptualised (Frey et al. 2014). BCI technologies are creating interesting opportunities for experiential learning and education by creating new methods of conceptualising the brain.

Teegi (Tangible EEG Interface), for example, is a project that uses a tangible character to visualise and analyse a user's brain activity in real-time through various EEG filters, such as motor, vision and mediation (Frey et al. 2014). The project also enables users to better understand the kinds of brain activity that can be detected in EEG signals in order to demystify BCI technologies.

Brainlight provides a similar interactive educational experience and has been developed into a workshop for primary and secondary students. In the Brainlight workshop, students are invited to interact with the artwork and partake in stimulus activities such as puzzles, maths problems, memory games, and emotive role play in order to predict and observe the changes in brain activity. In the process, students are introduced to the concepts of neuroscience, brain anatomy, emotional intelligence, mindfulness, data visualisation and BCI technologies.

Both Teegi and the Brainlight workshop demonstrates how biologically-driven interactive models can offer students tangible, memorable and novel opportunities for self-discovery by stimulating a unique engagement with their own bodies and minds.

8.5 Brainlight and the Audience

Brainlight's interactive method of using a person's mind to co-create the work, challenges the traditional role of an audience member. Typically, the viewer's psychological process is a private experience, hidden from the rest of the audience. Brainlight harnesses this passive experience, transforming the electrical activity that defines it, into the artwork itself, on display for all to see.

Since 2015, approximately 3200 people have used the artwork as a participant and an estimated 20,000 people have viewed it in exhibitions around the globe. On average, people tend to spend about 10 min with Brainlight, but in settings outside the gallery, away from crowds, it's not uncommon for people to spend an hour or more with the work.

During public showings of Brainlight, I often experiment with emotional cues by asking the participant to imagine scenarios relating to their lives, or to relive a memory. For instance, getting the participant to re-imagine the feelings they experienced during the birth of their first child; thinking of something that brings them a sense of peace; imagining a stressful scenario. As they settle into the feeling associated with the memory, the brain activity associated with that feeling affects the colour of the sculpture, allowing onlookers to witness an externalized embodiment of the participant's emotional state.

On many occasions participants have been able to identify emotional states that emit strong dominant frequencies permitting them to cycle through the different colours at will. Typically, this is achieved when the participant spends a few minutes experimenting with thoughts, memories or mental challenges until they find one that stimulates the desired colour. With practice, some people are able to hold on to that particular brain state and maintain the brain sculpture in the desired colour. Perhaps the most common state I've found people—(including children)—are able to maintain, are Beta waves (the highest level of active cognition, shown as red light) when attempting to solve a challenging mathematical problem.

Because interactivity in art, particularly with works that employ EEG, is a relatively new concept for some people, some approach the work with skepticism, requiring proof of its interactivity. As Rokeby suggested, the proof that will most easily satisfy the audience is 'predictability' (i.e. if one makes the same action twice, the work will respond identically each time) (1995). This test only works with Brainlight if a person's brain produces the same signal on their command, which is not a straightforward task. As Rokeby further observes, "the complexity of this relationship is, in this case, not so much a function of the complexity of the system, but of the complexity of the participants themselves" (1995). Whether Brainlight is seen as interactive or not is therefore highly dependent on the quality of the behaviour of the audience.

8.5.1 Emotion and Cognition

Emotion is core to the appreciation of art, “from ancient to modern times, theories of aesthetics have emphasized the role of art in evoking, shaping, and modifying human feelings” (Silvia 2005). The field of neuroaesthetics has shown complementary neurological pathways work in tandem to create both conscious and unconscious aesthetic response; “the cortical pathway, which leads to recognition and conscious thought; and the thalamo–amygdala pathway, which gives emotional colour and meaning to all information that passes through our senses” (Barry 2006).

Experiencing art nourishes our psychological needs which elicits a certain intrinsic pleasure. It provides a “sensory anchor” for our thoughts and emotions by inviting personal involvement with its affective impact (Perkins 1994). In artistic applications, BCIs can satisfy our psychological needs by having ‘influence’ over our affective state as well as giving users new creative abilities to express emotions (Gürkök and Nijholt 2013).

Brainlight’s interactive BCI creates a relationship between a viewer’s inner state and their influence on the artwork. Placing the audience at the center of a live neurofeedback interaction not only challenges the participant to witness and confront their own emotional state and aesthetic response, more interestingly, it challenges their ability to have agency over it, inviting them to experiment with methods of emotional regulation and control.

While the idea of control was not the initial intention of Brainlight (rather the intention was to have an encounter, whatever that encounter may be for one person or another) I have noticed that the artwork can provide a person with a sense of power when they gain control over the interaction. The opposite is also true, when someone does not gain control of the work, it can elicit a feeling of being powerless or out of control.

Our aesthetic response is deeply connected to the universal drive for pattern recognition. As Barry explains, “the brain is a meaning-seeking mechanism, and this suggests that recognition of pattern is at the heart of all perception, the process by which we make meaning from both stimuli from the outer world and prior experience stored in memory” (2006).

Our innate search for synthesis seeks to reduce complexity into its simplest form in order to understand it. In the same way, Brainlight simplifies the electro-chemical activity of the brain into a colour coded visual experience. The audience then attempts to make sense of patterns generated by a complex mix of brain activity which includes perceptual responses, memory and emotion. What becomes interesting is how audiences attempt to create a narrative and recognise a pattern that signifies personal meaning for them. Their desire for pattern recognition happens at the same time as their mind, emotions and subjective interpretation continually influence the artwork.

8.5.2 Games and Competition

For many participants, once they realise they can affect change within the artwork, the ability to control the colours on display quickly becomes the focus of the experience, rather than to explicitly attain awareness and control over their thoughts. Often audience members become competitive, trying to see how quickly they can get the artwork to respond, how long they can retain a colour and how easily they can go back and forwards between colours at will. This focus on controlling the colours may be partly due to the expectations I set up when explaining the artwork to participants, or it may be because controlling the colours is the most obvious, novel and satisfying outlet for creative interaction with the work.

Amusingly, audience interaction tends to become most gamified around the calm and meditative blue alpha state, which in a busy gallery, is usually the most difficult to accomplish. In order to experience this state, users need to contend with the many obstacles within the exhibition environment: eager onlookers, the brightly illuminated sculpture, the novelty of the situation, exposure to other sensory stimuli (such as noise), as well as their own state of mind and how comfortable they are being the spectacle in the room. Interestingly, when a participant does manage to attain the blue state, they must master their excitement in order to prevent the brain from switching immediately to red. This effect happens the other way around as well, and it is perhaps one of the most interesting manifestations of the feedback loop. Witnessing one's current state of mind, so often changes it.

This scenario is the focus in Hjelm and Browall's Brainball project (2000) where two players wearing EEG's must remain calm in order to win a competitive game. The tricky part of the game is that the players must master their ability to relax at the same time as competing. When a player gets close to winning they get excited and so a considerably excited player will be at a disadvantage.

Alongside competition, one of the reasons Brainlight has been so popular with the public may be attributed to our natural curiosity for self-knowing. I have observed that most viewers want to learn if they have "good" brains, they want to test their level of self-control; many seem to use it to demonstrate their "meditation prowess" to their peers. I have noticed though, that the more time someone spends with the work, the more they move beyond a superficial appreciation, to genuine curiosity about the inner workings of their mind.

8.5.3 Spectatorship and Surveillance

Trust is a central dimension in the relationship between human beings and technologies (Moritz 2017). Many of us have concerns about how we actively share our data and our ability to retain a level of control over what we choose to share. When people are faced with an interactive artwork, in the process of interacting they reveal something about themselves (Rokeby 1995). Brainlight is an example of a technology that "quantifies the self" by providing a level of self-reflection in exchange for participatory public surveillance in an exhibition context. During a Brainlight interaction an observer wearing the EEG becomes a "performer" and their mind becomes a public spectacle.

The spectatorship dynamic between audience and user means that some people feel a need to self-regulate their behaviour in order to try and retain a level of privacy. They do this by attempting to regulate their thoughts and emotions, as well as by limiting how much they verbally share about themselves to myself and the surrounding public. For an audience member to agree to participate in the experience they need to have a level of trust in the process of the collection, and display, of their personal data and how that data is situated in the view of the crowd's subjective gaze.

I have noticed a participant's level of trust is usually proportionate to their understanding of what EEG technology is capable of detecting and displaying about them. People who are not familiar with the limitations of EEG often believe that the artwork is revealing more about their inner self than it actually is. Because of this, people's fears and anxieties occasionally come to the fore—perhaps their mind would appear "abnormal" and embarrassing, perhaps intimate details about their emotional state or the type of person they are would be revealed to strangers. On many occasions these people have displayed a greater sense of awe towards the experience, viewing the artworks ability to "read one's mind" as an almost "mystical" quality of the technology.

Research has shown differences in art appreciation among those with artistic training and expertise compared to those with no expertise, revealing its influence on aesthetic engagement, interpretation and judgment (Else et al. 2015). In the case of Brainlight, I noticed that the viewers level of scientific expertise played a key role in influencing their response in relation to fears of surveillance. People who had neuroscience expertise, an understanding of EEG technologies or a higher level of scientific literacy, could appreciate the work for its novel visualisation of brain activity, tempered by an understanding of the current limitations of the technology.

While the inherent limitations of EEG mean we can't yet decode complex thoughts, we can already make assumptions about a person's mood, and it's possible that we may succeed in understanding more of the brain's complexity over time. An emerging neuroethical debate is starting to permeate the BCI research community about the possible misuse of BCIs in the future (Tamburrini 2009). Much of the debate is focused on ethical concerns regarding BCI as a medical intervention for locked-in patients, assistive therapies or BCI controlled prosthesis. However, as BCI is becoming more prevalent in popular culture, the perceived risks that relate more to the general public are also being explored (Nijboer et al. 2011). Social issues such as mind-reading and privacy, mind control, selective enhancement and social stratification are just a few examples.

An interactive theatre performance titled Noor: A Brain Opera addresses these ideas more directly by asking the question "is there a place in human consciousness where surveillance cannot go?" (Pearlman 2017). Similar to Brainlight's setup, a performer wears an EMOTIV EEG and as their brain state changes so does abstract video footage. The changing colours signify different emotions: yellow for excitement, pink for interest, turquoise for meditation, and red for frustration. The performance encourages the audience to consider a future where mental surveillance is possible.

Dunn states that "art can open us up to new ideas and beliefs, and artists can make a massive impact as role models, either in a positive or a negative manner. Because art communicates with us on so many different levels, and appeals to our senses, emotion, reason, language and imagination it inevitably affects us more than other areas of knowledge" (2013). The value and impact of art is highly determined by what the public bring to it with their prior knowledge in combination with the subjective meaning they generate from it. Works such as Noor and Brainlight do not provide concrete answers or positions, rather they provide space for audiences to formulate their own questions.

Interactive artworks that are highly engaged with by an audience, like Brainlight, are facilitating "interactive literacy", allowing the public to experiment with possible future relationships with technology. Having interacted with technologies at the experiential level, audiences may then have a better understanding and a deeper engagement with global issues around emerging technologies. Because these issues are likely to become more complex in the future, "understanding autonomy and feedback and permeability and transparency and internalization of tech and externalization of self are all things we need to become literate in if we are to make good decisions" (Ekman and Rokeby 2014).

8.5.4 Metacognition, Subjectivity and Intimacy

An encounter with Brainlight permits people to have a moment of self-reflection, occasionally providing a level of higher self-analysis that results from seeing their "mind" as an entity outside their heads. This third person perspective stimulates people to have a conversation with their own mind, whereby Brainlight acts as a symbolic "oracle" that embodies their own process of metacognition. This process has often stimulated personal insights or created new meaning around a participant's own thoughts and memories.

Indeed, in this context, the subjectivity of a person's interpretation becomes the work itself. Time spent with Brainlight allows a person to establish a personal identity with the work which becomes a reflection of their thoughts, feelings and presence.

The ambiguity involved in the audience's interpretation of their own brain data through the artwork raises interesting questions about accuracy versus subjectivity in "science inspired" art, and how bio-sensing technologies can mediate our subjective identities (Moritz 2017).

I realised early on that this blurring of personal interpretation and scientific accuracy would become a feature of Brainlight when I noticed participants were often eager to furnish the interpretations of their brain signals with their own subjective speculation about what might be driving their mind's behaviour.

Audience members revealed stresses they were under at work, stories of heartbreak and grief, aspirations and fantasies; stories unique to each person, but common to the human condition. Many of the interpretations participants brought to the work were deeply personal and unlikely to have been volunteered to a room full of strangers under ordinary circumstances. The nature of these intimate exchanges demonstrates how art and art spaces allow people to explore vulnerabilities that might remain concealed in other public social settings (Khut 2006).

This vulnerability raised further questions about my role as an artist in facilitating the interpretation of the artwork: how much should be explained and how much space should remain for people to generate their own meaning? While Brainlight uses traditional scientific tools to explore the mind, the artistic and aesthetic framework attempts to strike balance between providing a level of scientific validity and leaving room for ambiguity, uncertainty, subjectivity, imagination and emotional response.

8.6 Further Evolutions of Brainlight

Two further iterations of the original Brainlight have been created since 2015, which I'll briefly describe here.

8.6.1 Mini Brainlight

As the large perspex sculpture is cumbersome to transport I decided to create a miniature version of Brainlight (see Fig. 8.9) that packs down into a briefcase for easy portability. The "mini" sculpture is the size of a human brain and is illuminated by 190 individually programmed LEDs mapped to corresponding electrode positions and illuminated according to the EEG data received from the headset. The work was developed in collaboration with creative technologist and electronics engineer, Sami Sabik, who designed the custom printed circuit board, Sam Gentle, who programmed the software to interact with the LEDs and Neill Wainwright, who assisted in the design of the customised base.

8.6.2 Projection Mapping the Mind

Brainlight has also been re-configured as a projection mapping system, allowing any object, room or building to be illuminated with an interactive live visualisation of brain activity (Fig. 8.10). Created in collaboration with Sam Gentle, the original EEG processing software was adjusted to run on a "master" Raspberry Pi which communicates data to four secondary Raspberry Pi's over a network. Each secondary Raspberry Pi can be connected to a data projector which displays the correspond-

Fig. 8.9 *"Mini" Brainlight*, perspex sculpture with custom base and LEDs

Fig. 8.10 Projection mapped car using live audience brain activity for the launch event of MG3 × ELLE 2018

ing visualisation of the associated region of the brain. When the four projections are unified it creates a "complete brain" (frontal lobe, left and right hemispheres and occipital lobe). The animated visualisation was created through the cellular automata program used in the original Brainlight, with some adjustments to the size and movement of individual pixels, creating the impression of an electrically charged web of vibrant neural networks.

8.7 Discussion

As I have illustrated in this chapter, Brainlight unites art, BCI technology and the audience to realise new ways of exploring our biological selves, as well as creating new modes of audience interaction. The work contributes to an international community of artists, designers and technologists who have been utilising BCI technologies for artistic expression during the last 50 years. These artistic BCI projects are important to both research communities as well as the public because they explore, question and reveal new relationships with technologies and facilitate creative methods of connecting to each other and to ourselves. This discussion examines other artworks which utilise BCI technology in a similar way to Brainlight to explore our specific contributions to the artistic BCI field. I also discuss further methods of evaluating Brainlight and outline potential creative directions for the future.

Artists have been among the pioneers of EEG use outside clinical settings, designing situations and applications for EEG use in "real-life contexts" since the 1960s. One of the earliest interactive works was Nina Sobell's 1973 BrainWave Drawings, which paved the way for audience involvement in EEG generated biofeedback loops.

Akin to Brainlight's aim of exploring and sharing subtle non-verbal forms of communication, Sobell is interested in revealing a "universal mental language" (Sobell 2019). During a BrainWave Drawing session, two participants watch their brain activity changing in real time displayed over a closed-circuit video of themselves, creating a joint visual "drawing" of their silent communication. When describing her work, Sobell says, "in these projects I see myself as a facilitator or vehicle" (2019). As with Brainlight, Sobell facilitates the audience's experience and observes how people interact and improvise with the work in the moment. As with Brainlight, the social dynamics between participants, and the relationship between audience and artist become equally as important as the installation.

Another work with objectives and outcomes comparable to Brainlight in terms of "mirroring the self" for neurofeedback, educational, and entertainment purposes is the Mind-Mirror (Mercier-Ganady et al. 2014). This work enables the experience of seeing "inside your own head". The system uses a semi-transparent mirror positioned in front of a screen, allowing users to see a virtual display of their brain activity in different colours superimposed on their own reflection. Both Mind-Mirror and Brainlight facilitate an audience to "meet their own mind" externally by using realism. Brainlight uses an anatomically inspired brain sculpture and Mind-Mirror uses a literal mirror to visualise brain activity inside the skull.

While Mind-Mirror's technology is certainly advanced in terms of computer graphic capabilities, the work remains similar to classical 2D, screen-based, visual feedback, providing a single viewpoint for a single user which they must navigate by rotating their head while keeping their eyes on the mirror. Sobell's work is also largely screen based, using oscilloscopes and closed-circuit video. One clear distinction between these works is that Brainlight is a sculptural model with no screens or monitors involved. The advantage of Brainlight's three dimensional design is that the work can be experienced spatially, allowing large groups of people to view it from multiple angles. In combination with a wireless EEG headset, the participant is able to walk around the brain sculpture freely, allowing them to experience a tangible, 360° view of their changing brain activity.

In addition to creating live feedback loops, some artists are also documenting or recording audience experience in ways which can be later used to evaluate the work.

In George Khut's "Behind Your Eyes, Between Your Ears: Neurofeedback portrait project" the artist is able to capture and record an audiences subjective experience more tangibly through a series of brain-wave controlled video portraits (Khut 2015). A participant's face is overlaid with a colour projection and an electronic soundscape that is controlled via their alpha brainwave patterns. A voiceover of the participant's retrospective recollection of their experience during the EEG recording plays over the top. The artwork demonstrates a method of collecting and recording the experience of audience while using it as part of the work itself.

There are conflicting motivations when using audience experience to evaluate a work within an interdisciplinary space. Traditional methods for evaluation are very different for the fields of art, science or human computer interaction. Approaching Brainlight from a scientific standpoint, the inclination might be to rigorously test and measure its effectiveness in neurofeedback training. A study such as The Sensorium: Psychophysiological Evaluation of Responses to a Multimodal Neurofeedback Environment, which uses an immersive sound and light environment influenced by EEG and ECG signals, could be a possible model to replicate (Hinterberger and Fürnrohr 2016). The study used three phases, a mindfulness meditation, a guided body scan exercise, and a "Pseudo-Sensorium" using pre-recorded data that did not reflect the subject's own physiology, followed by a feedback questionnaire, in order to test its neurofeedback performance.

Alternatively, new research methods of evaluation may be necessary for more nuanced assessments of artworks that unify disciplines. Muller et al. describes the locus of encounter between art, science and the public as a "third space", a civic space of "trans disciplinary knowledge production, requiring new research methods that capture emergent knowledge". Evaluating an EEG sound installation of amnesic memory by artist Shona Illingworth in the Amnesia Lab exhibition in Sydney 2014, Muller et al. conducted a group-based psychosocial method of analysis—the visual matrix—designed to evaluate the transformative effects of aesthetic practice and interdisciplinary arts-science projects. The matrix allows participants to stay with the lived experience of the exhibition which enables researchers to "capture and characterize knowledge emerging in third space, where disciplinary boundaries are fluid and there is no settled discourse" (Muller et al. 2018). The visual matrix fosters a space of dialogue between scientific and artistic modes of thought without orienting to the established goals of either discipline. It also provides a way of capturing the "shared, complex, emergent and transformative aspects" of art-science exhibitions by illuminating how artistic intention is transformed into audience experience (Muller et al. 2015).

Most artists have limited ability to capture audiences affective and sensory responses to their work. Conventional studies that evaluate audience experience have the audience report on its impact after their experience. One benefit of artworks such as BrainWave Drawings, Behind Your Eyes, Between Your Ears: Neurofeedback portrait project and Brainlight, which all foster a real-time sharing of a participant's inner experience with the artist, is that by its very nature they provide a deeper insight into how the work is experienced by the audience during the moment of impact. Emulating the evaluation method outlined by Muller et al. could be a unique way to further investigate and document this process.

While it is interesting exploring ways in which technology can sense and communicate hidden inner biological states, it remains true that even the subtlest and most precise technological biosensors (both current and future) will nevertheless require a level of human processing, interpretation and analysis, as well as being subject to a decision making process of how to communicate the analysed data. Each one of these steps removes us further from the original source; thus "pure" unadulterated communication and a transferal of feelings through technology may never be possible, as it will always require a level of external human mediation.

Despite this, it remains interesting to imagine the future of these mediations and what scenario's might arise through further experimentation with technologies that are ever more sensate.

Appealing to the idea of digital synesthesia, future directions for Brainlight could be to expand brain activity from being translated through visual and auditory domain to include other senses, such as the transferal of the mind to other people's bodies through touch, vibration, or smell.

Another possibility would be to connect audiences in increasingly playful ways by further exploring the performative "spectacle" aspect of Brainlight for experiential entertainment. Audiences could be given more spectacular rewards for their ability to maintain a state of calmness. A great example is The Ascent, a "mind controlled levitation ride" which pairs an EEG headset with a 3-D theatrical flying harness, allowing users to "fly" by retaining a meditative state (Duenyas 2011). If they manage to levitate all the way to the top they trigger an explosive light and sound experience as a reward.

Multi-brain interactions are increasingly common in BCI art applications. Currently Brainlight allows a single person to explore their own mind in a general way, so there is fertile ground for expanding the work to include multiple users and to focus on more specific intimate interactions. A work such as EEG Kiss, for example, focuses on a singular intimate exchange, exploring how a kiss can be translated into data (Lancel and Maat 2014). The value of this would be to translate and share joyful human connections in new ways.

As this discussion has outlined, Brainlight has expanded on past similar work, while simultaneously there remains room for further evaluation of audience experiences and to further develop the work in new creative directions. This leaves exciting potential for Brainlight to collaborate with both the artistic and scientific communities on future research projects.

8.8 Conclusion

The Brainlight artwork, public exhibitions and audience interactions described in this chapter demonstrate how BCI technology is providing new sensory connections to our own hidden and immaterial neurobiological processes. Brainlight uses neuroscientific tools as a vehicle to explore the mind and our subjective responses in intimate, but public environments, beyond the usual clinical settings and laboratories where these technologies usually reside.

Interactive artworks such as Brainlight can encourage an increased self-awareness and self-mastery by offering new possibilities for extending or enhancing our senses through the technological augmentation of cognition. Brainlight does this through a visual display of an audience's metacognitive process, which includes the perception of cognition as well as its regulation.

In the three years of facilitating Brainlight interactions, the discussions that emerged between myself and the audience and among audience members extended to topics far beyond those directly relevant to the work and continued long after direct engagement with the work had ended. They ranged from philosophical debates about the phenomenology of the mind and the nature of consciousness to future speculation about post-humanism and how technology is redefining what it means to be human. While Brainlight uses a removable EEG device and is only a temporary experience, it stimulates discussions about humanity's relationship with technology and provides a glimpse into an imagined future where we might have more permanently integrated technological sensors, in the form of biological implants, finely calibrated to our individual bio-rhythms, which may one-day facilitate more precise non-verbal communication.

References

Adrian E, Matthews B (1934) The Berger rhythm: potential changes from the occipital lobes in man. Brain 57:355–385. https://doi.org/10.1093/Brain/57.4.355

Ahani A, Wahbeh H, Nezamfar H et al (2014) Quantitative change of EEG and respiration signals during mindfulness meditation. J NeuroEng Rehabil 11:87. https://doi.org/10.1186/1743-0003-11-87

Alonso J, Romero S, Ballester M et al (2015) Stress assessment based on EEG univariate features and functional connectivity measures. Physiol Meas 36:1351–1365. https://doi.org/10.1088/0967-3334/36/7/1351

(2014) Amnesia Lab. UNSW Art & Design. In: Artdesign.unsw.edu.au. https://artdesign.unsw.edu.au/unsw-galleries/amnesia-lab. Accessed 26 Jan 2019

Anadol R (2017) In: Refikanadol.com. http://refikanadol.com/works/melting-memories/. Accessed 13 Dec 2018

Ascott R (1999) The technoetic predicate. Leonardo 32:219–220. https://doi.org/10.1162/leon.1999.32.3.219

Barry A (2006) Perceptual aesthetics: transcendent emotion, neurological image. Vis Commun Q 13:134–151. https://doi.org/10.1207/s15551407vcq1303_2

Brookes M (2018) Giant brain to light up Royal Society Summer Science Exhibition—The University of Nottingham. In: Nottingham.ac.uk. https://www.nottingham.ac.uk/news/pressreleases/2018/june/giant-brain-to-light-up-royal-society-summer-science-exhibition.aspx. Accessed 30 Jan 2019

Cahn B, Polich J (2006) Meditation states and traits: EEG, ERP, and neuroimaging studies. Psychol Bull 132:180–211. https://doi.org/10.1037/0033-2909.132.2.180

Cavanagh J, Zambrano-Vazquez L, Allen J (2011) Theta lingua franca: a common mid-frontal substrate for action monitoring processes. Psychophysiol 49:220–238. https://doi.org/10.1111/j.1469-8986.2011.01293.x

Chanda M, Levitin D (2013) The neurochemistry of music. Trends Cogn Sci 17:179–193. https://doi.org/10.1016/j.tics.2013.02.007

Chiesa A, Serretti A (2009) A systematic review of neurobiological and clinical features of mindfulness meditations. Psychol Med 40:1239–1252. https://doi.org/10.1017/s0033291709991747

Cross I (2006) Music, cognition, culture, and evolution. Ann N Y Acad Sci 930:28–42. https://doi.org/10.1111/j.1749-6632.2001.tb05723.x

Duenyas Y (2011) The ascent mind controlled levitation ride—Yehuda Duenyas. In: Yehuda Duenyas. https://xxxyehuda.com/theascent/. Accessed 26 Jan 2019

Dunn M (2013) What is the relationship between art and ethics? In: Theory of knowledge. https://www.theoryofknowledge.net/areas-of-knowledge/the-arts/what-is-the-relationship-between-art-and-ethics/. Accessed 15 Dec 2018

Duvinage M, Castermans T, Petieau M et al (2013) Performance of the Emotiv Epoc headset for P300-based applications. BioMedical Eng OnLine 12:56. https://doi.org/10.1186/1475-925x-12-56

Ekman P (1994) Strong evidence for universals in facial expressions: a reply to Russell's mistaken critique. Psychol Bull 115:268–287. https://doi.org/10.1037/0033-2909.115.2.268

Ekman U, Rokeby D (2014) Transformations of transforming mirrors: an interview with David Rokeby. Postmod Cult. https://doi.org/10.1353/pmc.2014.0004

Else J, Ellis J, Orme E (2015) Art expertise modulates the emotional response to modern art, especially abstract: an ERP investigation. Front Hum Neurosci. https://doi.org/10.3389/fnhum.2015.00525

Fleck S, Simon G (2013) An augmented reality environment for astronomy learning in elementary grades. In: Proceedings of the 25th ICME conference francophone on l'Interaction Homme-Machine—IHM '13. https://doi.org/10.1145/2534903.2534907

Frey J, Gervais R, Fleck S et al (2014) Teegi: tangible EEG interface. In: UIST-ACM user interface software and technology symposium

Gruzelier J (2008) A theory of alpha/theta neurofeedback, creative performance enhancement, long distance functional connectivity and psychological integration. Cogn Process 10:101–109. https://doi.org/10.1007/s10339-008-0248-5

Gruzelier J (2014) EEG-neurofeedback for optimising performance. II: Creativity, the performing arts and ecological validity. Neurosci Biobehav Rev 44:142–158. https://doi.org/10.1016/j.neubiorev.2013.11.004

Gruzelier J, Hirst L, Holmes P, Leach J (2014) Immediate effects of alpha/theta and sensory-motor rhythm feedback on music performance. Int J Psychophysiol 93:96–104. https://doi.org/10.1016/j.ijpsycho.2014.03.009

Gsöllpointner K (2016) Syn-aesthetics of digital art. In: Gsöllpointner K, Schnell R, Schuler R (eds) Digital synesthesia: a model for the aesthetics of digital art, 1st edn. De Gruyter, Berlin, Bostonpp 10–28

Guljajeva V, Canet M, Mealla S (2018) NeuroKnitting | Varvara & Mar. In: Varvara & Mar. http://www.varvarag.info/neuroknitting/. Accessed 13 Dec 2018

Gürkök H, Nijholt A (2013) Affective brain-computer interfaces for arts. In: 2013 Humaine Association conference on affective computing and intelligent interaction. https://doi.org/10.1109/acii.2013.155

Hammond D (2007) What is neurofeedback? J Neurother 10:25–36. https://doi.org/10.1300/j184v10n04_04

Harvey A (2018) Music and the meeting of human minds. Front Psychol. https://doi.org/10.3389/fpsyg.2018.00762

Heanue M (2018) Group overview ‹ Affective computing—MIT Media Lab. In: MIT Media Lab. https://www.media.mit.edu/groups/affective-computing/overview/. Accessed 16 Dec 2018

Herrmann C, Strüber D, Helfrich R, Engel A (2016) EEG oscillations: from correlation to causality. Int J Psychophysiol 103:12–21. https://doi.org/10.1016/j.ijpsycho.2015.02.003

Hinterberger T, Fürnrohr E (2016) The sensorium: psychophysiological evaluation of responses to a multimodal neurofeedback environment. Appl Psychophysiol Biofeedback 41:315–329. https://doi.org/10.1007/s10484-016-9332-2

Hjelm S, Browall C (2000) Brainball-using brain activity for cool competition. In: NordiCHI, pp 177–178

Kawasaki M, Kitajo K, Yamaguchi Y (2010) Dynamic links between theta executive functions and alpha storage buffers in auditory and visual working memory. Eur J Neurosci. https://doi.org/10.1111/j.1460-9568.2010.07217.x

Khare KC, Nigam SK (2000) A study of electroencephalogram in meditators. Indian J Physiol Pharmacol 44:173–178

Khut G (2015) Behind your eyes, between your ears: neurofeedback portrait project. In: George Khut. http://www.georgekhut.com/behind-your-eyes-between-your-ears/. Accessed 25 Jan 2019

Khut G (2006) Development and evaluation of participant-centred biofeedback artworks. Doctor of Creative Arts (DCA), University of Western Sydney

Kleinsmith A, Bianchi-Berthouze N (2013) Affective body expression perception and recognition: a survey. IEEE Trans Affect Comput 4:15–33. https://doi.org/10.1109/t-affc.2012.16

Klimesch W (1999) EEG alpha and theta oscillations reflect cognitive and memory performance: a review and analysis. Brain Res Rev 29:169–195. https://doi.org/10.1016/s0165-0173(98)00056-3

Lancel K, Maat H (2014) Lancel/Maat—E.E.G. KISS. In: Lancelmaat.nl. https://www.lancelmaat.nl/work/e.e.g-kiss/. Accessed 26 Jan 2019

Leslie G, Mullen T (2011) MoodMixer: EEG-based collaborative sonification. In: Proceedings of the international conference on new interfaces for musical expression, pp 296–299

Lucier A (1976) Statement on: music for solo performer. In: Rosenboom D (ed) Biofeedback and the arts, results of early experiments, 1st edn. Aesthetic Research Center of Canada, Vancouver, pp 60–61

Lutz A, Dunne J, Davidson R (2007) Meditation and the neuroscience of consciousness: an introduction. Camb Handb Conscious 499–552. https://doi.org/10.1017/cbo9780511816789.020

Mantini D, Perrucci M, Del Gratta C et al (2007) Electrophysiological signatures of resting state networks in the human brain. Proc Natl Acad Sci 104:13170–13175. https://doi.org/10.1073/pnas.0700668104

Maskeliunas R, Damasevicius R, Martisius I, Vasiljevas M (2016) Consumer grade EEG devices: are they usable for control tasks? PeerJ 4:e1746. https://doi.org/10.7717/peerj.1746

Menon S, Sinha A, Sreekantan B (2014) Interdisciplinary perspectives on consciousness and the self, 1st edn, pp 1–8
Mercier-Ganady J, Lotte F, Loup-Escande E et al (2014) The mind-mirror: see your brain in action in your head using EEG and augmented reality. In: 2014 IEEE virtual reality (VR). https://doi.org/10.1109/vr.2014.6802047
Molina G, Tsoneva T, Nijholt A (2009) Emotional brain-computer interfaces. In: 2009 3rd international conference on affective computing and intelligent interaction and workshops. https://doi.org/10.1109/acii.2009.5349478
Moritz J (2017) Augmented humanity. Technoetic Arts 15:341–352. https://doi.org/10.1386/tear.15.3.341_1
Mullen T, Khalil A, Ward T et al (2015) MindMusic: playful and social installations at the interface between music and the brain. In: Nijholt A (ed) More playful user interfaces. Interfaces that invite social and physical interaction, 1st edn. Springer, Singapore, pp 197–229
Muller L, Bennett J, Froggett L, Bartlett V (2015) Understanding third space: evaluating art-science collaboration. In: 21st international symposium of electronic art
Muller L, Froggett L, Bennett J (2018) Emergent knowledge in the third space of art-science. Leonardo 1–11. https://doi.org/10.1162/leon_a_01690
Mühl C, Allison B, Nijholt A, Chanel G (2014) A survey of affective brain computer interfaces: principles, state-of-the-art, and challenges. Brain Comput Interfaces 1:66–84. https://doi.org/10.1080/2326263x.2014.912881
NEURON (2018) Blogul UMF » NEURON 2018. In: Blog.umftgm.ro. https://blog.umftgm.ro/tag/neuron-2018/. Accessed 10 Oct 2018
Nijboer F, Clausen J, Allison B, Haselager P (2011) The Asilomar survey: stakeholders' opinions on ethical issues related to brain-computer interfacing. Neuroethics 6:541–578. https://doi.org/10.1007/s12152-011-9132-6
Papatheodorou T, Chambers T (2018) Random quark—creative technology studio. In: Randomquark.com. http://randomquark.com/case-studies/mindswarms.html. Accessed 13 Dec 2018
Park L (2014) Lisa Park. In: Lisa Park. http://www.thelisapark.com/#/eunoia-ii/. Accessed 13 Dec 2018
Pearlman E (2017) Brain opera: exploring surveillance in 360-degree immersive theatre. PAJ: J Perform Art 39:79–85. https://doi.org/10.1162/pajj_a_00367
Peper E, Ancoli-Israel S, Quinn M (1979) Mind/Body integration: essential readings in biofeedback, 1st edn. Plenum Press, New York
Perkins D (1994) The intelligent eye: learning to think by looking at art. Getty Center for Education in the Arts, Santa Monica, Calif
Popian I (2014) iondesign | PROJECTS. In: iondesign. http://www.ionarch.com/projects. Accessed 13 Dec 2018
Ray W, Cole H (1985) EEG alpha activity reflects attentional demands, and beta activity reflects emotional and cognitive processes. Science 228:750–752. https://doi.org/10.1126/science.3992243
Rokeby D (1995) Transforming mirrors: subjectivity and control in interactive media. In: Penny S (ed) Critical issues in electronic media, 1st edn. Suny Press, pp 133–158
Schroeder A (2018) Schroeder-lab. In: Schroeder-lab. https://www.schroederlab.com/. Accessed 10 Oct 2018
Schroeder A. Avi Schroeder - הפקולטה להנדסה כימית. In: הפקולטה להנדסה כימית.https://chemeng.technion.ac.il/avi-schroeder/. Accessed 10 Oct 2018
Sherry J (2015) Neuroscience and communication. Commun Methods Meas 9:117–122. https://doi.org/10.1080/19312458.2014.999756
Sobell N (2019) Nina Sobell: artist statement http://ninasobell.com. Accessed 25 Jan 2019
Silvia P (2005) Emotional responses to art: from collation and arousal to cognition and emotion. Rev Gen Psychol 9:342–357. https://doi.org/10.1037/1089-2680.9.4.342
Stamps K, Hamam Y (2010) Towards inexpensive BCI control for wheelchair navigation in the enabled environment—a hardware survey. In: International conference on brain informatics. Springer, Berlin, Heidelberg, pp 336–345

Tamburrini G (2009) Brain to computer communication: ethical perspectives on interaction models. Neuroethics 2:137–149. https://doi.org/10.1007/s12152-009-9040-1
Vygandas Š (2018) Humanizing technology through post-digital art. PhD, KTH Royal Institute of Technology
Wadeson A, Nijholt A, Nam C (2015) Artistic brain-computer interfaces: state-of-the-art control mechanisms. Brain Comput Interfaces 2:70–75. https://doi.org/10.1080/2326263x.2015.1103155
Wellington J (1990) Formal and informal learning in science: the role of the interactive science centres. Phys Educ 25:247–252. https://doi.org/10.1088/0031-9120/25/5/307
Zioga P, Chapman P, Ma M, Pollick F (2014) A wireless future: performance art, interaction and the brain-computer interfaces. In: Proceedings of Inter-Face: international conference on live interfaces (ICLI 2014)